(23) Energy Conservation Sciences for operation and Security of Large-Scale Systems
The objectives of the proposed effort are to expand and/or supplement the research presently underway as past of the Center on Security of Large Scale Systems. In particular, the project will seek to (1) expand solid-state research in the area of Silicon Carbide (SiC) for the purpose of reducing size, weight, and cost of power converters for motor drives and distributed generation, (2) to investigate methods of motor control including the advantages of SiC devices to increase the efficiency and reduce the cost of electric drives, and (3) to incorporate the results of the Center's research in fuel cell testing and modeling to suggest design and operation of these devices in distributed generation during islanding of an Electric power Grid.

Total project cost: $322,834
Funding request: $249,999
Project Lead: Purdue University
Project Participants: Wright State University

Start Date: May 23, 2005
End Date: May 23, 2007

Presentations/Publications

None.

Patents

None.

Progress in Past Quarter and Current Status
The objective for this quarter was to complete simulation of SiC Schottky and PiN diodes rated for 1000-1500 V operation. Also, the completion of Schottky diode fabrication was to be reported. Both have been completed as of this time. In this report, results of current/voltage testing of SiC Schottky diodes will be presented. The comparison of *Medici* simulation results will be presented in the next quarterly report.

Schottky diodes, with edge lengths up to 3 mm, were fabricated. A number of new processing steps were used in the fabrication of these diodes to render the process more amenable to large-scale manufacture of devices. The cross section of the device is shown in Fig. 1. Typically, gold is used as an implant mask to define the resistive termination extension (RTE) region in the figure. Instead, a polysilicon implant mask was used to avoid metal contact with the semiconductor, and to avoid Au contamination in the reactive ion etching (RIE) tool.

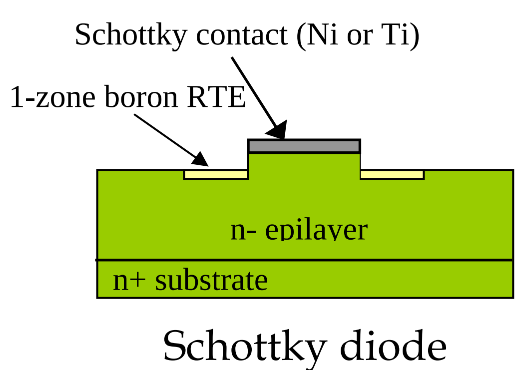

Fig. 1 Cross section of SiC Schottky diode.

Current-voltage data from 2mm x 2mm sized diodes are shown in Fig. 2. This figure represents typical data after reprocessing the diodes three times. After the first process run, ideality factors were approximately 13, indicating a very poor diode (an ideality factor of unity is desired). Upon reprocessing of the samples, ideality factors were reduced to approximately 3. A third and final reprocessing step, corresponding to the data in Fig. 2, resulted in ideality factors, n, of 1.10 (diode label "10"), and 1.09 (diode label "2F"). The bending over of the forward characteristics is attributed to series resistance.

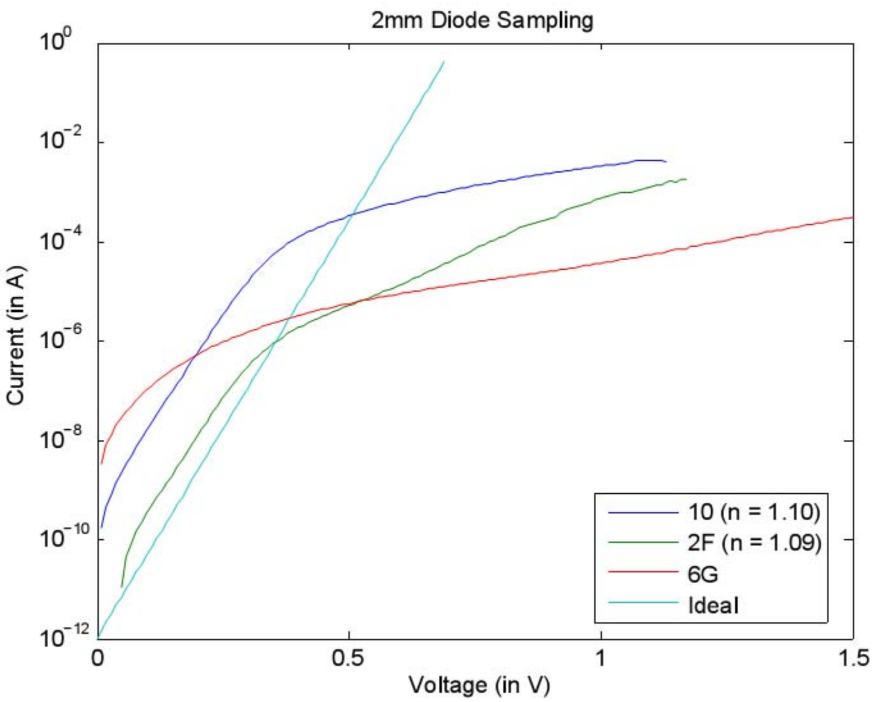

Fig. 2 Current-voltage data from 2mm x 2mm SiC Schottky diodes.

The need to reprocess the diodes was determined to be inadequate stopping power of the polysilicon implant mask. Boron ions penetrated through the implant mask creating a highly defective region at the Schottky contact. Subsequent processing, which included reactive ion etching steps, eliminated the defective region which resulted in satisfactory ideality factors approaching unity. In future SBD runs, additional thickness will be added to the polysilicon implant mask thickness.

Plans for Next Quarter:

Report on the *Medici* simulation of SiC Schottky and PiN diodes, and grow SiC epilayers required for the fabrication of 1000 V PiN diodes.

Task 2. Optimal Efficiency Motor Control Strategies

Marian Kazimierczuk, Wright State University

Objectives:

The objective of this part of the project was to design a dc/ac variable- frequency three-phase power inverter, using Si and SiC power devices, estimate the inverter power losses and efficiency, and compare the losses and efficiency with Si and SiC devices.

Background:

The benefits of silicon carbide devices include high-breakdown voltage, high-temperature, high-frequency, high-reliability, and nearly zero reverse recovery. In previous quarters, electrical and thermal characteristics of SiC power devices were studied and areas of applications were identified [1]. High-voltage SiC Schottky diodes appear to be the most promising SiC power devices for high-voltage, high-frequency applications, such as rectifiers and clamp circuits in dc/dc power converters and power-factor correctors [2]. The use of theses diodes allows the designers to avoid snubber circuits and increase the switching frequencies. Also, parallel combinations of power Si MOSFETs and SiC diodes are very promising arrangements in many applications. A topology of the dc/dc inverter was selected and designed. A Class D half-bridge dc/ac power inverter was selected for further investigations and the circuit was designed.

Publications:

The following conference papers have been reviewed, revised, and accepted:

[1] N. Das and M. K. Kazimierczuk, ``Applications of Silicon Carbide Power Devices in Power Electronics," Electrical Manufacturing and Coil Winding Association, Indianapolis, IN, September 18-20, 2006.

[2] D. Murthy and M. K. Kazimierczuk, ``Active Clamp Circuits for Flyback PWM DC-DC Converter," Electrical Manufacturing and Coil Winding Association, Indianapolis, IN, September 18-20, 2006.

Research Progress:

A variable-frequency three-phase dc/ac inverter was designed with inductive loads, using power MOSFETs and anti-parallel silicon carbide diodes. The dc input voltage was 400 V. The inverter was simulated for forward dc/ac power conversion using PSPICE. The voltage and current waveform obtained from simulation were studied extensively under inductive load conditions. The observations of the MOSFET voltage and current waveforms were made during the transistor ON-state, OFF-state, turn-on transition, and turn-off transitions. The conduction and switching power losses were estimated. Using the power losses and the output power, the efficiency was calculated.

Plans for Next Quarter:

In the previous quarter, the forward dc/ac power conversion was studied. The plans for the new quarter are to study the ac/dc three-phase power conversion under the energy recovery operating conditions. In this case, commercially available silicon carbide diodes will be used. The circuit will be simulated using the commercial large-signal model of the SiC diodes.

Task 3 Islanding and Distributed Generation for Enhanced Electric Power Grid Security

Academic Faculty:
Shripad Revankar, Associate Professor, Department of Nuclear Engineering, PU
Mitch Wolff, Professor, Department of Mechanical Engineering, WSU

Graduate Students:

Brian Wolf	M.S. Candidate Nuclear Engineering, PU
Karleine Justice	M.S. Candidate Mechanical Engineering, WSU
Carlos Gutierrez	M.S. Candidate Mechanical Engineering, WSU

Objective:

Investigate the control and performance of distributed generation during islanding of an electric power grid. High temperature fuel cell hybrid systems will be used for power generation.

Background:

Advancement in research of distributed generation of electrical power is a result of energy security issues and changing markets and technologies. Fuel cell hybrid technologies which integrate high temperature fuel cells with another power generation technology have promising abilities which make them an important research topic for development and commercialization. They meet many demands of U.S. energy goals of the future including independence from foreign sources, greater security, and pollution free emissions.

Research Progress:

(Purdue)

In the past quarter Purdue visited Wright State on September 7th. The purpose of the visit was to couple a turbine model to the MCFC fuel cell model and oxidizer to complete a multi-megawatt system. Coupling was successful, except the oxidizer did not work properly. It was assumed before that the oxidizer reactions were fast and spontaneous, so a simplified quasi-steady state model was implemented for the oxidizer. Due to the problems caused, a new dynamic model of the oxidizer was built and implemented into the hybrid system model. The hybrid model now works as predicted, however more controls need to be added to complete it. Other progress includes performing analysis on the scalability of the fuel cell system. The fuel cell system has been successfully scaled, however further investigation is needed to determine the linearity of scaled variables. A Solid Oxide Fuel Cell model has been partially developed.

(Wright State)

In the past quarter a complete explicit dynamic model of a MCFC has been developed which includes specific controls to the fuel cell system. The model was implemented using SIMULINK software and simulation of a plant trip, in which the fuel cell load starts at steady state and abruptly goes to zero has been performed. The steady state and dynamic behavior has been benchmarked with model results in the literature (Lukas et al. 1999). The model uses differential equations to calculate mass fractions, pressure, and temperature with basic simplifying assumptions. Also a dynamic model of an oxidizer has been developed and implemented to the fuel cell system. The oxidizer assumes that reactions taking place are complete and spontaneous given a minimum amount of theoretical air needed for oxidation. A Generic Microturbine Generator that will be coupled with the fuel cell has been developed with the following components modeled in Matlab/Simulink: Centrifugal Compressor, Radial Inflow Turbine, Turbine Diffuser, Combustion Chamber, and Primary Surface Recuperator. A counter-flow double-pipe heat exchanger SIMULINK model has been developed which calculates the pressure drops and outlet temperatures of the hot and cold fluids for a given set of inlet temperatures and mass flow rates. This model has been automated for variations in design parameters. A second meeting was held at Wright State University to link the fuel cell and the turbine models. Direct linking of the turbine models with the fuel cell models to create a complete dynamic fuel cell/ turbine hybrid system is nearly complete.

Plans for Next Quarter:

(Purdue)

In the next quarter, a hybrid system will be complete. The tasks needed to reach this goal include adding coupling controls between the fuel cell system and turbine system. Also, currently it is assumed that the fuel entering the fuel cell is pre-heated and has a constant flow rate. A super heater is being developed as part of a fuel preparation system, where the natural gas and steam are mixed before entering the fuel cell anode. Also, it is expected that a Solid Oxide Fuel Cell model will be completed and working properly.

(Wright State)

In the next quarter, the complete linked hybrid model will be operational. In addition, parametric studies of the dynamic hybrid system linking the fuel cell to the turbine should be completed. Control systems for the hybrid model will be included in the dynamic model.

References

Lukas, M. D., Lee, K. Y., & Ghezel-Ayagh, H. (1999). Development of a stack simulation model for control study on direct reforming molten carbonate fuel cell power plant. IEEE Transaction on Energy Conversion, 14(4), 1651-1657.