Improving Energy Efficiency in High-Power Electronics

The Michigan State University/Fraunhofer Diamond Diode project is part of the ARPA-E SWITCHES program, focused on developing next-generation power switching devices that could dramatically improve energy efficiency in a wide range of applications, including new lighting technologies, computer power supplies, industrial motor drives, and automobiles.

Developing Diamond Diodes and Transistor Devices

Together with R&D partner Fraunhofer USA, MSU is building diamond diodes for use in high-power electronics. This SWITCHES seedling project is focused on the doping of both p-type and n-type diamond and on the fabrication of high-quality diodes. Both Schottky diodes and merged Schottky/pn junction diodes are being built for high-voltage and high-current conditions.

Diamond diode design
- Low concentrations of initial defects or impurities
- Doped with specific impurities for semiconductor applications
- Substrates scaled to sizes needed for power electronics

Important design considerations
- Using heavily doped layers in devices = more charge carriers activated
- More charge carriers activated = devices with a lower resistance at elevated temperatures

Three doped diamond processes that run in diamond plasma-assisted CVD reactors have been established for the epitaxial deposition of heavily doped p-type and n-type semiconductor diamond, as well as the deposition of more lightly doped p-type diamond.

Potential Applications

- TRANSPORTATION: Hybrid and electric autos, trucks, busses, and trains
- INDUSTRY: Motor drives, advanced lighting technology, and computer power supplies
- POWER GRID: Power inverters for transformerless energy conversion

Diamond Outshines All Other Semiconductor Materials

Diamond is a material with superior properties for power electronics than any other semiconductor material. The properties of doped layers have been studied using several diagnostics to determine dopant concentrations and electrical properties.

Why diamond diodes?
- Diamond diodes improve reliability
- Compared to all other semiconductor materials, diamond diodes greatly expand the region of operation:
  - BREAKDOWN FIELD: Works at higher voltages
  - BAND GAP: Works at higher temperatures
  - THERMAL CONDUCTIVITY: Works at higher power
  - SATURATED ELECTRON DRIFT VELOCITY: Works at higher frequencies

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Diamond diodes will be the material of choice in the next generation of energy-efficient power-switching devices.