

## **CHAPTER 1**

### **INTRODUCTION**

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#### **GOALS OF THE STUDY**

In 1999, U.S. Government agencies requested the International Technology Research Institute (ITRI) to assess the state of high-temperature electronics basic research, development, manufacturing, and applications in Europe compared to that in the United States. The similar study was conducted in 1998 examining the status of high temperature electronics in Japan and the USA. ITRI assembled the High-Temperature Electronic (HTE) Panel to conduct a study on silicon carbide (SiC) and gallium nitride (GaN) R&D and production activities in Europe. The study was focused on the following topical areas:

- basic study of wide band gap semiconductors (SiC and group III nitrides);
- bulk crystal growth of wide band gap semiconductors;
- epitaxial growth of wide band gap 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. (Short biographies are in Appendix A). Coming from both academia and industry, they reflect the diversity of professional backgrounds currently contributing to the advancement of wide band gap semiconductor electronics in the United States.

- Vladimir A. Dmitriev (Panel Chairman), President, TDI, Inc. Expertise: wide band gap semiconductor epitaxial growth and device development.
- T. Paul Chow, Associate Professor, Rensselaer Polytechnic Institute. Expertise: power semiconductor devices.
- Steven P. DenBaars, Associate Professor, University of California at Santa Barbara. Expertise: growth and characterization of wide band gap semiconductors and device structures.

- Michael S. Shur, Patricia W. and C. Sheldon Roberts '48 Professor, Rensselaer Polytechnic Institute. Expertise: solid state device physics.
- Michael G. Spencer, Cornell University. Expertise: epitaxial and bulk growth of wide band gap semiconductors.
- George White, Georgia Institute of Technology. Expertise: electronic device packaging.

The panelists were accompanied on site visits to European organizations by the following representatives from the sponsoring organizations and ITRI (Appendix A):

- Usha Varshney, Program Director, National Science Foundation.
- John Zavada, European Research Office.

## **APPROACH**

Panelists and government sponsors prepared a list of organizations that have established leadership in some important aspects of high temperature electronics and wide band gap electronics in Europe. ITRI then contacted these organizations with letters of introduction from individual panelists to determine if they were willing to host a visit by the panel.

Before the trip, panel members collected information on recent achievements in high temperature electronics and wide band gap electronics in the United States. To provide some reciprocity, panel members gave presentations during site visits reviewing the status of high-temperature electronics in the USA.

Site visits took place from June 6 to June 12, 1999. Members of the panel arrived in Europe and had a planning meeting on Sunday 6 in Grenoble. On June 7, the panel had a meeting with leading French scientists from different organizations working on wide band gap semiconductors. This full-day meeting organized at CEA LETI gave the panel members an opportunity to obtain very helpful information on wide band gap electronics R&D in France. For the following site visits, the panel was divided in two teams. The visit schedule is shown in Table 1. On Friday June 11, both teams had joint meetings at Stockholm, visiting ABB, IMC, and RIT. By Saturday morning, June 12, we had a debriefing meeting at Stockholm to compare notes and come to some conclusions.

While the site visit format varied from site to site, mostly they had the following format:

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 band gap electronics in the United States. These presentations lasted 40 – 60 minutes.
2. Presentation of the organization's background and technical objectives in the wide band gap semiconductor field; some of these presentations gave details such as company size, income, research and production goals.
3. Discussion, extended question and answer period. These discussions, which typically lasted between two and four hours, were based on a detailed questionnaire 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 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 is accurate and does not inadvertently compromise proprietary information.

**Table 1.1**  
**Site Visit Schedule in Europe**

	<b>Team A</b>	<b>Team B</b>
	S. DenBaars	V. Dmitriev
	M. Shur	P. Chow
	G. White	M. Spencer
	J. Zavada	
	U. Varshney	
June 6	<b>Panel meeting, Grenoble, France</b>	
June 7	CEA LETI, Grenoble, France	
June 8	University of Ulm	Siemens (Erlangen)
June 9	Siemens (Munich)	University of Erlangen
June 10	HPRC, Warsaw	University of Linkoping
June 11	<b>IMC/ABB/RIT, Stockholm, Sweden</b>	
June 12	Panel meeting, Stockholm, Sweden	

The results of the study were reported at the 1999 Fall MRS Meeting in Boston on December 1, 1999. A special session devoted to the panel report was organized by Michael Shur and Randall Feenstra (co-chair of the MRS Symposium "GaN and Related Alloys") and chaired by Vladimir Dmitriev. At the session, John Zolper (ONR) and John Zavada (European Research Office) shared with the participants their views on the future of high-temperature electronics. Professor Sylwester Porowski (HPRC) gave an overview of bulk GaN effort in Europe.

### **THE US-EUROPE CONFERENCE**

It is ITRI's practice to hold workshops in the Washington, DC area to present the findings of its panels. For this study, it was decided to organize a US-Europe Conference on **Wide Bandgap Semiconductor Technology for Next Generation Electronic and Photonic Devices**. Leading European scientists and engineers were invited to report the latest results in the field. The conference was held in Arlington, Virginia on December 9 – 10, 1999. The following reports were presented at the conference on December 9:

1. Michael G. Spencer, Cornell University, SiC growth and processing technology
2. Vladimir Dmitriev, TDI, Inc., Progress and issues in SiC technology
3. T. Paul Chow, Rensselaer Polytechnic Institute, High voltage SiC power switching devices
4. Heinz Lendenmann, ABB Corporate Research, Application and operation of high voltage, high current SiIGBT / SiC diode modules

5. Steven DenBaars, University of California, Santa Barbara, GaN-based materials research in Europe
6. Sylwester Porowski, High Pressure Research Center, PAS, Application of pressure grown GaN substrates to epitaxy
7. Michael Shur, Rensselaer Polytechnic Institute, GaN-based electronic device research in Europe
8. Christian Brylinski, Thomson CSF, Wide bandgap microwave power devices
9. George White, Georgia Institute of Technology, High temperature electronic packaging in Europe
10. Roumen Kakanakov, Institute of Applied Physics, BAS, Ohmic contacts and packaging for wide bandgap semiconductors

On December 10, there was a general discussion on different aspects of wide band gap electronics. The following reports were presented after the discussion:

1. NSF programs (U. Varshney)
2. ONR programs (I. Mack)
3. DARPA programs (E. Martinez)

More than 100 experts in the field of wide band gap semiconductors attended the conference. Viewgraphs presented at the conference are available on the ITRI Web site (<http://itri.loyola.edu/ttec/>).

### **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 Europe and the United States. It consists of six chapters devoted to specific aspects of wide band gap electronics written by panel members and site reports. Brief biographies of panel members are given in Appendix A.