Diamond: a Brilliant Wide Bandgap Semiconductor

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Diamond is a semiconductor with extreme and unique properties which enable applications for high power and high frequency electronics, radiation detectors, electron emitters for ultra high voltage vacuum switches and traveling wave tube cathodes, and thermionic emitters for energy conversion. Diamond as a wide bandgap semiconductor shows outstanding electronic properties (breakdown field of 10 MV/cm, electron and hole mobilities > 2,000 cm^2/V-s, high saturated drift velocity, and low dielectric constant), and the highest known thermal conductivity. Its unique properties include excellent electron emissivity from hydrogen terminated surfaces, room temperature UV exciton emission and optical defect centers (N-V and Si-V) that have been considered for quantum communication.

In the last decade substantial progress has been made in p-type doping with boron, and in the last few years n-type doping with phosphorus has been demonstrated at a number of laboratories. Single crystal diamond substrates prepared by CVD with dimensions greater than 1 x 1 cm^2 are available commercially, several companies have developed strategies to provide substrates larger than 25 mm diameter, and there has been a recent report of > 90 mm diameter substrates. Moreover, Minimal Fab strategies for manufacturing on 12mm diameter substrates are being considered.

Recent results have shown high voltage p-i-n diodes with forward current densities greater than 1000 A/cm^2 and breakdown voltages greater than 1000V. These vertical devices were prepared by microwave plasma CVD of doped and undoped epitaxial layers grown on single crystal substrates. Moreover, p-i-n diodes with H-terminated surfaces have shown efficient electron emission appropriate for high voltage vacuum switches. Lateral MOSFET devices with ALD dielectrics have sustained a stable two dimensional hole-gas with sheet charge densities greater than 1×10^{13} cm^{-2}. Diamond surfaces have shown record low work functions and demonstrated thermionic energy conversion.

The presentation also describes a manufacturing cost analysis that indicates that diamond power electronics can be cost competitive with other wide bandgap devices while offering significant performance advantages for high voltage and high temperature applications.

The tremendous progress in diamond applications is now limited by important materials challenges including: reducing defect and impurity densities in substrates and epitaxial layers, understanding and limiting dopant compensation particularly for n-type doping, preparing stable dielectric interfaces that can sustain high mobility hole and electron channel conduction, preparing low resistance contacts to both p- and n-type diamond, and heterostructure formation for high mobility devices and III-V integration. As research progresses on all of these topics, new device concepts will be developed based on the outstanding, extreme and unique properties of diamond materials.

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