Perspective on diamond semiconductor

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Diamond with 5.45 eV bandgap is considered as one of the ultrawide band gap semiconductors. The perspective of diamond as a semiconductor is promising, especially considering its potential advantages in power device applications at high temperatures and harsh environments. The advantages include (1) high dielectric breakdown strength (>10 MV cm^{-1}) which is at least three times higher than that of SiC, (2) highest thermal conductivity (22 W cm^{-1} K^{-1}) far superior to any other semiconductor materials crucial for heat dissipation in high-power devices, and (3) high carrier mobility for both electron and hole (4500 and 3800 cm^2 V^{-1} s^{-1}, respectively), which can lead to faster-switching speeds and lower power losses. Compared with other semiconductors, the Baliga's figure of merit (BFM) of diamond is over 23000 relative to Si in 1. Many high-power devices have shown excellent performance at temperatures over 500 K.

To realize the applications of diamond semiconductors, a few challenges have to be addressed such as the substrate size and quality with reasonable cost, doping efficiency, and novel device structure and processing. Recently, (001) diamond wafers of a single crystal in a size of 2 to 4 inches have been realized by heteroepitaxial growth on Si and sapphire wafers, followed by homoepitaxial growth. However, the growth of large-diameter, high-quality diamond substrates by microwave plasma chemical vapor deposition (CVD) often results in higher dislocation densities, particularly at a high growth rate beyond 50 μm/h. Also, manufacturing large wafers with residual stresses by laser cutting and polishing is not an easy task to achieve surface roughness to subnanometer. For p-type doping of boron, it can be succeeded to obtain the hole mobility to 1000 cm^2 V^{-1} s^{-1} by CVD and ion implantation. However, phosphorus is currently the only n-type dopant in diamond, which has been demonstrated on (111) diamond by CVD, but it is very difficult for effective doping on (001) diamond. The high hole mobility has been utilized to fabricate unique two-dimensional hole gas (2DHG) devices.[1] Also, many MOSFETs and other devices have been fabricated, among which the power density of 875 MW cm^{-2} in terms of BFM is achievable.[2] Also, a recent report demonstrates that n-type diamond MOSFETs exhibit a high field-effect mobility around 150 cm^2 V^{-1} s^{-1} at 573 K.[3] The advancement of diamond technology could be crucial for meeting the growing electricity demand and achieving carbon neutrality by 2050.

In summary, the excellent properties of diamond make it an attractive material for next-generation semiconductor devices, particularly in high-voltage and high-power applications where efficiency and thermal management are critical. The ongoing research and technological advancements are likely to further enhance the feasibility of diamond semiconductors in the near future.

References

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