

CHAPTER 1

INTRODUCTION

Vladimir A. Dmitriev

GOALS OF THE STUDY

In fall 1997, the Office of Naval Research and the National Science Foundation requested that the International Technology Research Institute (ITRI) at Loyola College assess the current state of high-temperature electronics basic research, development, manufacturing, and applications in Japan, and compare the work being done in Japan to work going on in the United States. In consultation with the sponsors, the ITRI staff assembled a panel (see below for membership) to conduct a study on silicon carbide (SiC) and gallium nitride (GaN) R&D and production activities in Japan. The study focused on the following topical areas:

- basic research on wide bandgap semiconductors (SiC and Group III nitrides)
- bulk crystal growth of wide bandgap semiconductors
- epitaxial growth of wide bandgap semiconductors for device structures
- post growth technology for device fabrication (etching, metallization, edge termination, and passivation)
- packaging technology for high-temperature applications
- design of high-temperature devices on SiC and Group III nitrides
- applications and market for high-temperature electronic devices

THE STUDY PANEL

Six experts served as panel members for this study (for further biographical information see Appendix A). Coming from both academia and industry, they reflect the diversity of professional backgrounds currently contributing to the advancement of wide bandgap semiconductor electronics in the United States.

- Vladimir A. Dmitriev (Panel Chair), Senior Research Associate, Howard University. Expertise: wide bandgap semiconductor epitaxial growth and device development
- T. Paul Chow, Associate Professor, Rensselaer Polytechnic Institute. Expertise: power semiconductor devices
- R. Chris Clarke, Program Manager, Silicon Carbide Microwave Devices, Northrop Grumman Corp. Expertise: microwave power semiconductor devices
- Steven P. DenBaars, Associate Professor, University of California at Santa Barbara. Expertise: growth and characterization of wide bandgap semiconductors and device structures

- Michael S. Shur, Patricia W. and C. Sheldon Roberts '48 Professor, Rensselaer Polytechnic Institute. Expertise: solid state device physics
- Peter M. Stipan, Rockwell Automation. Expertise: electronic device packaging

The following representatives from the sponsoring organizations and ITRI accompanied and worked with the panel on site visits to Japanese organizations (see bios in Appendix A):

- Usha Varshney, Program Director, National Science Foundation
- Joanne H. Maurice, Air Force Office of Scientific Research
- Hiroshi Morishita, HMI, Corp. (ITRI Japan Representative)
- Cecil H. Uyehara, Uyehara International Associates (ITRI Senior Advisor for Japan Operations)

APPROACH

Panelists and government sponsors prepared a list of organizations that have established leadership in important aspects of high-temperature electronics and wide bandgap electronics in Japan. ITRI then contacted those organizations, with letters of introduction from individual panelists, to determine if they were willing to host a visit by the panel. Professor Hiroyuki Matsunami, Kyoto University, made many important recommendations on experts to contact in Japan.

Site visits took place during June 8-13, 1998. Members of the panel arrived in Japan and held a planning meeting on Sunday, June 7, in Osaka. Because of the large number of sites to visit, the panel was divided into two teams. The visit schedule and makeup of the two traveling teams are shown in Table 1.1. On Saturday morning, June 13, we held a debriefing meeting in Tokyo to collect our thoughts and impressions.

The format of the site visits varied, but the following was typical:

1. Introduction of participants and a brief discussion of the visit. At some sites, panel members gave short background presentations on the status of wide bandgap electronics in the United States. Typically, these presentations lasted 40–60 minutes.
2. Presentations by representatives of the host organization, giving background and technical objectives in the wide bandgap semiconductor field. Some of these presentations gave details such as company size, income, research and production goals.
3. Discussion, with an extended question and answer period. These discussions, which typically lasted between two and four hours, were based on a detailed questionnaire drawn up by the panel and sent earlier to the organizations. The panel did not ask organizations to answer every question on the questionnaire, but rather to focus on those issues most relevant to their own work. Before or after discussion, some host organizations provided laboratory or plant tours.

For each site visited, one attending panelist or other traveling team member had the task of writing a detailed site report. Each draft site report was then circulated to other members of the site visit team, who drew from their own notes to make additions to or deletions from the draft to ensure accuracy and completeness. ITRI then submitted each draft site report to the host organization for its own editing of the contents to ensure that the report was accurate and did not inadvertently compromise proprietary information.

Table 1.1.
Site Visit Schedule in Japan

	<u>Team A:</u> T. Paul Chow Steven P. DenBaars Peter M. Stipan Cecil H. Uyehara Joanne H. Maurice	<u>Team B:</u> Vladimir Dmitriev R. Chris Clarke Michael S. Shur Hiroshi Morishita Usha Varshney
June 8	Tokushima Univ. Nichia Chemicals	Matsushita Electronics
June 9	Furukawa Electric ISAS/MOE	Kyoto Univ. Matsushita CRL
June 10	NEC Tsukuba Lab. ETL/AIST/MITI	Ion Eng. Res. Institute
June 11	Sony CRL	Nippon Steel
June 12	Nagoya Inst. of Technol. Meijo Univ.	Jap. Atomic Energy Res. Inst.

PRESENTATIONS OF THE RESULTS

Results of the study were reported at the 1998 Fall MRS Meeting in Boston on December 2, 1998. A special session devoted to the panel report was organized by Michael Shur and Stephen Peaton (co-chair of the MRS Symposium "GaN and Related Alloys") and chaired by Vladimir Dmitriev. At the session, John Zolper (ONR), Elliot Brown (DARPA), and John Zavada (ARO) shared their views on the future of high-temperature electronics.

It is ITRI's practice to hold workshops in the Washington, D.C., area to present the findings of its panels. For this study, it was decided to organize a more elaborate U.S.-Japan Conference on Wide Bandgap Semiconductor Technology for Next Generation Electronic and Photonic Devices. In addition to the TTEC panel, leading Japanese scientists and engineers were invited to report the latest results in the field. The conference was held on December 7-8, 1998. The following presentations were made at the conference on December 7:

1. Hiroyuki Matsunami, Kyoto University. "High-quality epitaxial growth of SiC and doping control"
2. Vladimir Dmitriev, TDI, Inc. and Howard University. "SiC growth and doping"
3. Noboru Ohtani, Nippon Steel. "Seeded sublimation bulk growth of SiC"
4. Steven DenBaars, Univ. of California at Santa Barbara. "Status of Japan and U.S. GaN materials technology"
5. Hiroji Kawai, Sony Corp. "Issues for making high performance GaN-based FETs"

6. Michael Shur, Rensselaer Polytechnic Institute. “Nitride electronic devices”
7. Katsunori Ueno, Fuji Electric. “Devices and processes for SiC power applications”
8. T. Paul Chow, Rensselaer Polytechnic Institute. “High-temperature, high-voltage SiC power switching devices”
9. Toshitake Nakata, SiC Semicon Co. “Progress on the national project ‘R&D on Combustion Control Systems for Energy Conservation’ ”
10. R. Chris Clarke, Northrop Grumman. “A review of high-temperature, high-power SiC electronics in the United States and Japan”

On December 8, following a period of general discussion on different aspects of wide bandgap electronics, a number of program managers or representatives from U.S. government agencies discussed their programs. These included: J. Zolper, ONR; L. Goldberg, NSF; E. Martinez, DARPA. Mr. T. Oyama also made a presentation on the work being done by Ion Engineering.

More than 100 experts in the field of wide bandgap semiconductors attended the conference. Viewgraphs presented at the December 7 session are available on the TTEC Web site (<http://www.ttec.org>).

OVERVIEW OF THE REPORT

This written report is the final evaluation of the panel on the current status of silicon carbide and gallium nitride electronics in Japan and the United States. It consists of five chapters by panel members on specific aspects of wide bandgap electronics. These are followed by brief biographies of team members (Appendix A) and site reports (Appendix B).

ACKNOWLEDGMENTS

The panel wishes to thank all our Japanese hosts and our government sponsors—our Japanese hosts for their gracious hospitality and generous willingness to share their work and ideas with us; our government sponsors for the great opportunity to participate in this study. Cecil Uyehara and Hiroshi Morishita made our trip in Japan very well organized and pleasant. A special thanks to Bob Williams and his colleagues at ITRI, without whom there would not have been any visits, a conference, or a report.