AOARD REPORT

High Temperature Electronics Assessment

June 7 1993
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AOARD

As part of the AFOSR initiative, the High Temperature Electronics Assessment group has successfully completed the evaluation of high temperature electronics (HTE) technology in Japan. The group consists of Prof. Robert Davis of North Carolina State University, Prof. Hadis Morkoc of the University of Illinois, Mr. Kenichiro Nakano of Wright Laboratory, and Dr. S. Joe Yakura of AOARD. Between 25 May and 2 June 93, the assessment group visited Kyoto University in Kyoto, Nichia Chemical Industries in Tokushima, Sharp in Nara, Fujitsu Limited in Kawasaki, and the National Institute for Research in Inorganic Materials in Tsukuba. A report on the current status of U.S. and Japanese HTE technology is available by contacting Dr. G. Witt of AFOSR/NE.

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CC: Dr Geraold Witt, AFOSR
Prof Hadis Morkoc, Univ of Illinois
Prof Bob Davis, North Carolina State Univ
Mr Kenichiro Nakano, WL/ELRD

Date: 7 June 93

Subject: Trip Report - 25 May through 2 Jun 93
on High Temperature Electronics

ABSTRACT:
The High Temperature Electronics Assessment group has successfully completed the evaluation of high temperature electronics (HTE) technology in Japan. The group consists of Prof. Robert Davis of North Carolina State University, Prof. Hadis Morkoc of the University of Illinois, Mr. Kenichiro Nakano of Wright Laboratory, and Dr. S. Joe Yakura of AOARD. Between 25 May and 2 June 93, the assessment group visited Kyoto University in Kyoto, Nichia Chemical Industries in Tokushima, Sharp in Nara, Fujitsu Limited in Kawasaki, and the National Institute for Research in Inorganic Materials in Tsukuba. A report on the current status of U.S. and Japanese HTE technology is available by contacting Dr. G. Witt of AFOSR.

Purpose: Assess the current status of Japanese high temperature electronics technology.

Members of the Technology Assessment Team:
- Assoc Prof Hadis Morkoc (University of Illinois)
- Prof Robert Davis (North Carolina State University)
- Mr Kenichiro Nakano (Air Force's Wright Laboratory)
- Myself (AFOSR/AOARD)

Places and Persons Visited:
- Kyoto University in Kyoto on 26 May
  - Prof Hiroyuki Matsumani
  - Mr Mimoto
- Nichia Chemical Industries, LTD in Anan (close to Tokushima) on 27 May
  - Mr Shuji Nakamura
- Sharp Central Research Laboratory in Nara on 28 May
  - Dr Akira Suzuki
  - Dr Nobuo Hashizume
  - Dr Teraguchi
  - Dr Takiguchi
- Meijo University in Nagoya (did not visit the university; instead we met Prof Akasaki at the ANA Hotel in Tokyo and had meeting at AFOSR/AOARD office) on 29 May
  - Prof Isamu Akasaki
- National Institute for Research in Inorganic Materials

(NIRIM) in Tsukuba on 31 May
- Dr Osamu Mishima
- Dr Koh Era
- Dr Seiichiro Matsumoto

o Fujitsu Limited in Kawasaki on 1 June
- Dr Yuji Furumura
- Mr Masaki Yamabe
- Mr Masafumi Nakaishi
- Dr Toshihiro Sugii (belongs to Fujitsu Laboratories in Atsugi)

Comments, Observations and Findings:

<u>26 May at Kyoto Univesity in Kyoto</u>

1. Prof Matsunami is a faculty member of the Electrical Engineering Department at Kyoto University. His main line of research is in crystal growth of Silicon Carbide (SiC). He is considered as one of the prominent SiC experts in the world, having started the SiC research efforts in Japan and trained numerous graduate students in the past two decades. Based on conversation between Prof Davis and Prof Matsumani, it seems that there is a very close working relationship between them in terms of promoting SiC research efforts both in Japan and the US and training graduated students to carry on further research in this field. One of Prof Matsunami's students, Dr Suzuki, is continuing SiC research at Sharp Corporation and we had a chance to meet and discuss with him on the status of his research two days later at Sharp Corporation.

2. Prof Matsunami had a few questions to ask before we started discussing technical issues related to SiC research in Japan. He wanted to know the reason for the US Air Force's renewed interest on high temperature electronics research where it was abandoned sometime ago. Prof Davis replied by saying that because of the advance in technology, it is possible to grow crystals under better controlled environments that were not possible before. Prof Davis and Prof Morkoc believe that semiconductor technology has matured to a point where it is time to explore more aggressively into high temperature electronics again.

3. Prof Davis started the discussion by first covering issues associated with bulk crystal growth of SiC then proceeded to discuss other topics such as epitaxial film layers. The following are a few of important points discussed here.

- Westinghouse could grow 2" crystals.
- Nippon Steel can grow a 1" wafer(At Yokohama First Research Center).
- The poly type growth research is continued in Japan.
- Not much progress has been made in bulk crystal growth.
- Prof Matsunami has received a proposal from a Russian scientist to grow a bulk 4" crystal.
- It takes 0.7 mm/hr to grow a 6-H crystal with the seed (source) at around 2000 deg C.
- When the SiC bulk crystal is cut or sliced, the quality is almost as good as GaAr. Polishing is done using the diamond based materials.
- The Japanese are growing mainly an 1" wafer.

- For epitaxial film layers, a pressure level of 1 atm is sufficient for uniform growth using CVD. No attempt has been made to grow at low pressures. Perhaps the low pressure may help in achieving good uniformity.
- No research is done at Kyoto University on effects of hydrogen.
- No SiC alloy research is carried out in Japan.
- Problems in SiC are packaging and ohmic contact.

27 May at Nichia Chemical Industries in Anan

1. Mr Nakamura grows an Indium Gallium Nitride crystal. For LEDs he uses the Sapphire substrate.
2. Mr Nakamura did not provide any information on ohmic contact problems.
3. Currently, Mr Nakamura is doing the life testing of InGaN at 60 - 80 deg C. No preliminary results are available yet.
4. The yield for InGaN is at least 30%.
5. Nichia Chemical Industries, LTD is going to market InGaN LEDs this fall. R&D efforts will be continued toward blue laser diodes using InGaN.
6. Mr Nakamura showed us his GaN LED. It is significantly brighter than SiC LEDs.

28 May at Sharp Corporation in Nara

1. The main purpose of SiC research is to produce blue LEDs.
2. Fuji Electric is carrying out SiC research for power generator sensor applications.
3. Dr Suzuki provided us with recent publications on the growth of SiC and ZnS by Sharp Corpotation personell.

29 May with Prof Akasaki in Tokyo

1. Prof Akasaki has been an active participant of GaN research since 1974 and is considered as one of the prominent experts on GaN research in Japan. He has compiled numerous papers on GaN research in the past twenty years. He provided us with copies of tables and figures pertaining his GaN activities.
2. Prof Akasaki was aware of our visit to Nichia Chemical Industries and was curious of Mr Nakamura's progress in InGaN work.
3. Prof Akasaki showed us a draft proposal that he prepared to submit to ONR (attn Max Yoder). When I mentioned to him that the mission of AFOSR is to support basic research as in the case with ONR, he said that he may consider submitting his proposal to us instead. I believe, if funding for high temperature electronics research gets approved in the near future, AFOSR should consider supporting Prof Akasaki's research if he is willing to collaborate with Mr Nakamura. Prof Akasaki should provide good guidance for Mr Nakamura to extend InGaN LED research into InGaN laser diodes.

31 June at National Institute for Research
in Inorganic Materials (NIRIM)
in Tsukuba Science City

1. NIRIM is a research laboratory that comes under the Science and Technology Agency of Japan. There are about 150 scientists working at this laboratory in Tsukuba Science City. Our object of coming here was to talk with Dr Osamu Mishima and find out the status of Cubic Boron Nitride (CBN) research in Japan.

2. From NIRIM there were Prof Mishima and Dr Koh Era present in the meeting. Dr Mishima is a senior scientist in high pressure station group, specializing in high pressure device and CBN research. Dr Era is director of special research group, working specifically on CBN for optoelectronics materials. They mentioned that there are other scientists who work on CBN at NIRIM. They are Dr Taniguchi who does laser assisted chemical vapor deposition, Drs Komatsu and Mieno who work on low pressure CVM method. Currently, CBN research is not that active at NIRIM. The most active research area is in diamond. Many of the NIRIM scientists are working on the super diamond project which started this April and would last for next five years. The project has been funded for next two years and be funded for the remaining years at later time. The purpose of this project is to produce a thin film diamond.

3. Japanese corporations working with NIRIM scientists on CBN research are Sumitomo Electric, Showa Denko, and Toshiba Tangarui. One company that came to talk to NIRIM and showed an interest on CBN high pressure method is Ichikawa Jima Juko. It was not clear to me whether Ichikawa Jima Juko has established any collaboration with NIRIM.

4. Dr Mishima said that he can grow on average a 2-3 mm diameter BN crystal in elliptical shape. The maximum size of the crystal is up to 6-7 mm; however, it is not easily reproducible.

5. Since the BN research is somewhat similar to the diamond research, the discussion was extended into diamond research activities. One noticeable accomplishments in the diamond field was Dr Nakanishi's work in growing diamond using phosphate under high pressure and high temperature conditions. The pressure and temperatures were around 80 kbar and 2500 deg C, respectively.

6. Dr Tanigushi succeeded in creating CVM powder (p type) without synthesizer.

7. Dr Era mentioned that Dr Shin of the Institute of Solid State Physics (part of the University of Tokyo) observed the effects of Beryllium which showed very interesting spectra.

8. NIRIM has collaboration with Agriculture and Industrial Tokyo University to check electrical properties of BN. Be and Si doping ion implantation methods are used for checking.

9 Since 91, Dr Era has been carrying out research on BN excitation and luminescent. The excitation source that he uses is a XeF excimer laser at second harmonics. He measures the temperature dependent luminescent effect for defect energy levels from the ground state to 4 ev.

10. Dr Era said that there is a small research group formed in 91 to look into high temperature electronics. The group is headed by one of the professors at the University of Tokyo. The group

gets together every year at workshop to discuss its progress and publishes the annual report. Dr Era showed me the copy of the report and promised me that he would mail one copy for me. The raport is written in Japanese.

1 June at Fujitsu Limited in Kawasaki

1. The main object of visiting Fujitsu Limited is to talk with Dr Furumura and find out the status of his research in SiC. Unfortunately, due to the company interest, Dr Furumura's research has shifted in last few years from SiC growth to more in the area of using SiC for x-ray masks. Other Fujitsu scientists and mangers who joined the discussion with us were Mr M. Yamabe, Dr T. Sugii, and Mr M. Nakaishi. They briefed us on their work on SiC x-ray membrane and SiC emitter.