Docket #: S19-069

Heterogenous Integration of Diamond and GaN Transistors for Complementary Logic Operation

This invention is a set of structures and associated processes to integrate GaN with Diamond to develop a full complementary CMOS device capable of operation in high power and high temperature applications. GaN HEMTs take the advantage of its high mobility 2-dimensional electron gas (2DEG) at the interface of AlGaN/GaN, where electrons move freely in a quantum well due to the presence of polarization charge. On the other hand, diamond exhibits the highest breakdown field (10 MV/cm), the largest thermal conductivity (>20 W/cm.K) of any of the wide-bandgap materials with a bandgap of about 5.45 eV, can provide a high density 2-dimensional hole gas (2DHG) at the surface. Therefore, 2DHG from a hydrogen terminated diamond (hole-FET) can make a complementary logic with 2DEG from AlGaN/GaN HEMT.

Stage of Development

- Created and tested films
- These diamond films exhibit microscopic uniformity in crystal grain size, and macroscopic uniformity in thickness and interface abruptness via a process which is scalable to large wafer sizes
- Hole-FET fabrication using single crystal and polycrystalline diamonds
- Fabrication and high temperature characterization of a CMOS inverter including Hole-FET and HEMT

Applications

- High power and high frequency
- Complementary logic applications, particularly in high temperature and harsh environment

- A building block in any electronics operating in high temperature and harsh environment
- End user applications include power electronics, communications and sensors

Advantages

- Heterogeneous integration of diamond Hole-FET and GaN-based HEMTs is a complementary circuit which enables:
  - higher temperature operation that Si-based or other semiconductor CMOS fails
  - higher mobility holes and electrons the same time
  - extremely high-power output at high frequencies
- Scalable to large wafer sizes

Publications

- Ren, C., Malakoutian, M.,Li, S., and Chowdhury, S., Hydrogen-terminated diamond FET and GaN HEMT delivering CMOS inverter operation at high-temperature. *2020 Device Research Conference*
- Malakoutian, M., Laurent, M.A. and Chowdhury, S., 2019. A study on the growth window of polycrystalline diamond on Si3N4-coated N-polar GaN.*Crystals, 9* (10), p.498.
- Laurent, M.A., Malakoutian, M. and Chowdhury, S., 2019. A study on the nucleation and MPCVD growth of thin, dense, and contiguous nanocrystalline diamond films on bare and Si3N4-coated N-polar GaN. *Semiconductor Science and Technology, 35* (1), p.015003.

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