Device fabrication of β-Ga_2O_3/Diamond Heterojunction PN Diode

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1. Introduction

Diamond is one of the most promising semiconductor materials for high power applications because of its exceptional electronic and thermal properties. Diamond bipolar devices are promising for ultra-high voltage applications (>10kV), but diamond PN junctions have limitations due to (1) a high turn-on voltage (~5V) giving a significant on-state voltage drop and (2) n-type diamond having higher resistivity and poor ohmic contacts. The implementation of an alternative n-type UWBG semiconductors with shallow donor dopants should be considered. β-Gallium Oxide (β-Ga_2O_3) is a semiconductor that has gained significant attention due to its attractive properties like its wide bandgap (4.85eV), good n-type doping, and high breakdown field in the range of 8 MV/cm. Diamond's outstanding thermal properties can serve as a heat dissipater at high power operations, which can compensate for the poor thermal conductivity of β-Ga_2O_3.This study formed p-type diamond and n-type Ga_2O_3 heterojunction diodes and measured their electrical characteristics.

2. Fabrication process

For the fabrication of the pn heterojunction diode, a n-type β-Ga_2O_3 (010) substrate (Novel Crystal Technology, Inc.) with a donor concentration (N_d) of $1\text{-}9\times10^{18}cm^{-3}$ was bonded to the surface of a lightly boron doped diamond ($N_a=1\times10^{16}$ cm^{-3}) layer situated on top of a heavily boron doped diamond ($N_a \geq 1\times10^{20}$ cm^{-3}) epilayer grown by a Microwave Plasma Assisted CVD (MPACVD) reactor on a High Pressure High Temperature (HPHT) diamond substrate. A hydrophilic bonding process was used that is based on the OH termination of the surface of both materials as reported by Matsumae et al [1]. To achieve the bonding between both materials, the surfaces have been processed by chemical mechanical polishing (CMP) to obtain a roughness $R_a \leq 0.5$nm. In the device fabrication process the p- epilayer is mesa-etched to expose the surface of the p+ epilayer. The top surface of the diamond sample is then OH terminated using a solution composed of $H_2O_2/NH_4OH/H_2O$ (1:1:4) at a temperature of T=75ºC for 10min. The β-Ga_2O_3 surface was OH terminated using a MPACVD reactor, by exposing the substrate to an oxygen plasma for 10 sec, at a power of P=1000W and a pressure of 1Torr. After the OH termination steps, both samples are placed in contact, preserving them in a desiccant for 3 days, and finally annealing them at 250ºC for 24hrs.

3. Device results and conclusion

The OH surface termination of both materials was verified by a contact angle measurement performed after each termination step. Both materials had a hydrophilic surface giving a contact angle near 55°. The I-V characteristic of the fabricated pn diode shows a rectifying ratio above 10^8 at ±20V, the reverse current is around $I=10^{-12}$ A, and the ideality factor is $\eta=3.2$. For comparison, earlier work by Sittimart et. al. [2] had an ideality factor of $\eta=2.7$. These ideality factors and the forward turn voltage being well below 5 volts are indicative of interfacial states at the heterojunction. In conclusion, the properties of diamond and β-Ga_2O_3, the heterojunction bonding process and the device fabrication process have been carefully examined.

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References

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