

C286

STATEMENT OF : **RICHARD BOYD TODD**
SEX : **MALE**
DATE OF BIRTH : **19th DECEMBER 1954**
AGE : **58 YEARS OLD**
NATIONALITY : **AMERICAN**
PASSPORT : **503416632**
ADDRESS : **1771 BITTERROOT DR,**
MARION,
MONTANA
USA
LANGUAGE SPOKEN : **ENGLISH**

- 1 I am the biological father of Shane Truman Todd ("Shane").
- 2 I am commonly known as Rick.
- 3 I am currently an airline pilot with American Airlines since 1988, flying international routes on a Boeing 777.
- 4 Prior to working with American Airlines, I have worked in my family's mortuary business from 1971-1972, 1976-1977 and 1984-1987, and also on an ad-hoc basis. I had also worked as an active duty United States Naval Aviator for 6 years ie from 1978 to 1984.
- 5 My family's mortuary business ie "Todd Memorial Chapel" started in 1907. This business is now 106 years old.
- 6 I now produce, at **Tab 1**, an extract from www.toddmemorialchapel.com depicting information of the family business.

7 Many of the statements and facts I give and make herein will bear much similarity with those of my wife, Mary Todd. This is because we were together throughout the entire events.

8 Shane was a wonderful son. He was a joy to the family and a loving and fabulous big brother. He was an intense person and a perfectionist. He always wanted things to be done extremely well. He was very smart and started talking at a very young age. He had a strong sense of honor since he was a little boy and throughout his entire life. If he thought something was wrong, he would try to correct it.

9 Shane and all the boys are close to all of us. We are a close-fitted family.

10 When Shane made the decision to come down to Singapore, I did not like his decision because of a story a fellow pilot had told me and I told Shane so. However we did not support his decision.

11 When Shane was in Singapore, he would keep in touch and communicate at least weekly mostly with Mary via Skype and email. Most of the time, we just had audio coverage. I did not communicate with Shane as much as Mary because a significant of the amount of time I was on flight trips. I am aware that Shane had a girlfriend in Singapore, as Shane told us about his girlfriend and he had also sent us her pictures.

12 Shane was a brilliant engineer and I came to know that he was doing extremely well which impressed his employers. At the Institute of Microelectronics ("IME"), a Singapore firm which Shane was working in, he received many projects and upon completion, he would receive more and some were out of his area of expertise. Initially, he worked under Julius Tsai Ming Lin ("Julius"). He liked Julius and enjoyed working under him and in his department.

13 Shane was later transferred to Dr Patrick Lo Guo-Qiang's ("Patrick") department. He liked Patrick but thought he worked too much and even said that he worried about him.

14 After the transfer, Shane would frequently complain about his work in the IME. He was not comfortable with the culture of "working people to death". He said that he was being asked by the IME to collaborate with a Chinese company, and was extremely uncomfortable with this arrangement. He told me us that the Chinese people he was dealing with were asking him questions he was uncomfortable answering. He felt like he was being asked to compromise US security.

15 In the two months prior to Shane's death, he had constantly made statements in his conversations with us that seemed to depict his life in some form of danger. In every conversation Mary and I had with him, from February to the time of his death, Shane would mention how he was afraid he would never see us again. As a father, I was alarmed and told him to keep in touch with us.

16 Shane had told Mary and I that he would call us every week, and if we did not hear from him, to call the US Embassy immediately. Initially, we had both thought that this was an exaggeration. One time he did not call and Mary emailed him to ask him if he was okay, he apologized and said that he had just gotten busy.

17 Mary and I were concerned about him, and told him to return home, to which he said he could not until he gave the IME a 60-day notice. To my knowledge, he did so in March. However, Shane told us that he was offered SGD\$20,000 to stay in IME for another 30 days to finish up a project he was working on. He agreed to this offer.

18 Sometime in June before his death, Shane (who had been looking for jobs in the US) received a job offer from Nuvotronics in Virginia. He had also asked us to hold off on Father's Day and Dylan's 21st birthday celebration until he returned to USA.

19 I last spoke to Shane on Father's day on 18th June 2012 when he called me. He told me how excited he was to come back to the US. He also emailed me on 18th June 2012 to ask me for bank information, so that he could wire his money from Singapore back to the USA. This was the last I heard from him. I set it up for him to transfer the money in my mother's Wells Fargo account. He never made the transfer.

20 I now produce, at **Tab 2**, a copy of the said email.

21 At 9:45 am (ie Singapore time at 11.45pm), I received a voice message from Mary. She said, "Rick, you need to call me immediately". By the tone of her voice, I figured that something bad had happened. I called her back and she told me that at about 7:30 am (ie Singapore time at 9.30pm), she received a Facebook message from Shirley, Shane's girlfriend in Singapore, informing us of his death. She had discovered the body when she went to check up on him in his apartment. I cried out in shock and dismay. At first, I took the message at face value and that was that he had killed himself. However, I recalled how he had been in fear for his life in the past two to three months and things began to surface and I began to doubt if he had hanged himself.

22 We made arrangements to meet in Denver. We flew to John Wayne Airport in California and then to Singapore. We arrived in early in the morning of June 26th. I was together with Mary and my two other sons. We met with Traci Goins from the US Embassy.

23 Mary and I spoke to Traci in private about our suspicions regarding Shane's death and that we believed he had been murdered. We told Traci about everything Shane told us (him being uncomfortable and being in fear for his life, etc). Traci called the Embassy to discuss our situation and to get advice on what and how much we should tell the Police. After their discussion, Traci advised us to tell the police everything we know.

24 Later, on the same day, I met IO Muhammad Khaldun at the police station in Singapore. I was accompanied with my wife and Traci Goins (from the American Embassy).

25 To the best of my memory, IO Muhd Khaldun told me and my wife (in the presence of Traci Goins) that Shane had used an electric screwdriver to drill holes in his bathroom walls. Shane had then supposedly screwed bolts into the wall, to which he attached ropes and pulleys. The rope was wrapped around the toilet seat and slung over the bathroom door. According to IO Muhammad Khaldun, he said Shane fashioned a noose, put it around his neck, stood on a chair on the outside of his bathroom door facing the bedroom, and jumped off the chair, killing himself by asphyxia.

26 Afterwards, Mary and I were handed what Khaldun described as Shane's suicide note. It was a two-paged typed paper. IO Khaldun who was present together with WSGT Rajina Sharma d/o Rajandran (C31) informed us that no one had read the letter yet, and requested for permission to make copies of the note for Traci, and himself.

27 All of us in the office then proceeded to read the note. Our sons, John and Dylan, were in another room.

28 After interviewing Mary, IO Muhammad Khaldun went on to interview me. He asked me a variety of questions regarding my relationship with Shane, the suicide note, and Shane's mental condition.

29 When being asked about the suicide note, I stated that I was surprised that there was no mention of the Chinese technology transfer in the letter considering he was a man of honor. He did not outline anything about the "things he did wrong". Maybe he did not want to cast aspersion upon his family. The act of him committing suicide in a foreign country did not suit his personality. The whole thing would cause so much pain to his family; this is very unlikely of him, as a man of honor. I do need to qualify that he had a depression episode in his undergraduate days and his mother asked him if he was contemplating suicide, he said no, but he needed help. If I remembered correctly, he was deficient in serotonin and took some medication which helped and was weaned off it.

30 Two months prior to his death, (ie April 2012), his mother had asked him whether he was depressed and he said no. This was nothing like the phase in college.

31 This time Shane was genuinely concerned for his safety. I believe sometime in March or early April 2013, we received a medical record from the University of Florida, the first page was very difficult to read as the handwriting was not clear. The second page outlined that the doctor would have prescribed something but Shane refused. Shane decided to handle his condition through a discipline of diet and exercise. As far as I am aware, Shane never had seen any mental health professional until Spring of 2012.

32 I have a similar thing with Shane. It is called a familiar tremor (fingers shaking when undergoing stress). His girlfriend mentioned that his friends had

noticed his fingers were very shaky lately. This is common reaction for people with familial tremors when they are under an extreme amount of stress.

33 I wish to state that Shane had never expressed that he was facing financial problems. He never asked the family for money and was financially stable. He has never been a burden. There is no greater burden than dealing with his death. "Damage" would be the last thing I would suggest that Shane has done. He has always been helpful to us even from Singapore he had given input to me for a very difficult business relationship I was involved in. If suicide were really in his makeup, which it was not, he would have drowned himself while kite surfing in the United States.

34 With reference to the alleged note, it states *"going to the beach to drink Shirley Temples, bean dip at happy hour, fishing and snorkeling in the Keys and going to church on Sundays"*. I would like to state that those were true except for Shirley Temples on the beach. Further, the message was not detailed according to Shane's standards. He was an extremely detailed person. If he was asked to clean the bathroom or any task, he would make the effort to get it right. When he wrote, it was the same. He would do numerous drafts until he got it right. I cannot accept that he did not do more than a few drafts of the suicide notes.

35 The notes were not detailed. To me this was unlike Shane.

36 I was later shown what was described to be Shane's diary from the IME which was retrieved from his house but the handwriting did not show any signs of shaking which should have indicated if he was under a lot of stress. My children and I have familiar tremors that get worse with stress and caffeine.

37 I now produce, at **Tab 3**, a copy of Shane's diary from IME.

38 On June 27th 2012, I went to the morgue with my family to identify Shane's body.

39 On June 29th 2012, I went to Shane's apartment with my family for the first time. There, Mary noticed several irregularities with the condition of the apartment and the description that IO Muhd Khaldun had given us. The apartment did not look like a crime scene at all as there was no tape stopping entry to the premises. From the looks of the premises, it was obvious that Shane was in the middle of packing. Clothes were neatly stacked and getting ready to box. Laundry was obviously being done. There was furniture marked for sale.

40 Shane's laptops and mobile phone had been removed from his apartment by the Singapore Police. We then spent the rest of the day packing up his personal belongings, including a hard disk drive that the Police did not remove from his apartment. Mary asked me if it was a MAC Speaker. Shirley Sarmiento, Shane's girlfriend also heard this exchange. I did not answer her that question, but I said, "put it in the bag." There was also a Sony LAN and an entertainment system that was designed to take the back-up hard-disk drive. However, it was later in July that I discovered it was a hard-disk drive.

41 I now produce, at **Tab 4**, a copy of photo of the hard-disk drive.

42 Several of Shane's friends dropped by Shane's apartment to visit us on that day.

43 On June 30th 2012, Mary and I decided to host a get-together of Shane's friends. 20 or so friends attended. All of them expressed doubt that Shane had committed suicide and we expressed our concerns that he was murdered.

44 Shane's body was shipped to Todd Memorial Chapel in Pomona, California. I directed my cousin, John Todd, owner of the mortuary to immediately take pictures of Shane from all sides upon arrival.

45 John Todd, directed his employee, David Martinez, a licensed embalmer to take pictures. [Some of these pictures are already produced in Court on 16th May 2013].

46 We commented on the wounds on Shane's body at the wake when his body was lying in the casket. Even though his body was heavy with make-up, they were clearly visible. The embalmer, David Martinez was the director at the visitation and was also a licensed embalmer. He mentioned that at he noticed the wounds as well whilst tending to the preparation of Shane's body.

47 During the memorial service, two separate doctors and other relatives also commented on Shane's hands bearing signs of defensive wounds. My daughter-in-law, Corynne Todd, took pictures of the wounds on his hands and on his head. We buried Shane in Pomona, California.

48 On 2nd July 2012, I sent an email to Shane's future employers ie Nuvotronics to inform them of Shane's demise. In that said email I also informed Kate de Gastyne that I was assuming that there was foul play involved in Shane's death.

49 I also had subsequent telephone conversations with one David Sherrer wherein Shane and David had been talking about publishing, patents and vacation time.

50 I now produce, the following:

- i. at **Tab 5**, the exchange of emails with Kate de Gastyne from 15th June to 22nd June 2012;
- ii. at **Tab 6**, the email of 3rd July 2012.

51 After the funeral and arrival in Montana, Mary and I began our investigation of Shane's death. During our investigations I remembered the back-up hard-disk drive that I had told Mary to "put in the bag." I thought that that could have been a hard drive. I retrieved it from the bag and plugged it into my Macbook Pro just to verify that it was a hard-disk drive. No files were opened.

52 My brother-in-law, Richard Elwell, told me to get a computer expert to have a look at the hard-disk drive. I immediately told my son, John Todd to take it to one Ashraf Massoud ("Ash") in Southern California.

53 The following establishes the chain of custody prior to making an Encase Image of the hard drive: Chain of Custody of Shane Todd's Hard Drive:

- 6/28/2012 Rick and Mary Todd take possession of hard drive from Dr Shane Todd's apartment
- 7/23/2012 John Todd Takes Possession and delivers it to Ashraf Massoud in Ontario, California.

54 I directed Ash to access the hard drive and pull out documents related to IME-Huawei-GaN project. He was able to access and pull out the following documents for which he referred to in his Conditioned Statement exhibited as **Tabs 1-10**:

- Export licence IME at **Tab "1"**
- Huawei_Wafer Probe Requirement.pptx and Wafer Probe Requirement QA at **Tab "2"**
- Interview feedback form for Wang Weizhu at **Tab "3"**

- Schedule 1 Huawei GaN Project Plan at **Tab "4"**
- Sales Order Creation form at **Tab "5"**
- Veeco-Visit_Proposal 1.docx at **Tab "6"**
- 1-on-1 Feedback session.xlsx at **Tab "7"**
- IMRE-IME-Veeco-200mm GaN Shane.docx at **Tab "8"**
- PFP Cabability Indicators-GaN.PDK1.pptx at **Tab "9"**
- Shane Passdown list.docx at **Tab "10"**

The said documents give insight to the nature of work Shane has been involved with since April 2011, acuminating to a work trip to Huawei the following year.

55 An Encase copy was made of the hard drive and then, Mr Ashraf Massoud ("Ash") worked from the copy. Searches were done specifically for suicide and came out negative.

56 I now produce at **Tab 7**, files accessed by Ash.

57 However, it became apparent that Shane had backed up his system just prior to his farewell lunch and again in the evening. What became blatantly apparent was there was access at 3:40 in the morning. Shane was completely done with work. He had no financial interest nor intellectual interest in accessing those files at that time in the morning. I felt whoever was associated with those files would lead to his killers. Also, people sent us articles about Chinese practices and Huawei itself. Briefly, the article talks about how killing its opponents while trying to make the death seem like a suicide, accident or natural death.

58 I now produce at **Tab 8**, the said articles.

59 The file that was accessed on 27th June 2012 was particularly telling as it was done three days after his Shane's body was found.

60 A couple of months later, IO Khaldun sent us the results from Health Science Authorities (HSA). Mary and I then decided to contact an expert for a second opinion with regards to Shane's death, as we still did not believe that it could have been a suicide.

61 We contacted Dr. Edward H. Adelstein, the Deputy Chief of Pathology at the Harry S Truman Veterans Hospital in Missouri. Mary and I sent Dr. Adelstein the photos (already admitted in Court on 16th May 2013) and autopsy report that had been provided by the (HSA). I acknowledged this report with an email sent on September 27, 2012.

62 I now produce at **Tab 9**, a copy of my said email dated 27th September 2012.

63 On September 30, 2012 a letter was written to IO Khaldun outlining concerns and the MOCVD device that was purchased.

64 I now produce at **Tab 10**, a copy of my said email dated 30th September 2012.

65 I further emailed to IO Khaldun telling him on 8th October 2012, that I had Dr Adelstein review the HSA report and this was countered by his report of 8th October 2012.

66 I now produce the following:

- i. at **Tab 11**, a copy of my said emails dated 8th and 12th October 2012;

ii. at **Tab 12**, C210, a copy of my said email to IO Khaldun.

67 We realized that we were not getting anywhere with the police investigators. Despite our communications to the Singapore Police, we were informed by people that had been interviewed that they were concentrating on suicide focusing on depression.

68 Mary and I decided to fly back to Singapore in order to meet with the US Ambassador, Singapore Police and the IME in order to get a better handle on the situation. We met with the US Ambassador, Singapore Police, and the IME.

69 Traci Goins informed us that the Singapore police had said that they had provided us the hard disk drive. I kept this in mind as I wanted to ask them personally what Traci claimed they were saying was true. We met with the US Ambassador about what we had experienced.

70 In the afternoon, December 12, we met with the IME. They brought a fairly large staff to the meeting. The police was also present. I asked them a number of questions:

- *There was an award that Shane received in the spring of this year. Do you remember the name of the award and when it was given?*
- *Was it associated with a monetary value?*
- *When was the last bonus award that Shane had received awarded and paid?*
- *When did Shane first start meeting with Huawei?*
- *When was his last meeting with Huawei?*
- *Do you know the names of the attendees?*
- *Has the Singapore Police contacted you about Huawei in relation to Shane?*
- *Have they interviewed you personally about Shane?*

- *Have they interviewed Prof Kwong?*
 - *Did they ask about MOCVD, GaN or Veeco k465i?*
 - *Has the FBI contacted you about the transfer of sensitive technology to the Republic of China?*
 - *Did anybody in the IME forbid their employees to talk about Shane with outsiders?*
 - *Can we meet with some of Shane's friends?*
- And to the police I asked the following:*
- *Have you contacted the IME in regards Shane's relationships with Huawei?*
 - *Have you interviewed Patrick or Prof Kwong?*
 - *Have you interviewed anybody about MOCVD, GaN or Veeco k465i?*
 - *Have you interviewed Huawei?*

71 We met with the police again on 13 December 2013. We went to the interrogation room and we met with Craig Bryant, US Counsel, IO Mohammed Khaldun and I believe DSP Sukhdev Singh. I cannot remember if Gurchan Singh was there at the time. He was there earlier. I immediately confronted them about the story IO Khaldun told us in the way Shane hung himself during his first interview. They said that was their initial impression and was not true. I also confronted them about IO Khaldun about telling us that he gave us the hard-disk drive. He said he did and I said no he did not.

72 He then presented us with an inventory sheet with my wife, Mary's, signature at the bottom. There was an item on the bottom of the sheet titled "hard disk". There was not description of this item even though all there was detailed descriptions of other items. My assumption was that the hard disk, if indeed real, was a cd or DVD. I asked IO Khaldun to give me the serial number and the make and model. He said that he did not have it. I then asked him to describe it. He kind of shrugged and said that it laid flat, was black and maybe

had a wire hanging out of it. I refer to **Tab 2**. It is not the same as described by the said IO.

73 I then sought another expert opinion on the nature of Shane's work. I contacted one Steve Huettner, an expert on the applications of GaN technology who was engaged in order to give a perspective on the implications of Shane's work.

74 I now produce the following :

- i. at **Tab 13**, Steven Huettner's CV;
- ii. at **Tab 14**, a powerpoint presentation showing Shane as the Team Leader in the GaN-on-Silicon TSRP: Device Characterization and Process Design Kit (PDK) Establishment;
- iii. at **Tab 15**, Steve's report dated 14th May 2013 on GaN Development;
- iv. at **Tab 16**, Steve's report dated 18th May 2013 on Statement about power capability;
- v. at **Tab 17**, an article on AIGaN/GaN by Shane and his team.

75 Based on my investigations, I believed that Shane did not commit suicide. Thus I sought interventions and assistance from my Senators in USA, spearheading to this inquest.

76 I have faith and strong belief in the opinions of both Mr Ashraf and Dr Adelstein. I also sought an opinion from Dr Porntip Rojanasunan, a top Thai forensic pathologist. I had a Skype conference call with her together with Peter Ong (one of my team of lawyers) when he flew to Bangkok on Friday evening, 17th May 2013. Dr Porntip was shown the reports from HSA, photographs taken

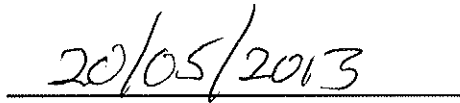
from the scene, and mortuary, in Singapore, and when Shane's body was lying in the casket in USA for the memorial service. Dr Porntip was also shown the reports from Dr David Fowler and Dr Valerie Rao. She was not shown the report put up by Dr Adelstein as I wanted to have an objective report. She had indicated to me that she has seen more murder cases as compared to Dr Wee of HSA and that her conclusion was – it is not suicide. I shall in my supplemental conditioned statement put up her opinion. I am now convinced that a 2nd autopsy should have been done, and I have to consider obtaining an opinion from another expert who can come to Singapore to testify or to have Shane's body exhumed.

77 We were informed that Shane would have to sign an ITAR document in order to purchase the Vecco machine.

78 I now declare that this statement (signed by me and consisting of 16 pages) is true to the best of my knowledge and belief. I make this statement knowing that if it is tendered in evidence, I may be liable to prosecution if I have willfully stated, in it, anything that I know to be false or do not believe to be true.


RICHARD BOYD TODD

NAME AND SIGNATURE




DATE

TAB 1

TODD Memorial CHAPEL
Family Owned & Operated Since 1907

HOME | SEARCH | DIRECTIONS



Home About Us Services Resources Contact Us

About Us



In April, 1907, back in the days when Pomona was still in the village stage, Mr. Walter B. Todd founded the firm known today as Todd Memorial Chapel. He was impressed by the hospitality and friendliness of Pomona's citizens, by the opportunities Pomona afforded those who sincerely wanted to become a part of the community and grow and prosper with the town. It was his desire to create an institution which would reflect the atmosphere of kindness and understanding of the community in which it was located, and through helpful, neighborly service, became a credit to that community. The institution early assumed a position of leadership in the mortuary field throughout Pomona Valley and the State of California. As time went on facilities were expanded and additions were made to the personnel. Here, too, Mr. Todd established a wise and thoughtful policy, carefully selecting his associates for their ability not only to serve professionally but also for their sincere desire to take an active part in community life.

When Mr. Todd passed away in 1933, active management of the organization was assumed by his son, John R. Todd, who carried on with the same sincere desire to broaden and increase the scope of the services this institution had to offer. Following John R. Todd's sudden death in 1947, his sons, Richard K. Todd and John W. Todd, together with Lawrence C. Smith, carried on the program Walter B. and John R. Todd started. They greatly broadened the scope of the services provided by Todd Memorial Chapel, and in 1954, Todd Memorial Chapel in Claremont was constructed. Today, Todd Memorial Chapel is actively managed by fourth generation, John R. Todd and fifth generation, Brian E. Pewe, along with Keith E. Pewe.

Throughout our existence, we have maintained price structures that make it possible for all to utilize the services we offer. Most of all, after one hundred years, Todd Memorial Chapel is still a home-town, valley-wide institution, an organization offering helpful neighborly service, dedicated to the needs of all faiths and serving all cemeteries.



John R. Todd



Keith E. Pewe



Brian E. Pewe

TAB 2

Gloria James

From: MRy Todd <ricktodd@me.com>
Sent: Sunday, 19 May, 2013 4:22 PM
To: Gloria James
Subject: Fwd: account number was sent

Sent from iCloud

Begin forwarded message:

From: Richard Todd <ricktodd@mac.com>
Date: June 17, 2012 8:18:40 PM
To: Shane Todd <gus2mt@gmail.com>
Subject: **account number was sent**

Please verify you need the account number again. I was texted to you.

Sent from my iPhone

On Jun 18, 2012, at 10:20 AM, Shane Todd <gus2mt@gmail.com> wrote:

> Hi Dad,
>
> Thanks so much for the info. Below is all of the info I need
>
> Beneficiary Name: Richard B. Todd
> Beneficiary Bank & Branch Name: Wells Fargo Bank
> Beneficiary Bank Address: _____
> Beneficiary Bank Account Number: _____
> Currency: United States Dollar
> Swift Code: WFBIUS6S
>
> Can you please send me the missing info, i.e. the bank address and
> account number?
>
> Love,
>
> Shane
>
> On 6/17/12, MRy Todd <ricktodd@me.com> wrote:
>> Dear Richard Todd:
>>
>> Thank you for contacting Wells Fargo. My name is Heidi, and it is my
>> pleasure to assist you today.
>>
>> I understand that you would like information regarding incoming wire
>> transfers.
>>
>> The methods by which a wire can be received into your Wells Fargo
>> account are:
>>

>> - Using Wells Fargo's routing transit number, 121000248, for federal
>> wires
>> - Using Wells Fargo's Swift code: WFBIUS6S
>>
>> Note: International Bank Account Numbers (IBANs) are not required for
>> incoming wires.
>>
>> The following information must be provided to the originator of the
>> wire:
>>
>> - Routing Transit Number: 121000248
>> - Bank Name: Wells Fargo Bank
>> - Beneficiary Account Number
>> - Beneficiary Account Name (customer's name as it displays on their
>> statement)
>> - SWIFT Code (for international wires only): WFBIUS6S
>>
>> The fee for incoming domestic wire transfers is \$15.00 and for incoming
>> International wire transfers, it is \$16.00. International wires may be
>> subject to additional fees, which will be deducted prior to funds being
>> deposited in your account.
>>
>> On behalf of Wells Fargo, thank you for your business. We are happy to
>> have you as our customer and appreciate the opportunity to assist you
>> today.
>>
>> Sincerely,
>> Heidi B
>> Wells Fargo Online Customer Service
>>
>>
>>
>> Original Message Excluded:
>> -----
>>
>>
>> Sent from my iPad
>>

TAB 3

Share Todd

INSTITUTE OF
MICROELECTRONICS

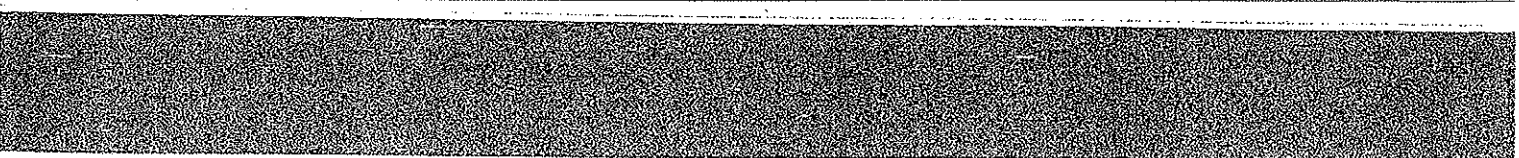
1202-00042
M-03



MOTO

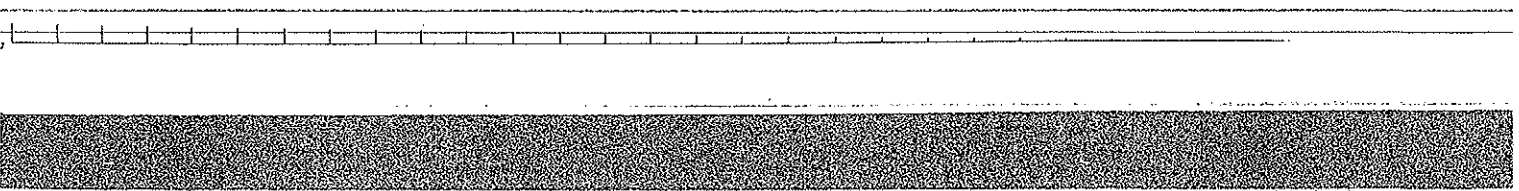
1000-0000

10-03



Year Planner

1 JANUARY		2 FEBRUARY		3 MARCH	
1	1		1		
2	2		2		
3	3		3		
4	4		4		
5	5		5		
6	6		6		
7	7		7		
8	8		8		
9	9		9		
10	10		10		
11	11		11		
12	12		12		
13	13		13		
14	14		14		
15	15		15		
16	16		16		
17	17		17		
18	18		18		
19	19		19		
20	20		20		
21	21		21		
22	22		22		
23	23		23		
24	24		24		
25	25		25		
26	26		26		
27	27		27		
28	28		28		
29	29		29		
30			30		
31			31		



Year Planner

4 APRIL		5 MAY		6 JUNE	
	1		1		
	2		2		
	3		3		
	4		4		
	5		5		
	6		6		
	7		7		
	8		8		
	9		9		
	10		10		
	11		11		
	12		12		
	13		13		
	14		14		
	15		15		
	16		16		
	17		17		
	18		18		
	19		19		
	20		20		
	21		21		
	22		22		
	23		23		
	24		24		
	25		25		
	26		26		
	27		27		
	28		28		
	29		29		
	30		30		
	31				

Year Planner

7 JULY		8 AUGUST		9 SEPTEMBER	
	1		1		
	2		2		
	3		3		
	4		4		
	5		5		
	6		6		
	7		7		
	8		8		
	9		9		
	10		10		
	11		11		
	12		12		
	13		13		
	14		14		
	15		15		
	16		16		
	17		17		
	18		18		
	19		19		
	20		20		
	21		21		
	22		22		
	23		23		
	24		24		
	25		25		
	26		26		
	27		27		
	28		28		
	29		29		
	30		30		
	31				

10 OCTOBER	11 NOVEMBER	12 DECEMBER
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
20	20	20
21	21	21
22	22	22
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31

DATE 29 Feb 2012

Prof. Qihua Xiang

- van der Waals epitaxy
- GaN growth wasn't successful
- * vapor pressure too low, temperature too high

Meeting with EP

Productivity under performing

- asking staff to do presentations
- RFP major source of IP and publications

Capability

- IP
- Publications
- Know how

GaN Weekly Meeting

- talk to Silveo about PDK needs

Visit to Veeco / VDL

- wafer transfer Module outside of tool protrudes a certain distance 17" comes out to 500 mm

Height of slow box higher by

- height is 2518 mm

- BRSLM

door height should be at least 2.6m

DATE 06 / 03 / 2012 Roll's Royce Meeting

- Rajan suggests to buy samples and open up to find device size

- Introduce ^{of} Report during Roll's Royce meeting

08/03/2012 TSRP Meeting

- Ganesh ^{Sunada} able to model Current Collapse

Aerospace - 50 - 250 °C

- Cooling is a key aspect

- Threshold voltage as a function of temperature

- 5 KW load inverter

- bringing to high frequency brings inductor to smaller figure of merit

DATE / /

- instead substrate cooling using microchannels etched into substrate

- Simulate threshold voltage variation versus process variation

- add RF structures for benchmarking

Silvaco PDK

→ Silvaco does not do design

→ 1D nets

→ before

→ slowly add

Is step down transformer included?

Yes includes transformer

2) Mark up on furnace? 25%?

3)

furnace 230k

margin

margin

hookup cost 10k

Elec

JVC Japanese Company

SATES yather is good enough for H₂ purifier

5 years

1.5 um thick 200 um wafers

AZurno approach EVE in Austria

Singapore

MOVID Facilities

- No purifier may not need to be mass

As is already purified

Socel confirms that I M E

N₂ purifier is < 1 ppb

- Getter based purifier

- pallette will not be ready until August

- Socel provides integrated solution hookup and gas installation

- if we go with other contractor - who will do the gas installation?

Cost of gases

$$N_2 = 0.168 / m^3$$

$$NH_3 =$$

$$H_2 = \$7.8 / m^3$$

drop Na purifier

To indicate price bidded, then indicate we asked for clarifications,

David Cummings University of Glasgow

Surface plasmon polariton - surface plasmons
- resonantly coupled with incident light

- Drake Model for surface resonance

color CMOS imagers

- traditionally put down polymer filters
- plasmonics

planar diffractive lenses

- nanoimprint plasmonic optics
- Terahertz research

- bolometer - VnO_2 material ~30% TCR

- probe cameras

Rolls Royce Circuit Simulation

- Ravinder suggests comparing device using minimum device performance

compare Si vs. SiC
Si vs. GaN

Ravinder planning to use LTSpice

Raviinder Says we can look at

Circuit simulation using LTspice

- forget next week

How do we get device temperature from simulation?

Ask about approval before submitting paper

- David is involved with GSN cooling

- Haiheng to look to see if there is device model in literature for something close to 600V

Action Items

1) Raviinder to do inverter simulation

2) Yong Tian to do heat sink size

versus junction temperature

3) Haiheng to look at GSN device models at around 600V

Rolls Royce Meeting

03 April 2012

- Raviinder to present circuit simulation next week

- Haiheng to investigate C-V measurements

- Yuan Li to start on extracting circuit model from device simulations

- Yong Tian to work on heat sink sizing

GSN Group Meeting

03 April 2012

- prepare plan for Veco collaboration

Azzurro

Silvaco

- utmost parameter extraction

- Model circuit simulation

Silvaco Evaluation

- device can be fully turned off

Smart Spice

↳ Utmost

- simulate circuit using

1) Download AMS software package

2) Include thermal model (Flip chip)

thermal simulation

Mocup facilities

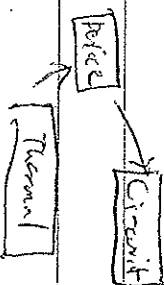
- Schedule - LGA, PD

- critical path

- bottle neck

- Update Gantt Chart for Rolls Royce

- Framework for circuit simulation



Reminder

- Sims PNM
- switch to space vector PNM

Non ideal components

- gate driver circuit

- replace switches with non ideal

components

- Filter

Yang Sim

- needs info Rolls Royce

- Yang Sim to work on heat sink model

Agilent B1505A

user mapping can be controlled by

Easy Expert

- decision needs to be made between

Silvaco & Sentaurus

- contract Sentaurus about

Rolls Royce

Want to extract simple circuit

model by net work, capabilities

model by net after

size of transistor

Size =

$R_{on} = 0.5 \Omega, 1.5 \mu m^2$

Current = 20A

assume 0.8A/ μm

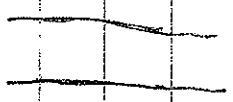
Importing thermal simulation

weight of the cooling device

in simulation put thermal

effect on device de current

F50C



2.5mm x 0.5mm

50mm

1)

Hawaii Visit

SKUL

- HiSilicon Program
- Strategy and development

- business development

- strategic analysis

Veo

- CMOS (connectivity)

Maxin Zhang

- Singapore

HiSilicon

- Hawaii silicon arm
- \$4.2 billion yearly revenue
- RF to Si electronics
- Fabless company

What is performance gap between GaN-on-Si and GaN-on-SiC

RF Power Amplifier

- efficiency

- linearity

- power output

- \$250 million USD for power devices

40%

50%

60%

Johnson Althrey Luicks

Marcus to sign off

Exhaust take-off point \rightarrow Marcus to confirm

Marcus to confirm gas cabinet room

Request drain in CLE extension

Send updated water loader

Heat Sink

$750C / 33W = 227K/W$

Meeting with GMT

1) Pure silane or diluted silane for ~~in-situ~~ Si-N growth

2) Hi ~~low~~ ^{low} pressure Al_2 tank

Hi boiler ready by mid-June

3) 1) Forming in Flammable gas room
1) Forming in regular gas room

4) Exhaust -

connect scrubber exhaust to acid exhaust

McLone - General exhaust

5) Bigg scrubber

6) George to send drawings to Ann Vornick

7) send updated facilities doc to George

8) INE to check if exhaust

can go through back in back of wet bench

9) Drain out

10) Punkte de Ketter

Meeting with Ivan to discuss

1) Planning for process engineer to visit IAE

2) Agreement to GAN on Si specs

3) 8" or 6" ? What thickness?

4) What amount of time will process engineer stay for?

5) Shipping of substrate carriers

Senhans

PMI Interface

- models > 20 accessible

- mix mode

< end survey PCM Device

- Can't use Senhans for PDK
or circuit simulation

- No parameter tuning

Sales modeling (under development)

- supports behavioral and SPICE compact
models

Schedule

- Meeting with Rolls Royce

- no available models for higher
voltage- propose another meeting w/ Rolls Royce
in 15 days

- simulation

Device Parameters

set up meeting with Yuan Li
to give device parameters

- order more wafers from Veeco

Meeting w/ Veeva

Sfflaco

1) Almost all command prompt

2) SQL database creation

SRDBS >> list servers

password: simusad

> list databases

SRDB SGLP2613 >> create

Utmost 4

login

Synopsis PDK

ii PDK -inter portable PDK
in two parts

PyCells - generate pcells

10 w. Pers w/ spacer
20 w. Pers w/ spacer

2mm Gen any layer
MOEBIA

Send Marcus list of MO Sources

- plan tentatively for 2nd week of
Summer

- engs move to move in tool

- high level DOE for GEN HEMT growth

- format substrate carrier boat

Agilent V89 JSA

Noise Figure Analyzer

Agilent E8363B

PNA Network Analyzer

Cascade MicroChamber

12000

Focus Microwave i Tuner

Model 1568-2C

PNA Pulse

AMCAD has pulse set to 40GHz

40GHz AMCAD Pulse Test Set

~ 75K to 85K to add pulsed PNA-X

Rolls Royce Meeting

- need to see if additional pretests is needed for

- Set fuel is worse than water for heat sink

- quantity temperature difference between

- Full package design in solid works

- Flooding microchannel

- calculate weight based on different con Equations

- analysis on loss components, where does the loss go?

- Simulate invt for in silico SPICE

- for 2 slides on executive Summary

Friday Ravinder gives all circuit simulations

2.5mm x 2.5mm

) Need to know efficiency

1) Thermal Resistance of chip
GAN-on-Si \rightarrow thin down to 100um

2) More complete package for chip to outside world

1) UMB purpose, direct connect ^{from cylinder} tool for tool maintenance

2) eye wash in adjacent classroom

3) self contained breathing apparatus another part of building

pressure regulator,

NO-KSPACE SETTINGS

SILVACO example NO-KSPACES analog

Rolls Royce Meeting

Consider SOx system

- ^{gamma} what weight reduction can be
- conventional vs. liquid coating
- can thermal approach be scaled up to SOx?

⇒ how do we calculate kW/kg?

Rolls Royce to send data on system weight calculations

⇒ what areas have limits

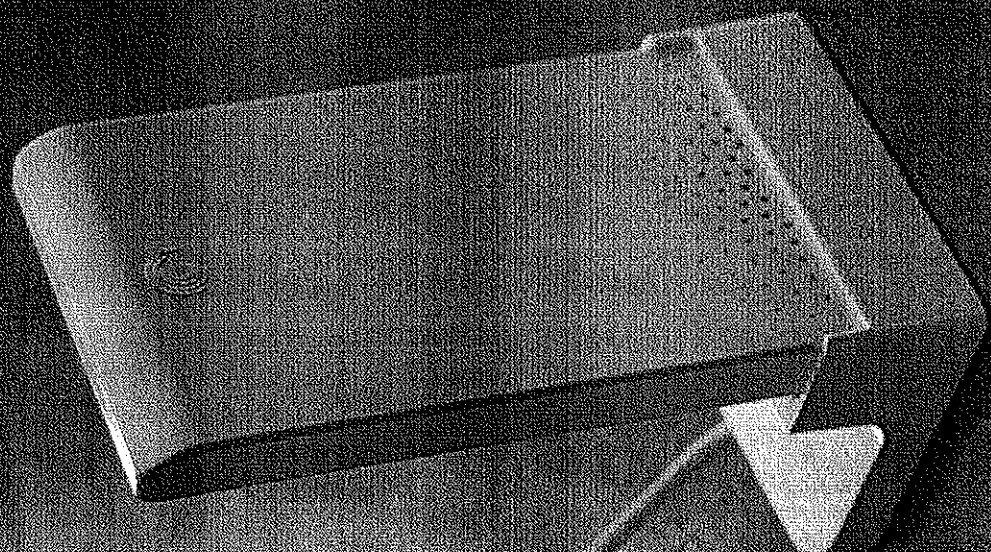
⇒ really interested in frequency and temperature improvement

⇒ device models for GAN, SiC, SiC

Johnson Matthey

- ~~ED~~ Blended Flow controller (need to put this option)
- exhaust hood
- heat issues

TAB 4



TAB 5

5

Kate de Gastyne

From: Kate de Gastyne
Sent: Friday, June 22, 2012 8:29 AM
To: 'Shane Todd'
Subject: RE: Nuvotronics' Offer: Please confirm receipt.
Categories: Orange Category

Certainly. If you have any more questions, or negotiation points, please do not hesitate to contact me, or let me know if you would benefit from another phone/Skype conference with David, Dara or other members of the team.

Kate de Gastyne
Nuvotronics, LLC
HR/Contracts Administrator
(800) 341-2333 x135

-----Original Message-----

From: Shane Todd [mailto:shanetodd80@gmail.com]
Sent: Thursday, June 21, 2012 10:15 PM
To: Kate de Gastyne
Subject: Re: Nuvotronics' Offer: Please confirm receipt.

Hi Kate,

Thanks for answering my questions, I am glad that you encourage publications and patents at Nuvotronics. I do not hold active DOD security clearance but I would be able to apply for security clearance if needed.

Again I appreciate the offer from Nuvotronics and I look upon it highly. Please allow me more time for consideration and I will be in contact with you soon.

Best Regards,

Shane

On 6/22/12, Kate de Gastyne <kdegastyne@nuvotronics.com> wrote:
> Thanks Shane. To answer your questions,
>
> Regarding publishing research results, yes, but we have a review
> process to ensure that nothing we consider proprietary is published
> without patent protection first being obtained.
> Patents: Yes, we encourage all employees to disclose inventions. We
> have a patent committee that meets quarterly to review all invention
> disclosures and the disclosures are prioritized based on strategic and
> potential monetary value to the company. Applications are filed based
> on priority as our budget allows.
>
> Typically vacation time offered would be three weeks of vacation plus
> one week of sick leave and two floating holidays, on top of the nine
> paid scheduled holidays, so essentially a PTO bank of 248 hours per year.
> Although these accrue on a prorated basis, there is flexibility in
> allowing borrowing of time before it is accrued, if desired.
>

> Actually sent Thursday,
> June 21, 2012 @ 4:04 pm
> Eastern Standard Time (US)
> (see attached)
> 4th page of
> this.pdf

> What else can I answer for you?
>
> Please also confirm to me whether you currently hold any level of
> active DoD clearance, or if you are eligible to pursue such clearance, if needed.
> Thanks.

>
>
> Kate de Gastyne
> Nuvotronics, LLC
> HR/Contracts Administrator
> (800) 341-2333 x135

>
> From: Shane Todd [mailto:shanetodd80@gmail.com]
> Sent: Thursday, June 21, 2012 11:01 AM
> To: Kate de Gastyne
> Subject: Re: Nuvotronics' Offer: Please confirm receipt.

>
> Hi Kate,
> Thank you again for sending me the offer from Nuvotronics. The offer
> is generous and I am very grateful Nuvotronics has extended it to me.
> The job scope you have proposed for Polystyrate and MEMS process
> development also aligns with my interests so I think the work would be
> a good fit for me. If you can please answer the following questions I would appreciate it.

>
> 1) Does Nuvotronics allow employees to publish research results?
> 2) Does Nuvotronics encourage employees to file patents? Are there any
> employee incentives to file patents?
> 3) What will be the vacation time offered to me?
> I look forward to talking with you soon.

>
> Best Regards,

>
> Shane

>
> On Wed, Jun 20, 2012 at 10:46 PM, Kate de Gastyne
> <kdegastyne@nuvotronics.com<mailto:kdegastyne@nuvotronics.com>> wrote:
> Shane,
> As I will be out of the office some next week, I wanted to check to
> see that you have received the information below. Please confirm receipt.

>
> If there are any questions I can answer at this time, please let me know.

>
> Thank you!

>
> Kate de Gastyne
> Nuvotronics, LLC
> HR/Contracts Administrator
> (800) 341-2333 x135<tel:%28800%29%20341-2333%20x135>

>
> From: Kate de Gastyne
> Sent: Friday, June 15, 2012 4:59 PM
> To: Shane Todd (shanetodd80@gmail.com<mailto:shanetodd80@gmail.com>)
> Subject: Nuvotronics' Offer
> Importance: High

> Dear Shane:

> Thank you for talking with us last week, and sharing your experience

> and career goals. We would like to offer you a position in the

> Process Engineering group. Your main tasks would focus on Research

> and Process Development of new areas of interest to us in further

> advancing the PolyStrata technology. This would include some MEMS

> process development, some integration process development in

> PolyStrata, and a variety of other development projects to keep you

> challenged. We believe you will fit well with our team and will

> contribute to Nuvotronics' success in this role, but we also think you

> have great potential to grow within the company. With your experience

> in design and your processing knowledge, the possibilities for you to

> branch into other areas after some time, if you so desire, will be

> available to you. You bring a unique blend of both design and process

> experience that will help shorten the learning curve for you and here at Nuvotronics and we hope you will join our team.

>

> We offer full-time employees a generous benefit package, including

> 401(k) with up to 4% employer match. Please see the attached flyer

> for additional details on provided and voluntary benefits. We would

> offer to start you at an initial salary of \$105,000/year, plus a

> one-time relocation package of \$5,000.

>

> As you consider this position, I am sharing links on the New River

> Valley area of Virginia, and some of the things that Montgomery County

> and surrounding areas can offer:

> <http://www.businessweek.com/lifestyle/virginia-town-is-best-place-in-t>

> [he-us-to-raise-kids-11152011.html](http://www.businessweek.com/lifestyle/virginia-town-is-best-place-in-t)

> and

> <http://montgomerycc.org/wp-content/uploads/2010/10/2012-Chamber-Magazine.pdf>.

> We are in close proximity to Virginia Tech and Radford University,

> and a short drive from Roanoke, VA.

> <http://www.virginia.org/Cities/Roanoke/>

>

> We understand a decision of this magnitude takes time and reflection,

> but we are also looking at other candidates for the position. Please

> let us know your thoughts on the offer by June 22, and, if possible,

> an answer by July 6. We would contemplate a start date of September

> 4, 2012. Once we get your feedback, we would follow up with a formal

> offer letter and confidentiality agreement, and ask that you verify citizenship status.

>

> If there are any questions that you have as you consider this

> information, please do not hesitate to reach out to any of us. We

> feel confident it could be a great match for us and for you.

>

> Kate de Gastyne

> Nuvotronics, LLC

> HR/Contracts Administrator

> (800) 341-2333 x135<tel:%28800%29%20341-2333%20x135>

>

> This e-mail and any files transmitted with it may be proprietary and

> are intended solely for the use of the individual or entity to whom

> they are addressed. If you have received this e-mail in error please

> notify the sender and delete the e-mail.

>

>

Kate de Gastyne

From: Kate de Gastyne
Sent: Thursday, June 21, 2012 4:04 PM
To: 'Shane Todd'
Subject: RE: Nuvotronics' Offer: Please confirm receipt.

Thanks Shane. To answer your questions,

Regarding publishing research results, yes, but we have a review process to ensure that nothing we consider proprietary is published without patent protection first being obtained.

Patents: Yes, we encourage all employees to disclose inventions. We have a patent committee that meets quarterly to review all invention disclosures and the disclosures are prioritized based on strategic and potential monetary value to the company. Applications are filed based on priority as our budget allows.

Typically vacation time offered would be three weeks of vacation plus one week of sick leave and two floating holidays, on top of the nine paid scheduled holidays, so essentially a PTO bank of 248 hours per year. Although these accrue on a prorated basis, there is flexibility in allowing borrowing of time before it is accrued, if desired.

What else can I answer for you?

Please also confirm to me whether you currently hold any level of active DoD clearance, or if you are eligible to pursue such clearance, if needed. Thanks.

Kate de Gastyne
Nuvotronics, LLC
HR/Contracts Administrator
(800) 341-2333 x135

From: Shane Todd [mailto:shane todd80@gmail.com]
Sent: Thursday, June 21, 2012 11:01 AM
To: Kate de Gastyne
Subject: Re: Nuvotronics' Offer: Please confirm receipt.

Hi Kate,

Thank you again for sending me the offer from Nuvotronics. The offer is generous and I am very grateful Nuvotronics has extended it to me. The job scope you have proposed for Polystrata and MEMS process development also aligns with my interests so I think the work would be a good fit for me. If you can please answer the following questions I would appreciate it.

- 1) Does Nuvotronics allow employees to publish research results?
- 2) Does Nuvotronics encourage employees to file patents? Are there any employee incentives to file patents?
- 3) What will be the vacation time offered to me?

I look forward to talking with you soon.

Best Regards,

Shane

On Wed, Jun 20, 2012 at 10:46 PM, Kate de Gastyne <kdegastyne@nuvotronics.com> wrote:

Shane,

As I will be out of the office some next week, I wanted to check to see that you have received the information below. Please confirm receipt.

If there are any questions I can answer at this time, please let me know.

Thank you!

Kate de Gastyne

Nuvotronics, LLC

HR/Contracts Administrator

(800) 341-2333 x135

From: Kate de Gastyne
Sent: Friday, June 15, 2012 4:59 PM
To: Shane Todd (shanetodd80@gmail.com)
Subject: Nuvotronics' Offer
Importance: High

Dear Shane:

Thank you for talking with us last week, and sharing your experience and career goals. We would like to offer you a position in the Process Engineering group. Your main tasks would focus on Research and Process Development of new areas of interest to us in further advancing the PolyStrata technology. This would include some MEMS process development, some integration process development in PolyStrata, and a variety of other development projects to keep you challenged. We believe you will fit well with our team and will contribute to Nuvotronics' success in this role, but we also think you have great potential to grow within the company. With your experience in design and your processing knowledge, the possibilities for you to branch into other areas after some time, if you so desire, will be available to you. You bring a unique blend of both design and process experience that will help shorten the learning curve for you and here at Nuvotronics and we hope you will join our team.

We offer full-time employees a generous benefit package, including 401(k) with up to 4% employer match. Please see the attached flyer for additional details on provided and voluntary benefits. We would offer to start you at an initial salary of \$105,000/year, plus a one-time relocation package of \$5,000.

As you consider this position, I am sharing links on the New River Valley area of Virginia, and some of the things that Montgomery County and surrounding areas can offer: <http://www.businessweek.com/lifestyle/virginia-town-is-best-place-in-the-us-to-raise-kids-11152011.html> and <http://montgomerycc.org/wp-content/uploads/2010/10/2012-Chamber-Magazine.pdf>. We are in close proximity to Virginia Tech and Radford University, and a short drive from Roanoke, VA. <http://www.virginia.org/Cities/Roanoke/>

We understand a decision of this magnitude takes time and reflection, but we are also looking at other candidates for the position. Please let us know your thoughts on the offer by June 22, and, if possible, an answer by July 6. We would contemplate a start date of September 4, 2012. Once we get your feedback, we would follow up with a formal offer letter and confidentiality agreement, and ask that you verify citizenship status.

If there are any questions that you have as you consider this information, please do not hesitate to reach out to any of us. We feel confident it could be a great match for us and for you.

Kate de Gastyne

Nuvotronics, LLC

HR/Contracts Administrator

(800) 341-2333 x135

This e-mail and any files transmitted with it may be proprietary and are intended solely for the use of the individual or entity to whom they are addressed. If you have received this e-mail in error please notify the sender and delete the e-mail.

TAB 6

Gloria James

From: Rick Todd <ricktodd@mac.com>
Sent: Sunday, 19 May, 2013 4:58 PM
To: Gloria James
Subject: Fwd: Nuvotronics

Begin forwarded message:

From: "MRy Todd" <ricktodd@me.com>
Subject: Re: Nuvotronics
Date: July 3, 2012 11:45:29 AM MDT
To: David Sherrer <dsherrer@nuvotronics.com>
Cc: GoinsTL@state.gov

Dear David:

I am copying the State Department on this email. I hope you don't mind. I would like to forward other emails you write to them as they are working with the FBI in house in Singapore.

Shane had mentioned to my wife, Mary and me, that he was dealing with the Chinese. He said that the questions they were asking was making him very uncomfortable. He also said that there was things that he did that he thought might have compromised U.S. interests and which he was very uncomfortable. He started backing away from them. That is when I believe that was in fear for his life and he was very anxious to get out of Singapore. When he told me his fear, both, his mother and I said to get out as it would damage his ability to get a good job in the USA. We believe that he was killed that evening that last day of work or early in the morning the day after.

Shane had mentioned in the past that things that he worked on could definitely have weapon application or defense applications if in the wrong hands. We are laymen, the FBI and State Department, etc, can you help shed light on what he was doing that could have compromised US Interests?

Thanks,
Rick
Sent from iCloud

On Jul 03, 2012, at 08:36 AM, David Sherrer <dsherrer@nuvotronics.com> wrote:

Dear Mr. Todd,

I cannot begin to say how sorry I am for you, his family, and friends. I wanted to follow up with you given the circumstances.

The interview process was conducted by me and our head of operations, Dara Cardwell. As I basically "grew up" doing hands on process engineering to make new

devices, I personally worked with Dara on filling this role. Shane did work under Noel MacDonald who 18 years ago ran the Cornell NanoFabrication facility (CNF) where I took up residence for a month at a time when I started the first predecessor to my company today..

Shane had written to our company a personal letter expressing his interest and had done work at UCSB extremely relevant to our own technology here for next generation microwave hardware. He listed Robert York as a reference, who published some of the seminal works on microwave power amplifiers which is a focal area for our company.

Because of the nature of our work, we can only hire US citizens and green card holders. Of dozens of candidates we interviewed, Shane stood out as our very top choice. This despite having little experience (compared to some candidates with 20 to 30 years' experience) and needing to be relocated back to the USA, we believed and were willing to bet that Shane would exceed them all. For us, there was no close second choice. I wrote to your son a few times about employment with us since the interview, most recently asking him to tell me if there was anything we could offer that would ensure our employment deal was the best among any others he received. When I didn't hear back from Shane after a week passed I asked Kate in HR to try to reach him.

To answer your two questions: Is there anything on your side that he shared?

Nothing specific that would stand out to me except his strong desire to return to the US and his interest in helping to develop the type of technology we are working on here. He sent a personalized cover letter to the company, his resume, and two papers he authored that are relevant to us. I will forward what he sent. When we spoke, I mentioned we are located in a rural area in the mountains of Virginia expecting this may turn him off to the company and was surprised to learn he had already researched our surrounding area, and knew off-hand the relatively low cost of living in our area. I asked him why he was so interested in working for Nuvotronics, as clearly he could go anywhere for employment. He explained that in graduate school he studied our technology from our publications and felt his background was particularly relevant, which it is.. In the two papers he wrote and published that he forwarded, he has referenced some papers that were authored by staff members here (Rob Reid and Ken Vanhille). They are only two or three among his dozens of references..

Had anything changed from his potential employment status?

No, we told him he had a standing offer and that we would like him to start as soon as possible. I probably sent him 2 or 3 e-mails on the topic of joining here.

I am deeply saddened by your loss. I don't know where Shane's career would have taken him, but I am confident he would have helped to change an industry. I told him that if he could spend a few years learning our unique fabrication technology, he could quickly transition into more senior program manager or product developer/manager roles. Frankly I worried more about how I could provide him sufficient opportunities and challenges to both attract and help keep him here. I would have liked to have known your son and have had the opportunity to work with him. I hope that you find answers to the cause of this tragedy and

receive cooperation and proper efforts from the authorities there. If there is anything we can do to support you please let me know.

With condolences and sincerely,

David

David Sherrer

President, Nuvotronics

This e-mail and any files transmitted with it may be proprietary and are intended solely for the use of the individual or entity to whom they are addressed. If you have received this e-mail in error please notify the sender and delete the e-mail.

TAB 9

From: Richard Todd <ricktodd@me.com>
Subject: Re: Post Mortem and Toxicology Reports
Date: September 27, 2012 9:17:35 PM MDT
To: "Muhammad Khaldun SARIF (SPF)"
<MUHAMMAD_KHALDUN_SARIF@SPF.GOV.SG>

Dear Khal:

Thank you for this report. I plan to send you some more information after this email on what we have discovered. Since you sent me this email, I thought I would keep this email on the subject on the postmortem. I have some question about the the report. Specifically, the following:

"Ligature:

The ligature, removed from the body prior to the autopsy, **was received separately from the investigation officer.** It comprised two pieces of black strap, measuring 1.9 cm at its widest. The straps were made of woven, synthetic fibres. There was a black plastic buckle and a fixed knot at one end of the first piece of ligature, while the other end was frayed and labeled as "A". The frayed end measured 17.5 cm from the knot. The second piece of the ligature comprised three frayed ends radiating from a fixed knot. The ends were labeled "B", "C" and "D" and measured 11.5 cm, 11 cm and 26 cm respectively from the knot. A white towel, measuring 64x41 cm, with an "IKEA" tag and patchy light brown stains was received together with the ligature. The ligature and the towel were returned to the investigation officer."

When we had talked to his girlfriend, she said that when she found Shane, it appeared he was hanging from a something that looked like a computer chord. The mark around Shane's neck is fairly narrow and appears to be consistent with his girlfriend's observation. There was a significant indentation on top of the door that appeared to be the result of more of a rounded type of ligature. (I can send you the pictures if you would like.) The mark on Shane's neck goes straight back. Marks that go straight back are found in cases where victims have been garroted. With hanging, the marks tend to angle upward.

If you will notice in the enclosed pictures, Shane's hands are extremely bruised and his head was also bruised. Even though the bruising had been attempted to be covered with makeup by the mortuary, both hands have been obviously traumatized. If somebody had come up behind him, it would probable that he would struggle in order to release himself. A fall or some other area where contact with hard surfaces would be likely be contacted from thrashing side-to-side but much harder to explain if he could save himself from hanging by being 6' 1" and just standing up. This would not be evident at first appearance as he been dead long enough to cause the blood to pool in the hands as they were hanging down. This became much more evident after he had been embalmed. My brother-in-law has forwarded the pictures to his forensic pathologist at the university in which he works. I am waiting to hear the results

Thanks,
Rick Todd.

On Sep 19, 2012, at 2:15 AM, Muhammad Khaldun SARIF (SPF) wrote:

Dear Rick and Mary,

Please find attached documents, i.e Post Mortem and Toxicology Report, of the deceased Shane Todd.

2 Please acknowledge upon receipt of the documents. Thank you.

Regards,

MUHD KHALDUN

Investigation Officer

Central Police Police Division | Singapore Police Force

DID: + 65 6557 3349 | Fax: +65 6220 6457

E-mail: muhammad_khaldun_sarif@spf.gov.sg

<image001.gif>

<image002.gif> <image003.gif> <image004.gif> <image005.gif> <image00

A Force For The Nation

•WARNING• "Privileged/Confidential information may be contained in this message. If you are not the intended recipient, please do not disseminate, distribute or copy this e-mail. Any unauthorized communication of any information in this email to any unauthorised person is an offence under the Official Secrets Act 1968." If you have received this email in error, please notify the system manager.

<Autopsy Report.pdf><Analytical toxicology laboratory.pdf>

TAB 10

September 30, 2012

Dear Khal:

As you know at our initial interview, we informed you that Shane was in fear for his life. This fear was repeated almost every week when he called us. In fact, he told us if we did not hear from him within a week that we should get in touch with the US Embassy. It has now become more apparent in what and why Shane had expressed this fear.

Shane went shopping for a MOCVD (Metal Organic Chemical Vapor Deposition) system in 2011 for IME. He needed to have a machine in order to produce GaN (Gallium Nitride). At the time, IME needed GaN for the GaN-on-Si power electronics program. From his research, he determined that a machine made by Veeco (a company in New Jersey) was best suited for his needs. It is important to note that GaN has military applications as well as civilian. The military applications includes missile guidance systems and high power jamming systems. For this reason, Veeco has been restricted from export of certain of its machines to only those countries that are trusted by the United States. (Singapore is a country that is trusted by the United States.) The machine we believe IME purchased was the Veeco k465i and one of those machines with restrictive export rules. This can easily be verified by submitting a subpoena to Veeco.

After IME bought the multimillion dollar machine, they sent Shane for training on it in January, 2012. This machine is highly technical and requires a large amount of expertise in the area of GaN in order to operate it. (Ever since Shane's death, IME has been advertising for experts in this area and

it is believed that they still do not have anybody qualified.) Upon returning to Singapore, IME's business relationships introduced Shane to a large number of IME's customers. We don't know how many, but we believe that the company or companies were Chinese fronts. (A company may say that they are from Singapore, yet they really represent mainland China.) Shane felt increasingly uncomfortable with individuals in which he was being introduced. It got to the point where Shane told us that he felt he was being asked to compromise US security and he feared for his life. They would speak Mandarin in the meetings in which he was involved. Yet, he was the resident expert on the machine. This made Shane uncomfortable enough that he expressed an interest in learning Mandarin to us and to his girlfriend. Shane refused to do what he was being asked to do and turned in his sixty day notice at IME. Shane found a good job with a company in Virginia and was planning to fly back to the US on July 1. Shane was killed June 23, right after his last day of work.

We believe that Shane was murdered because he refused to become involved with the transfer of technology to China by way of front companies in Singapore. The motive of the Chinese Government would be obvious. They were unwilling to let Shane leave Singapore, when he knew whom the players were and the company/companies they represented. Shane needed to be eliminated. The negative implications of this scenario are obviously extremely significant for the Singapore and USA. The USA can ill afford the loss of such significant technology and Singapore can ill afford the loss of being a trusted partner to the United States.

Our beliefs are based on these facts:

- Shane warned us that he feared for his life and why he was

in fear.

- Physical evidence that Shane was garroted.□

- We are in possession of a Shane's back up hard drive. It has been analyzed forensically. Evidence from Shane's external back up hard drive, showing that Shane's computer was accessed on June 23 at 3:29AM and again on June 27 (three days after he was found dead), where highly technical (Veeco) data was created and erased.

Sincerely,

Richard and Mary Todd (406) 407-8270

TAB 11

From: Mary Todd <toddmomof4boys@yahoo.com>
Sent: Sunday, 19 May, 2013 5:57 PM
To: gus@gjclaw.com.sg
Subject: Fw: Fwd: The Death of Shane Truman Todd, Phd
Attachments: Shane Todd.docx

----- Forwarded Message -----

From: Richard Todd <ricktodd@mac.com>
To: Mary Todd <toddmomof4boys@yahoo.com>
Sent: Tuesday, October 9, 2012 1:42 AM
Subject: Fwd: The Death of Shane Truman Todd, Phd

Begin forwarded message:

From: Richard Todd <ricktodd@mac.com>
Subject: **The Death of Shane Truman Todd, Phd**
Date: October 8, 2012 10:34:05 AM MDT
To: "Muhammad Khaldun SARIF (SPF)"
<MUHAMMAD_KHALDUN_SARIF@SPF.GOV.SG>, Gurcharn_SINGH@spf.gov.sg
Cc: "Adelstein, Edward H. CMOVAMC" <Edward.Adelstein@va.gov>
Bcc: Raymond Bonner <ray@raymondbonner.com>, bryantcp@state.gov, "Goins, Traci L" <GoinsTL@state.gov>, Matthew Foster <matthew.foster@ic.fbi.gov>, John Todd <jrichardtodd@gmail.com>, Dylan Todd <todddylan@mac.com>, Jennifer_Madgic@tester.senate.gov

Dear Khal and Gurcharn:

Mary and I had Dr Adelstein, who is a respected pathologist in the United States, review pictures of Shane's body and his autopsy report. Please review his investigative report on the cause of Shane's death.

In light of what Shane told us in the months prior to his death, the sensitive nature of his work in regards to the Veeco k465i system GaN-on-Si and the transfer of its technology to the Chinese, I am asking you to change your focus from a suicide investigation to a murder investigation. There needs to be a collaboration on the forensic computer evidence that we have from Shane's back up hard drive and what you have on the Shane's computers. Mary and I would like to fly to Singapore to meet with you, the FBI and the Department of Homeland Security If they are available there. Please inform us when we can meet so we can make arrangements to fly to Singapore.

Yours Truly,
Rick Todd

Thank You,
Rick Todd

October 8, 2012

Subject: Review of Autopsy findings on Shane Todd

I have carried out over 25 autopsies on individuals whose death was determined to be by asphyxiation from a ligature around neck and the manner of death was determined to be a suicide.

The observations are based on the review of the autopsy findings and the pictures provided. They lead to the following observations and conclusions:

1. The lung weights were the right 440 g and the left 380. Since the right lung has three lobes and the left two the right lung weighs more than the left. The weights recorded are the normal weights for an individual of his size and thus indicated that his death was rapid and he likely was unconscious within 15 – 30 seconds after the ligature was applied to his neck.
2. In my experience the sequence of events in a suicide is that the individual falls forward and the ligature occludes the jugular vein first impeding the flow of blood out of the brain and unconsciousness occurs. This often leads to the development of petechiae in the eyes and skin around the eyes. However, if the ligature is applied with great force it then compresses both the artery and vein at the same time and no petechiae are formed as was in this case. After unconsciousness occurs the heart continues to beat for 3 – 5 minutes and during this time there is an involuntary effort to maintain life and this leads to the development of pulmonary edema and often intraparenchymal hemorrhage which is manifested by heavier lung weights. None of these changes were present.
3. Since the deceased falls forward, I have never experienced a circumferential ligature mark as is present in his death. Further the ligature mark over the posterior neck is considerable thinner than the described ligature presented to the medical examiner. Further there are suspicious bruises superior to the ligature suggesting that there may have been attempts to remove the ligature by the victim. These may appear later after the autopsy is completed and are present on photographs taken at the time of burial
4. There are multiple blunt trauma injuries to both hands which are not described in the autopsy, yet very visible at the time of the funeral. Again, these often become more visible after death, but still should have been described at the time of the original autopsy. Further there is make-up applied to the middle of the forehead which is likely covering up an injury to the skin over his cranium.
5. Perhaps the most important information is that the deceased did not have a history indicating that he was considering taking his life, while there is a significant history that he felt his life was being threatened.

..

In summary, based on the information I have received, the autopsy findings and the pictures provided I would suggest the following sequence of events that lead to his death which I believe to be a homicide.

1. He engaged in a fight as evidenced by the blunt trauma to both hands
2. He was killed by an encircling ligature (Garroting) and death occurred quickly
3. After death he was suspended by a broader based ligature in an attempt to obscure the original thinner ligature

I am truly sorry for your loss; I if there is anything I can do to further justice in this case, please contact me. My cell phone is 573 – 999 - 7177.

Edward H. Adelstein, D.V.M., M.D.
Chief of Pathology Harry S. Truman Veterans Hospital
Deputy Medical Examiner of Boone and Callaway Counties.

TAB 12

From: "Muhammad Khaldun SARIF (SPF)" <MUHAMMAD_KHALDUN_SARIF@SPF.GOV.SG>
Subject: RE: Fourth Input to Singapore Police
Date: October 12, 2012 2:03:47 AM MDT
To: Richard Todd <ricktodd@me.com>
Cc: "Gurcharn SINGH (SPF)" <Gurcharn_SINGH@spf.gov.sg>

Dear Sir,

We acknowledge receipt of your emails and the attachments.

2 We are enclosing a copy of the late Shane's psychiatric report. Kindly acknowledge receipt.

3 Please be informed that at this stage, as our investigations are still incomplete, we will not be able to reply to your queries as yet.

4 Please do not hesitate to contact us should you have any further queries.

With Warmest Regards,

MUHD KHALDUN Investigation Officer
Central Police Police Division | Singapore Police Force DID: + 65 6557 3349 | Fax: +65 6220 6457
E-mail: muhammad_khaldun_sarif@spf.gov.sg

A Force For The Nation •WARNING• "Privileged/Confidential information may be contained in this message. If you are not the intended addressee, you must not copy, distribute or take any action in reliance thereon. Communication of any information in this email to any unauthorised person is an offence under the Official Secrets Act (Cap 213). Please notify the sender immediately if you receive this in error."

From: Richard Todd [mailto:ricktodd@me.com] **Sent:** Friday, 12 October, 2012 12:35 AM
To: Muhammad Khaldun SARIF (SPF); Gurcharn SINGH (SPF)
Subject: Fourth Input to Singapore Police

Dear Khal and Gurcharn:

I am sending you a link to a news report that came out in the United States. <http://www.cbsnews.com/video/watch/?id=7424702n&tag=contentMain;cbsCarousel> Huawei is a company that Shane was working with while in Singapore. Please note in the enclosed Excel Sheet color coded red that somebody had accessed Shane's back up hard drive. We believe that Shane was dead at this time. There is no logical reason for him to access a file for a job where he was no longer working and no longer had financial interest. It obvious from the results of the pathologist report and the fact that Shane's external back up hard drive was accessed after Shane's death, that Shane was murdered. We believe that whoever did this to Shane were interested in the files that were accessed. It is our assertion that the "NEMS Switch" and the other highlighted red files has to do with Shane's prior involvement with Huawei.

The files highlighted in blue were accessed on June 27, 2012. As you know, Shane was discovered dead on June 24th. There is a file that was created and erased called "characterization result to veeco.pptx". **Veeco is the company that made the machine that is restricted for export by the US government.** Why would somebody access and create and erase the Veeco file? We can't explain how this file was accessed on June 27. You told us on June 26 that you had Shane's (singular) computer. Was there another computer that had not yet been recovered? This is why it is imperative we are allowed access to Shane's computers in order to determine which computer was accessing the remote hard drive.

This is our fourth input to you with our questions. Other than the

coroner's report, we still have not heard from you. Would you please respond to our questions.

Thank you,
Rick Todd

TAB 13

7/2/13

Huettner CV 2013

Steve Huettner joined Nuvotronics in January 2011, and holds the position of Chief Engineer.

At Nuvotronics he has led the development of Time Delay Units for commercial and government customers, time delay units are used in phased array radar.

He is also developing Smart Power Amplifiers, using PolyStrata® low-loss power combiners that exploit compound semiconductor gallium nitride to achieve high power and efficiency.

Most of Mr. Huettner's current work is covered under International Trafficking in Arms Regulations (ITAR).

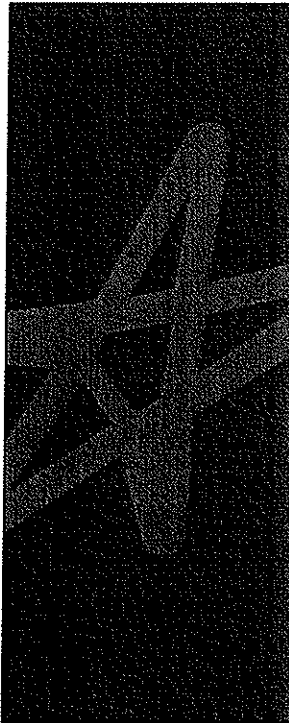
Previously as an Engineering Fellow at Raytheon Missile Systems (top 1% of engineering pool), he gained 30 years of RF sensor design experience for military applications. His work included device developments such as ways to improve GaN HEMT RF performance, and designing high-performance components that use GaN HEMTs.

Steve received his Bachelors of Engineering with High Honors from Stevens Institute of Technology (1980), and Masters of Science in Electrical and Computer Engineering from University of Massachusetts at Amherst (1982). He has four US patents, with five more pending.

He is a member of the IEEE Microwave Theory and Technique Society, and serves on the Technical Program Committee for the IEEE Compound Semiconductor Integrated Circuit Symposium, the preeminent international forum for developments in compound semiconductor integrated circuits and devices, embracing GaAs, InP, GaN, SiGe, and RF CMOS technologies.

He is the creator of the popular web site Microwaves101.com, which has been a valued resource for the worldwide microwave engineering industry since 2000.

TAB 14



GaN-on-Silicon TSRP: Device Characterization and Process Design Kit (PDK) Establishment

- TSRP
- Project Leader and Team Members
 - Project Leader: Shane Todd
 - Project Team: Yuan Li, Zuhui Chen
- Collaborators (University/RI/Hospital)
 - Zhou Xin (NTU)
- Project Duration
 - 3 years (01 April 2011 – 31 March 2014)



KPI Status

KPI Indicators	Total target as per grant		IME Stretch KPI in FY11	Actual	
	Collaborator KPI	IME KPI		Collaborator KPI	IME KPI
No. of Prestigious Journal Papers published	4	4		0	1 (under review)
No. of Prestigious Conference Papers published	3	3		0	2
No. of Invention Disclosure	1	1		0	0
No. of patent filed	1	1		0	0
No. of patent granted	1	1		0	0



What new capabilities have been developed?

New Capabilities to be developed	Status of Capability Development	Capabilities beneficial to	Plan for next phase		
			Industry Project with RCA\$	Next phase for future development	Integrated Capability/ Cross lab Project
Load Pull Measurement	Setup almost complete, verifying characterization procedure	Characterization of high power/high frequency transistors under large signal biasing	Huawei		NTU/NUS
High Voltage/high Power Power Device Analyzer Measurement	Tender Requisition submitted, receiving product demos	Characterization of breakdown voltage > 3000 V, current measurement > 20 A, Power measurement > 400 W	Azzurro		NTU/NUS
Pulsed IV Characterization Measurement	Tender Requisition submitted, receiving product demos	Characterization of device performance while eliminating self heating effects and characterization of trap behavior	Azzurro		NTU/NUS

Page 3



The challenges & problems the project are facing and how to address them

Challenges / Problems (e.g. Technical constraints etc.)	Impact	Mitigation action
NTU CMOS-compatible GaN HEMT process development has been delayed. Estimated completion date is Feb 2012 (6 month delay)	No ability to characterize devices for PDK establishment	Developing process independently at IME, will use IME process for PDK establishment
Yong Zhong leaves IME	Transfer of responsibilities causes project delay, especially for equipment purchase / measurement setup	Shane taking over project leadership

The objective is to identify potential show-stoppers.

Page 4



Contributions/Problems from External Collaborators

The objective is to assess true collaborations and the leverage factor.
 Page 5



Deliverables

Deliverables	Original Grant Completion Date	Actual/ Current Completion Date	If delayed, Why?
Journal: GaN Schottky diode 1/f noise investigation	Nov 11	Oct 11	No delay but still under review
Journal: Silicon based photonic driver	Jan 12	Jun 13	NTU process development delay, will use IME process PDK
Journal: GaN power amplifier	Jan 12	Jun 13	NTU process development delay, will use IME process PDK
Journal: MISHEMT power performance	Feb 14	Feb 14	No delay
Conference: GaN Schottky diode 1/f noise investigation	Jun 11	Jun 11	No delay
GaN Schottky diode power performance	Jun 11	Jun 11	No delay
Conference: Silicon based photonic driver	Jun 12	Jun 13	NTU process development delay, will use IME process PDK
Conference: GaN power amplifier	Jan 12	Jun 13	NTU process development delay, will use IME process PDK
Invention Disclosures (2)	Jan 13	Jan 13	
Primary Patent Application Filed (2)	Mar 13	Mar 13	
No of Patents Granted (2)	Mar 14	Mar 14	
No Research Staff Hired (2)	Jan 12	Jan 12	

Page 6



TAB 15

Evidence for Inquest

Steve Huettner

14 May 2013

The information below was gathered in order to put some perspective on gallium nitride technology.

In my career I was involved in gallium nitride HEMT for the past ten years. I don't have a deep theoretical knowledge how gallium nitride HEMTs are produced, my expertise more practical: is in how to apply its breakthrough performance to greatly increase the performance of existing RF systems, and use it in new ways to enable systems that were previously not possible.

History of GaN development

The US government paid for the early development of gallium nitride. One program alone, Darpa's Wide Bandgap Semiconductor for RF Applications (WBGs-RF) invested \$100M over 2002-2008. Here is a quote from the WBGs-II program solicitation on FedBizOpps website:¹

"Awards totaling approximately \$75 to \$110 million over four years are expected to be made during the first half of calendar year 2005. Multiple awards are anticipated."

In the article *The DARPA Wide Band Gap Semiconductors for RF Applications (WBGs-RF) Program: Phase II Results*, Mark Rosker¹ et al, GaasMantech 2009ⁱⁱ. Mark Rosker tells how the key to meeting the goals was in the device epi layer (the so-called "recipe"). Rosker was the Darpa program manager for this project.

"Key to achieving Phase II's goals and surpassing what had been previously achieved for stable devices was the systematic investigation of the role of the device epi-layer design and device fabrication methods on performance and reliability. New analytical models developed in the program assist with understanding device stability [2]. Improvements in PAE and gain were achieved through careful design of the buffer layer and reduction of gate current leakage. The role of buffer layer doping and the barrier strain and thickness were carefully investigated to balance the requirements for high power density and stable operation. In addition, the teams investigated various back barriers to increase carrier confinement."

Darpa's mission is as follows, according to Fifty years of Innovation and Discovery, By Dr. Richard Van Atta:

DARPA's primary mission is to foster advanced technologies and systems that create "revolutionary" advantages for the U.S. military. Consistent with this mission, DARPA is independent from the military services and pursues higher-risk research and development (R&D) projects with the aim of achieving higher-payoff results than those obtained from more

incremental R&D. Thus, DARPA program managers are encouraged to challenge existing approaches and to seek results rather than just explore ideas. Hence, in addition to supporting technology and component development, DARPA has funded the integration of large-scale “systems of systems” in order to demonstrate what we call today “disruptive capabilities.”

Underlying this “high-risk – high-payoff” motif of DARPA is a set of operational and organizational characteristics including: relatively small size; a lean, non-bureaucratic structure; a focus on potentially change-state technologies; and a highly flexible and adaptive research program. What is important to understand at the outset is that in contrast to the then-existing defense research environment, ARPA was designed to be manifestly different. It did not have labs. It did not focus on existing military requirements. It was separate from any other operational or organizational elements. It was explicitly chartered to be different, so it could do fundamentally different things than had been done by the military service R&D organizations.

Darpa tends to publish a lot of results (but not details), which broadcasts what is possible to everyone. The IEEE provides a worldwide professional forum where gallium nitride these results are published; perhaps 90% of the details of a recipe that IME was developing can be obtained from professional journals.

All of Darpa’s efforts (and there are many) started out as GaN on silicon-carbide. Silicon carbide is an expensive material and is available only in four inch wafers. Silicon is available in much larger format, even up to 18 inches in commercial fabs.

What is the significance of GaN?

The article “GaN Revolution: After Long Germination, Industry Readies High-Power Chips”, Defense News, Feb. 28, 2011, Dave Majumdarⁱⁱⁱ, talks to the capabilities of GaN for improving the range of military radar and cell phone base stations

“Generally speaking, GaN power amplifiers are particularly useful for high-output or high-frequency devices such as cell-phone base stations, jammers, tactical radios, satellite-communications stations, power-distribution systems, and military radar systems, Rosker said.

Colin Whelan, a Raytheon engineer who works on GaN technology, said a GaN-based active electronically scanned array radar could search five times the volume as a similarly sized GaAs-based radar, or at a 50 percent greater range. You could even halve the size of the radar and still deliver greater performance.

The article also touches on the struggle to make the process reliable:

Rosker said the road to a practical GaN-based chip was not easy. Early chips degraded into uselessness in less than a week, and for no discernable (sic) reason.

"There were plenty of theories about what the problem was, no real clear understanding of what caused the physical degradation," Rosker said.

Through an effort led by DARPA, the underlying problem was largely corrected, yet the exact nature of the degradation, though basically understood, is still debated, Rosker said."

GaN was first targeted for military applications because it cost so much. In *GaAs GaN War Debunked*^{iv}, Balistreri states(as of 2010) cost was prohibiting GaN from commercial systems.

...the first application of GaN technology was in defense systems where cost was not as prominent a factor as performance. In commercial applications, acceptable performance is assumed and cost becomes the driver, which currently makes GaN less competitive than GaAs for many applications, regardless of the latter's technical merits.

What has changed since 2010, is that GaN-on-silicon is showing performance almost as good as GaN on SiC, but is far less expensive. Darpa did NOT see this coming. GaN on silicon was pioneered by a US company called Nitronex, which was recently sold by the original investors; it failed to capture substantial market share.^v

Eight inch silicon wafers cost a few dollars and yield 400% more area compared to four-inch silicon carbide wafers that were pioneered by Darpa. Soon, all cell base stations will be replaced with GaN transmitters using GaN-on-Si technology, which will be less expensive and more powerful than the GaAs transmitters that are used today. This upgrade represents billions of dollars of business, a market that is far greater than the military use of GaN.

The advantage of GaN for cellular infrastructure is discussed in "How Something You've Never Heard Of Is Changing Your World, John C. Zolper, Ph.D, August 12th, 2012, TechCrunch^{vi}

"RFHIC Corp of Suwon, South Korea, which makes GaN-based radio frequency and microwave components for telecommunications and broadcasting industries, estimates U.S. carriers could save approximately \$2 billion per year by using GaN technology for their wireless infrastructures. Large carriers, including Sprint, have already launched GaN-powered towers in several markets."

In "Military Spending and GaN Adoption Driving RF Power Semiconductor Markets"^{vii}, Zolper claims that that GaN has two significant markets, wireless infrastructure and military:

“Other than wireless infrastructure, the vertical market showing the strongest uptick in the RF power semiconductor business has been the military, which Wilson describes as being now “a very significant market.” While the producers of these devices are located in the major industrialized countries, the military market is now so global that equipment buyers can come from anywhere.”

Why is the specification on Shane’s computer a concern?

If you read the export restrictions on microwave power transistors, the US starts restrictions at 3.2 GHz at a power level of 60 watts. See Commerce Control List Supplement No. 1 to Part 774 Category 3, Export Administration Regulations Bureau of Industry and Security December 7, 2012^{viii}

b.3. Discrete microwave transistors having any of the following:

b.3.a. Rated for operation at frequencies exceeding 3.2 GHz up to and including 6.8 GHz and having an average output power greater than 60W (47.8 dBm);

The specification calls for a 150 watt transistor at 3 GHz. Such a transistor would output close to 150 watts at 3.2 GHz. The way the specification was written it seems like it was deliberately trying to skirt the export law.

ⁱ <https://www.fbo.gov/index?tab=core&s=opportunity&mode=form&id=dfd64a58dd4de51db5a85884bd4deed8>

ⁱⁱ <http://www.gaasmantech.org/Digests/2009/2009%20Papers/002.pdf>

ⁱⁱⁱ <http://www.defensenews.com/article/20110228/DEFFEAT01/102280305/GaN-Revolution>

^{iv} http://www.triquint.com/products/tech_library/docs/articles/GaAs%20Vs%20GaN%20War%20Debunked%20MPDigest%20September%202010.pdf

^v <http://www.businesswire.com/news/home/20120626005493/en/Gaas-Labs-Acquires-Leader-Gallium-Nitride-RF>

^{vi} <http://techcrunch.com/2012/08/12/how-something-youve-never-heard-of-is-changing-your-world/>

^{vii} <http://www.abiresearch.com/press/military-spending-and-gan-adoption-driving-rf-powe>

^{viii} <http://www.bis.doc.gov/policiesandregulations/ear/ccl3.pdf>

TAB 16

Statement about power capability

Steve Huettner

18 May 2013

The United States specifically starts restrictions for output power of an RF transistor at 3.2 GHz. The requirement is that discrete microwave transistors from 3.2 to 6.8 GHz that exceed 60 watts are subject to export control at a power level of 60 watts. The power level that triggers export control gradually decreases with frequency, as transistors possess a natural reduction in power capability as frequency. See "Commerce Control List Supplement No. 1 to Part 774, Category 3", page 6, from Export Administration Regulations Bureau of Industry and Security December 7, 2012. This document is available on the Department of Commerce websiteⁱ

b.3. Discrete microwave transistors having any of the following:

b.3.a. Rated for operation at frequencies exceeding 3.2 GHz up to and including 6.8 GHz and having an average output power greater than 60W (47.8 dBm);

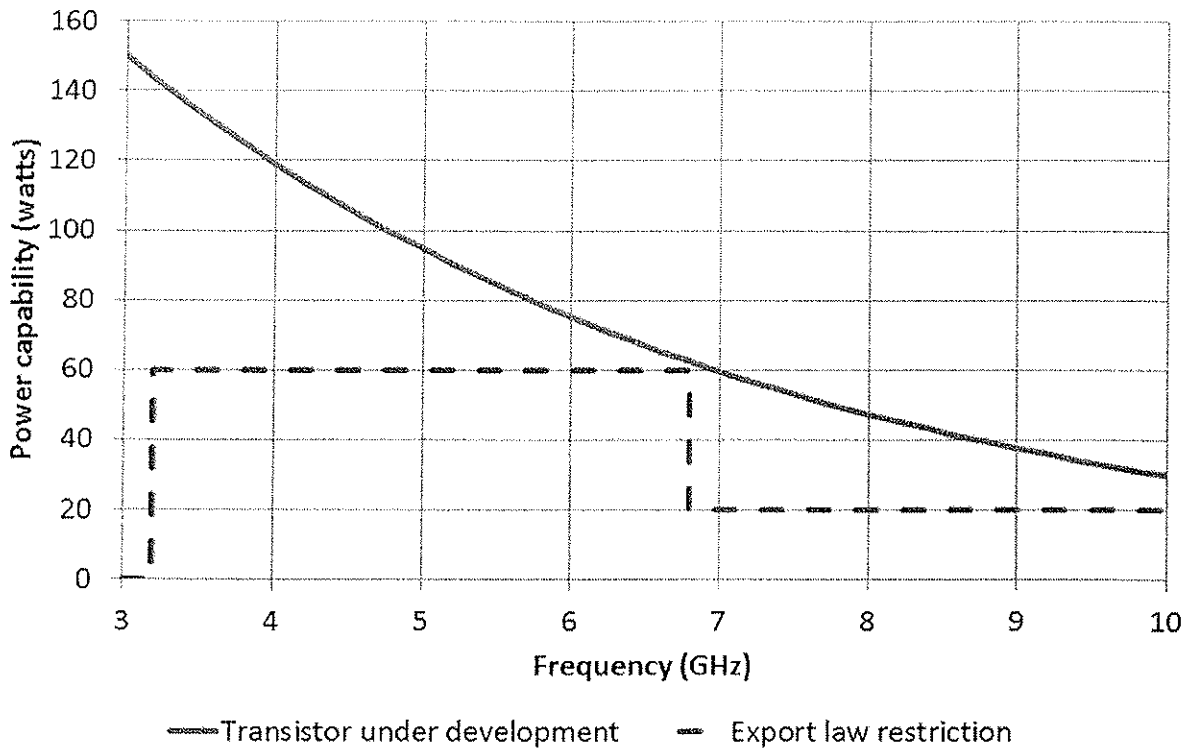
The next frequency band defined for export control is 6.8 to 31.8 GHz, where 20 watts is the boundary.

The specification found on Shane's hard drive calls for a 150 watt transistor at 3 GHz. Such a transistor naturally would also be capable of close to 150 watts at 3.2 GHz and therefore an export violation. One convenient way to approximately scale the power capability of a transistor is to project that it scales down by a factor of two for every doubling in frequency. On the plot I supplied, this relationship shows that a 150 watt, 3 GHz transistor is capable of 143 watts at 3.2 GHz, 137 watts at 3.4 GHz, etc. (blue line). It far exceeds the defined boundary for export control (red line on the plot) across the 3.2 to 6.8 GHz band and into the 6.8 to 31.8 band.

To me, that 150 watt/3 GHz specification was written to deliberately skirt United States export controls in order to obtain very high power capability.

If Shane were to look up the export control on microwave transistors, he would have seen that 60 watts/3 GHz is the nearest threshold. Shane had superior knowledge of gallium nitride power transistors, it would have been obvious to him that the 150 watt transistor they were developing far exceeds the power threshold in the frequency band 3.2 to 6.8 GHz. Thus he would have surmised that developing a transistor with very high power capability at 3 GHz would put himself and Veeco in direct violation of export laws.

Power capability versus frequency
Gallium nitride transistor under development



¹<http://www.bis.doc.gov/policiesandregulations/ear/ccl3.pdf>

TAB 17

AlGaIn/GaN two-dimensional electron gas heterostructures on 200 mm diameter (111)-oriented silicon substrates

S. Tripathy,^{1, a)} Vivian K. X. Lin,¹ S. B. Dolmanan,¹ M. K. Kumar,¹ Joyce P. Y. Tan,¹ Shane Todd,² Veeco,³ Veeco,³ D. L. Kwong,² G. Q. Lo^{2, b)}

¹*Institute of Materials Research and Engineering, A*STAR (Agency for Science, Technology and Research), 3 Research Link, Singapore 117602*

²*Institute of Microelectronics, A*STAR (Agency for Science, Technology and Research), 1 Science Park Drive, Singapore*

³*Veeco Instruments Inc., 394 Elizabeth Ave., Somerset NJ 08873, USA*

The authors report on the epitaxial growth and characterization of crack-free AlGaIn/GaN heterostructures on 200 mm (111)-oriented silicon substrates. The total nitride stack thickness grown by the metal-organic chemical vapor deposition (MOCVD) technique is about 3.6 ± 0.1 μm . The structural and optical properties of these layers are studied by cross-sectional scanning transmission electron microscopy, high-resolution x-ray diffraction, photoluminescence, and micro-Raman spectroscopy measurements. An average threading dislocation density of the order of $1.25 \times 10^9 \text{ cm}^{-2}$ is estimated on the surface of these nitride structures grown on such a large area silicon platform. A comparatively large wafer bowing correlates well with the in-plane stress measured from the Raman measurements. The top AlGaIn/GaN interfaces reveal the formation of a two-dimensional electron gas (2DEG) with an average sheet resistivity of 350 Ω/sq , a sheet carrier concentration of $1.02 \times 10^{13} \text{ cm}^{-2}$, and an average mobility value of 1500 cm^2/Vs . The experimental results show immense potential of 200 mm GaN-on-silicon technology for electronic devices.

^{a)}Email: tripathy-sudhiranjan@imre.a-star.edu.sg

^{b)}Email: logq@ime.a-star.edu.sg

Recently, Gallium nitride (GaN) based solid-state devices have shown exceptional capabilities for electronic devices operating at high power, high-frequency, and high-temperature. The fundamental properties of AlGaN/GaN material system also make it an ideal candidate for high-power microwave devices. However, a large scale deployment of GaN electronic devices in consumer market applications requires a reduced cost. Due to the lack of commercially available large area GaN substrates, GaN heterostructures are currently grown primarily on sapphire, silicon (Si), and silicon carbide (SiC). For electronic applications, Si substrate is a very attractive alternative, being much cheaper than sapphire and SiC when substrate diameters are higher than 150 mm. There has been lot of interest to grow III-nitride heterostructures on silicon substrates due to the tremendous market potential to be integrated with well-developed Si microelectronic circuit technologies.¹⁻³ However, the GaN on Si epitaxy suffers from a significant mechanical strain that is caused by the lattice mismatch, a large difference in thermal expansion coefficients between substrate and epilayers, and the thermal gradients through the wafers. These result in high density of misfit and threading dislocations (TDs) in the AlGaN/GaN heterostructures grown on Si substrates. Beside the tensile stress generated in GaN epitaxial wafers on Si, the large diameter wafers show a pronounced bowing effect leading to non-uniform electronic properties. To relieve the tensile stress and to achieve crack-free GaN heterostructures, a wide variety of buffer and inter layers such as low-temperature AlN,⁴ graded AlGaN buffers,⁵ and Al(Ga)N/GaN superlattices⁶ have been used. For integration with Si Foundries based on complimentary metal-oxide-semiconductor (CMOS) technologies, it is desirable to scale up GaN epitaxy to 200 mm Si substrates. However, ~~tilt-to~~ tilt-to date there ~~hasve~~ has been less success in achieving high quality AlGaN/GaN heterostructure ~~over~~ on 200 mm Si substrates due to issues like epilayer cracking, wafer bowing, and high density of point and line

defects when nitride stack thickness exceeds 3.0 μm . To showcase high electron mobility transistors (HEMTs) on 200 mm Si platform with comparatively similar device performances levels as reported currently on Si substrate platform,^{7, 8} it is necessary to grow thicker GaN buffer to minimize the buffer leakage and also to improve the layer crystalline quality. In this letter, we show report crack-free AlGaIn/GaN heterostructures on grown on 1mm thick, 200 mm diameter (111)-oriented silicon substrates and present an in-depth characterization study of epilayers grown by MOCVD. with a The GaN buffer is ~2.5 μm thick (total nitride stack thickness >3.5 μm) using a Veeco K465i-TurboDisc-MOCVD-tool, and present an in-depth characterization study of epilayers grown by MOCVD. The optical, electronic, and structural properties of the layers show their suitability for electronic devices.

The epitaxial growth of GaN on 1.0 mm thick Si (111) substrates was carried out in a Veeco Turbodisc K465i high throughput MOCVD tool equipped with a DRT 210 in-situ process monitor. The starting Si(111) substrate with resistivity (~ 0.001 ohm cm) was heated to ~ 1000 °C in H_2 atmosphere and annealed for about 3 min to remove native oxide from the surface. First, a high temperature AlN buffer (thickness 100-110 nm) was grown followed by five AlGaIn buffer layers with an Al content grading from 20 to 80%. Next, the GaN layer with a thickness ~ 2.5 μm on top of the graded buffers was overgrown with two thin strain-compensating AlN interlayers.⁴ In order to make GaN semi-insulating for electronic applications, carbon doping has been used. About 18 to 20 nm thick target AlGaIn barrier layer with a 2 nm thin GaN cap was grown to form a 2DEG interface. The layer thicknesses of the epilayers, the buffer and interlayers, as well as the top $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layers were determined using a Philips FEI CSM 300 transmission electron microscopy (TEM) set up. To analyze the crystalline quality of the as-grown layer structure, high resolution x-ray diffraction (HRXRD) measurements were performed with a PANalytical X'Pert

PRO diffractometer using a 4-bounce hybrid mirror monochromatized Cu K α 1 radiation ($\lambda = 1.5406 \text{ \AA}$) and an open detector for the ω and $\omega-2\theta$ scans. HRXRD measurements were performed to obtain the full-width at half-maximum (FWHM) of x-ray rocking curves of various symmetrical and asymmetrical Bragg reflections and a quantitative evaluation of dislocation densities was also performed. The dislocation density was further confirmed by the etch pit densities of the samples evaluated by performing hot phosphoric acid etching followed by atomic force microscopy (AFM). Variable temperature micro-photoluminescence (PL) measurements were performed to probe the optical quality of the 2DEG at the top surface. The characteristics of optical phonons originating from such 2DEG AlGaN/GaN interfaces were probed by variable temperature UV micro-Raman measurements using a Jobin Yvon LABRAM-HR setup. The electrical properties of the 2DEG structures were probed by Hall effect measurement system.

Figure 1 shows the cross sectional TEM micrographs of the AlGaN/GaN heterostructure grown on 200 mm Si substrate. Two sets of measurements were performed to check the total nitride stack thickness including the AlN starting buffer, graded multiple AlGaN buffer layers, the low-temperature (LT) AlN interlayers, and top AlGaN/GaN interfaces. To probe AlGaN/GaN 2DEG interfaces and the nature of dislocation propagation, we have also explored imaging of high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM). The z-contrast HAADF-STEM images show the crystalline nature of the Al(Ga)N epilayers and accurate thickness profiles. An average thickness of about $\sim 3.6 \mu\text{m}$ nitride stack is confirmed from TEM data. High resolution TEM imaging shown in Fig. 1 also reveals $\sim 18 \pm 2 \text{ nm}$ Al $_x$ Ga $_{1-x}$ N barrier layer with a thin $\sim 2.0 \text{ nm}$ GaN cap. The thickness of two LT-AlN interlayers within the thick GaN template is about 10 - 11 nm. The bright field HR-TEM shows clearly the five AlGaN buffer layers of total thickness $\sim 1.0 \mu\text{m}$. Deposition of AlN nucleation

layer on Si(111) before GaN growth has often used to avoid the diffusion of Ga into the substrate. Furthermore, the thermal expansion coefficients of AlN is between those of GaN and Si and hence to control strain balance on the large area wafer, we have used five graded $\text{Al}_{1-x}\text{Ga}_x\text{N}$ buffer layers ($x = 20$ to 80%). The LT-AlN interlayers are grown at an intermediate temperature of 860 °C. The LT-AlN interlayer offers in-plane compressive stress because of the ~2.5% lattice mismatch between the AlN and GaN, and usage of such multiple interlayers helps to partially offset the thermal tensile stress during temperature ramp-down.⁹ Thus, the use of bottom AlGaN/AlN buffers and LT-AlN eventually led to realization of a crack-free 200 mm AlGaN/GaN heterostructure on a 1 mm thick Si(111) substrate.

With this substrate thickness and post growth in-plane stress gradient introduced, we have measured a wafer bowing of about 125 μm and curvature of 24 km^{-1} . These values are relatively higher when we compare to a bowing and curvature values of about 40 μm and 15 km^{-1} respectively measured from a similar 150 mm AlGaN/GaN heterostructure (total nitride thickness 2.9 μm) on 1.0 mm thick Si(111). However, this is quite comparable to reported results on a thinner 200 mm GaN template.⁷ In addition, the compressive strain field in the interlayer also leads to dislocation bending and annihilation of some screw dislocations as seen from TEM imaging. However, at the same time, some lattice mismatch induced misfit dislocations also appear at these interfaces, propagating to the top AlGaN barrier layer. In order to estimate the average threading dislocation (TD) density in such 200 mm epiwafers, we have further explored the HRXRD and AFM measurements. In addition, we have seen a wafer bowing in excess of 100 μm which could result in non-uniform electronic properties of the 2DEG interfaces due to an expected variation of Al content and in-plane stress. Therefore, micro-

Formatted: Superscript

Raman, micro-PL, and Hall measurements were performed across the epiwafer to estimate such variation associated with wafer bowing.

Figure 2a shows a post-growth picture of the 200 mm wafer with AlGaIn/GaN epitaxial structure on the surface. Figure 2b shows a typical HRXRD ω - 2θ scan of (0002) diffraction plane of epitaxial AlGaIn/GaN structures on 200 mm Si. The spectrum shows clear satellite peaks at lower Bragg angle side representing good crystalline quality interfaces. The dominant peak is from the thick GaN layer, while the peaks at higher Bragg angles originate from the Al_xGa_{1-x}N and AlN layers. The inset shows the rocking curves of (002) and (102) diffraction planes of such thick GaN layer. The full width at half maximum (FWHM) measurements of the XRD rocking curves of (002), (102) and (105) are about 527, 1248, and 813 arcsecs, respectively, which are comparable to GaN crystal quality reported in literature for such 2DEG heterostructures on a 150 mm Si substrate.⁸ The FWHM of x-ray rocking curves of the symmetrical and asymmetrical Bragg reflections are also studied, and a quantitative evaluation of threading dislocation (TD) densities is carried out using the Hordon and Averbach model.¹⁰ By plotting the square of the FWHM of each rocking curve of reflections against $\tan^2\theta$, where θ is the Bragg angle, a linear plot is fitted to estimate an average TD density (D) from the y -intercept of the plot, using the relation $D = y - \text{intercept}/4.36b^2$, where b is the length of the Burgers vector ($b_{\text{screw}} = 0.5185$ nm, $b_{\text{edge}} = 0.3189$ nm).

The screw and edge dislocation densities are then calculated from the plots using the data obtained from symmetrical and asymmetrical reflections, respectively. From our study, we estimated an average screw and edge dislocation density to be about 0.53×10^9 cm⁻² and 1.5×10^9 cm⁻², respectively. It is well known that mainly three types of TDs: pure-edge, pure screw, and mixed-type, dominates the MOCVD grown GaN epilayer and the HRXRD technique usually

collects information from the whole GaN stack. To further complement the dislocation density at the top 2DEG interfaces, we have carried out estimation of etch pit density. In AFM micrographs of GaN surfaces, the pure-edge TDs are typically merged into the terraces while step terminations are usually associated with screw/mixed TDs. The AFM imaging gives a root mean square roughness of about 0.2 – 0.3 nm on the as-grown surface. The etch pit density at the top surface is studied after hot phosphoric acid etching and AFM imaging. From the AFM images of the as-grown and etched samples, the etch pits are mostly found at the step terminations. Hence, we consider the etch pit densities to be mostly screw/mixed type TDs, and are estimated to be about $1.25 \times 10^9 \text{ cm}^{-2}$ agreeing closely with the TD density calculations from the HRXRD measurements.

In order to address the optical properties of the 2DEG hetero-interfaces, we have carried out micro-PL and micro-Raman measurements. The emission from top AlGaIn barrier is studied using ultraviolet (UV) PL spectra excited using 266 nm laser. The multiple peak spectral deconvolutions give rise to peaks originating from the top AlGaIn barrier and underlying GaN 2DEG channel. As expected, due to a relatively large wafer bowing, a linescan across the full 200 mm wafer shows that the much broader and weaker room-temperature PL peak from AlGaIn varies from 340 nm (3.647 eV) to 350 nm (3.542 eV), whereas the stronger PL peak centered around 3.402 eV appears from the underlying GaN layer. PL peak from GaN using both 266 and 325 nm laser excitations show a variation from 3.402 to 3.410 eV across the wafer and such a variation is related to the presence of in-plane biaxial stress in the nitride stack. A relatively large variation of AlGaIn peak is due to the combination of a fluctuation in Al content and the significant red shift due to a presence of a biaxial tensile stress. Figure 3 shows the variable temperature PL spectra recorded close to the wafer center. At 77 K, the strong PL peak at 3.454

eV corresponds to a near-band-edge free exciton transition from GaN while the broad peak located at 3.562 eV corresponds to the emission from top thin $\text{Al}_x\text{Ga}_{1-x}\text{N}$ barrier layer. Due to the tensile stress induced at the top 2DEG interfaces, a significant red shifted PL peak is observed.

The PL line scan across the 200 mm wafer using 325 nm excitation shows a much-very uniform spectral intensity distribution of GaN band-edge and much weaker deep level yellow luminescence, thus representing good crystalline quality at the 2DEG GaN channel region.

To study the 2DEG interface properties, we have performed UV micro-Raman spectroscopy. The 325 nm UV Raman near-resonantly excites the top $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ interfaces. Figure 4a shows the Raman spectra recorded from the 200 mm AlGaIn/GaN wafer under $z(x, _) - z$ polarization geometry. The Raman spectra are excited with a low laser power to avoid thermal red shift. Beside the typical GaN E_2 -high mode at 566 cm^{-1} , the Raman spectra are dominated by peaks at 600, 727, and 772 cm^{-1} . A variation of stress in the nitride layers due to a large wafer bowing factor leads to a significant change in the GaN E_2 -high phonon peak position. The softening of the E_2 -high optical phonon peak from the strain-free peak value (567.5 cm^{-1}) recorded from a freestanding GaN substrate, reveals the presence of a biaxial tensile stress. Using the relationship between in-plane stress and E_2 -high peak shift, the UV Raman data across the 200 mm wafer show an average tensile stress of 0.46 GPa induced in the nitride layer.¹¹ Figure 4b presents the variable temperature Raman spectra from such an AlGaIn/GaN heterostructure. The low-temperature spectra could clearly distinguish all Raman active modes. The weak feature around 700 cm^{-1} can be attributed to a disorder-activated mode related to lattice defects at the AlGaIn/GaN interfaces.¹² The other two modes at 600 and 727 cm^{-1} are the interface modes from AlGaIn/GaN system.¹³ The interface mode at 727 cm^{-1} appears at the expense of the $A_1(\text{LO})$ phonon of GaN and represents the 2DEG nature of the hetero-interface.

The temperature-induced shifts of the two interface modes are opposite (from sample temperature variation of 77 K to 350 K) as such modes show an anti-symmetric potential and interact more strongly with free carriers. Furthermore, spectrum at 77 K clearly show the $A_1(\text{LO})$ -like phonon peak at 777 cm^{-1} originating from the thin AlGa_xN barrier. At low-temperature, the quasi-LO phonon from GaN also appears due to the top thin GaN cap interface inhomogeneity. The room-temperature deconvoluted $A_1(\text{LO})$ peak of AlGa_xN has been used to estimate the Al content using the relationship reported in Ref. 14 for samples with low Al content range when excited close to resonance. Using the experimental data and the relationship of AlGa_xN LO phonon peak vs Al content: $\omega_{\text{LO}}(x) = 734 + 356.8x - 814.7x^2$; average Al compositions of $15 \pm 3\%$ are obtained across the full wafer. Although Al composition fluctuation occurs due to a variation of biaxial stress in such a large wafer area, micro-Raman method addresses such local inhomogeneities across the full wafer. Such variation could be easily correlated to the wafer bowing and electrical characteristics across the 200 mm Si platform. To check the applicability of such AlGa_xN/GaN interfaces for high electron mobility transistors, Hall effect measurements are performed on the sample from center to edge. The sheet resistivity from the center to edge in such a 200 mm wafer shows an average value of $350 \text{ } \Omega/\text{sq}$ with a variation of about 15%, a maximum sheet carrier concentration of about $1.02 \times 10^{13} \text{ cm}^{-2}$, and an electron mobility value of $1500 \text{ cm}^2/\text{Vs}$. Due to a strong wafer bowing and Al composition variation in the AlGa_xN barrier, the center to wafer edge mobility variation is about 20%. Such variations could be compensated with further improvement in our epitaxy and more exotic designs of interlayer spacing.

In summary, we report on the 200 mm AlGa_xN/GaN epiwafer development on Si substrate platform. An in-depth characterization study is presented to check the applicability of such

MOCVD grown material system for high-voltage electronics. The structural and optical characterization shows tremendous potential of such device grade GaN layers on silicon.

Acknowledgements: The authors thank funding support from TSRP SERC GaN-Si Power Electronics Program Project -102 169 0126.

References

- ¹T. K. Li, M. Mastro, and A. Dadgar, *III–V Compound Semiconductors: Integration with Silicon-Based Microelectronics*, CRC Press, Parkway NW (2010).
- ²S. Arulkumaran, T. Egawa, and H. Ishikawa, *Solid-State Electronics* **49**, 1632 (2005).
- ³L. S. Selvaraj, A. Watanabe, and Takashi Egawa, *Appl. Phys. Lett.* **98**, 252105 (2011).
- ⁴A. Dadgar, J. Bläsing, A. Diez, A. Alam, M. Heuken, and A. Krost, *Jap. J. Appl. Phys. Part 2 Lett.* **39**, L1183 (2000).
- ⁵H. Marchand, L. Zhao, N. Zhang, B. Moran, R. Coffie, U. K. Mishra, J. S. Speck, S. P. DenBaars, and J. A. Freitas, *J. Appl. Phys.* **89**, 7846 (2001).
- ⁶E. Feltin, B. Beaumont, M. Laugt, P. de Mierry, P. Vennegues, H. Lahreche, M. Leroux, and P. Gibart, *Appl. Phys. Lett.* **79**, 3239 (2001).
- ⁷A. R. Boyd, S. Degroote, M. Leys, F. Schulte, O. Rockenfeller, M. Luenenbuerger, M. Germain, J. Kaeppler, and M. Heuken, *Physica Status Solidi C* **6**, S1045 (2009).
- ⁸K. Cheng, M. Leys, S. Degroote, J. Derluyn, B. Sijmus, P. Favia, O. Richard, H. Bender, M. Germain, and G. Borghs, *Jap. J. Appl. Phys.* **47**, 1553 (2008).
- ⁹A. Dadgar, T. Hempel, J. Bläsing, O. Schulz, S. Fritze, J. Christen, and A. Krost, *Physica Status Solidi C* **8**, 1503 (2011).
- ¹⁰M. J. Hordon, and B. L. Averbach, *Acta Metallurgica* **9**, 237 (1961).
- ¹¹S. Tripathy, Vivian K. X. Lin, S. Vicknesh, and S. J. Chua, *J. Appl. Phys.* **101**, 063525 (2007).

¹²V. Y. Davydov, I. N. Goncharuk, A. N. Smirnov, A. E. Nikolaev, W. V. Lundin, A. S. Usikov, A. A. Klochikhin, J. Aderhold, J. Graul, O. Semichinova, and H. Harima, *Phys. Rev. B* **65** 125203 (2002).

¹³V. K. X. Lin, S. B. Dolmanan, S. L. Teo, H. H. Kim, E. Alarcon-Llado, A. Dadgar, A. Krost, and S. Tripathy, *J. Phys. D: Appl. Phys.* **44**, 365102 (2011).

¹⁴M. Yoshikawa, J. Wagner, H. Obloh, M. Kunzer, and M. Maier, *J. Appl. Phys.* **87**, 2853 (2000).

Figure Captions:

FIG. 1. Cross-sectional TEM images of the AlGaN/GaN heterostructures and full nitride stack on a AlN nucleation layer on Si(111). (a) and (b) represent bright-field XTEM of layers and the top AlGaN/GaN interfaces. (d) and (e) represent the HAADF-STEM z-contrast images of the same sample showing different interfaces and much accurate thickness profiles.

FIG. 2. (a) Picture of the 200 mm GaN-on-Si wafer after growth. (b) HRXRD ω - 2θ scan of (0002) diffraction plane of AlGaN/GaN heterostructures on 200 mm Si(111). The inset shows the rocking curves of (002) and (102) planes giving a measure of tilt and twist in such large area epiwafer.

FIG. 3. (a) Variable temperature micro-PL spectra from AlGaN/GaN heterostructure on Si(111) recorded under 266 nm laser line excitation. The broader PL at higher energy side appears from the top thin AlGaN barrier. (b) PL spectra excited under 325 nm laser line show a much uniform GaN luminescence profile across the 200 mm wafers.

FIG. 4. (a) Room temperature micro-Raman spectra from AlGaN/GaN heterostructure on Si(111) recorded under 325 nm laser line excitation from various positions across the wafers. (b) Variable temperature Raman spectra excited under 325 nm showing the presence of disorder activated (DA), interfaces modes IF1 and IF2, and AlGaN $A_1(\text{LO})$ modes. The inset shows peak

fitting showing the position of AlGaN AI(LO) at 776.2cm^{-1} . The quasi-LO (Q-LO) phonon of GaN appears at low temperature.

Figure 1

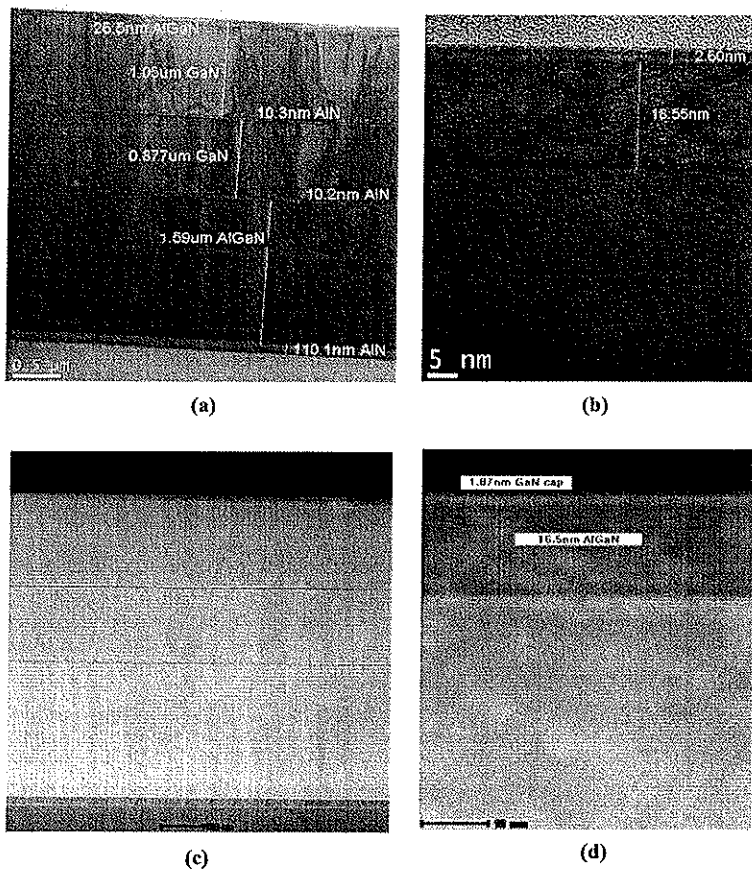
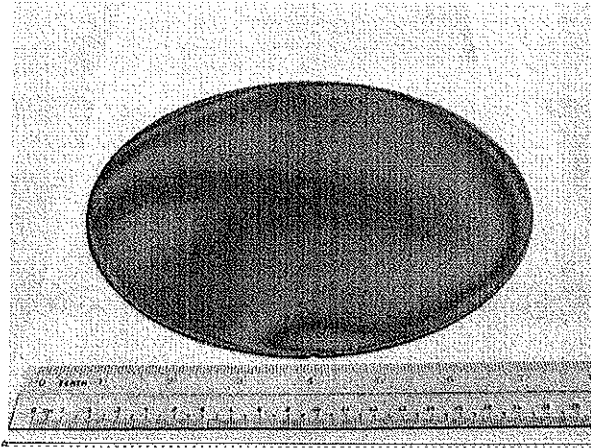


Figure 2

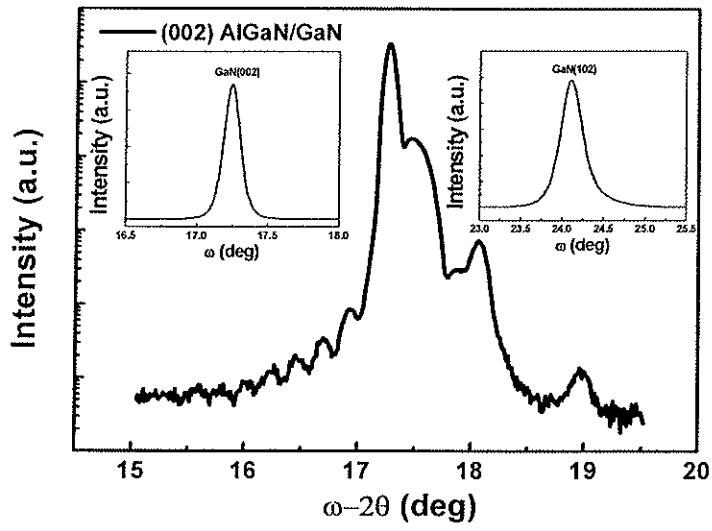


Formatted: Font: Bold

Formatted: Centered

(a)

Formatted: Font: Not Bold



(b)

Figure 3

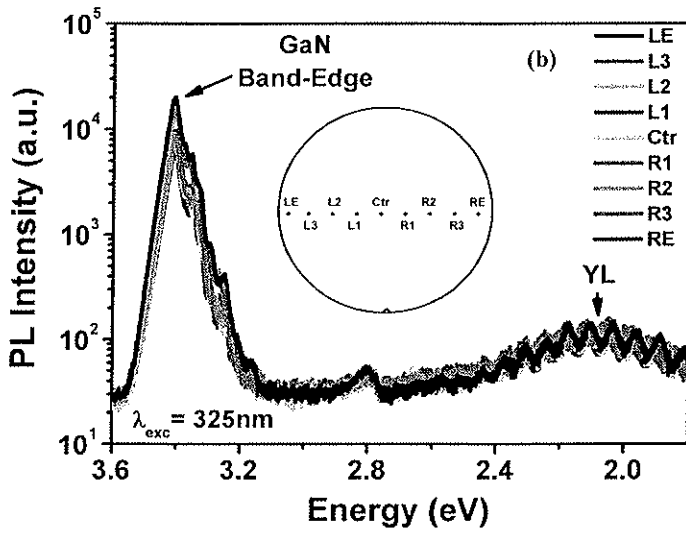
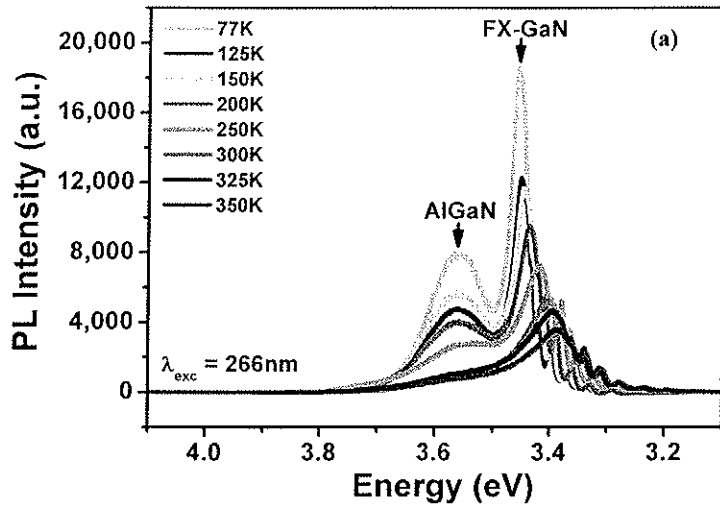


Figure 4

