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Dielectric strength, optical absorption, and deep ultraviolet detectors of hexagonal boron nitride epilayers

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Hexagonal boron nitride (hBN) epilayers have been synthesized by metal organic chemical vapor deposition and their dielectric strength, optical absorption, and potential as a deep ultraviolet (DUV) detector material have been studied. Based on the graphene optical absorption concept, the estimated band-edge absorption coefficient of hBN is about 7 × 10^{5} /cm, which is more than 3 times higher than the value for wurtzite AlN (∼2 × 10^{5} /cm). The dielectric strength of hBN epilayers exceeds that of AlN and is greater than 4.4 MV/cm based on the measured result for an hBN epilayer released from the host sapphire substrate. The hBN epilayer based DUV detectors exhibit a sharp cut-off wavelength around 230 nm, which coincides with the band-edge photoluminescence emission peak and virtually no responses in the long wavelengths. Based on the present study, we have identified several advantageous features of hBN DUV photodetectors: (1) low long wavelength response or high DUV to visible rejection ratio; (2) requiring very thin active layers due to high optical absorption; (3) high dielectric strength and chemical inertness and resistance to oxidation and therefore suitable for applications in extreme conditions; (4) high prospects of achieving flexible devices; and (5) possible integration with graphene optoelectronics due to their similar structures and lattice constants. © 2012 American Institute of Physics.

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 coefficient (23) to be due to its layered structure. Recent theoretical studies for the high band-edge emission efficiency in hBN is thought for DUV device implementation. One of the major reasons for the high band-edge emission from hBN is more than two orders of magnitude higher than that of AlN, which is considered to be a highly efficient emitter. This means that only a very thin layer of hBN with approximately 70 nm (~5λ) in thickness will absorb all incoming photons. This together with its inherent nature of layered structure makes hBN an exceptionally efficient emitter. However, its potential as a DUV photodetector material has not yet been explored.

As a natural consequence of the crystal structure of hBN, very different bonding, i.e., strong covalent bonding within the basal planes and weak bonding between planes, leads to high anisotropy in most basic properties of hBN. Therefore, it is expected that the electrical conductivity is much higher within the planes than in the direction perpendicular to them (c-direction). By taking the high optical absorption and anisotropy into consideration, we exploited a micro-strip geometry for the photodetector fabrication. We expect the design to improve the collection of photoexcited carriers and at the same time to more effectively utilize the lateral transport properties within the basal planes in hBN. The inset of Fig. 1(a) shows the schematic of the device layer structure employed in this study. The metal-semiconductor-metal (MSM) detector consists of micro-strip interdigital fingers (4 μm/4 μm of width/spacing) of Schottky contact formed by a bilayer of Ni/Au (5 nm/5 nm). Micro-strips were formed by inductively coupled plasma dry etching with ~0.2 μm etching depth. For device characterization, bonding pads were then formed by depositing an Au (200 nm) layer. For the steady current response measurements, an electrometer (Keithley 617) and a source-meter (Keithley 2410) are connected in series. A broad spectral light source in conjunction with a monochromator was used as an excitation source covering wavelength range from 800 to 180 nm.

The typical I-V characteristics of hBN epilayer based MSM detectors are shown in Fig. 2(a). The devices exhibit low dark current and current density of ~200 pA and 10^-10 A/cm^2 at a bias voltage of 100 V, respectively. The relative spectral responses have been measured at different bias voltages (V_b) and an example is shown in Fig. 2(b) for V_b = 30 V. These hBN MSM detectors exhibit a peak responsivity of 5.48 eV (or 227 nm). An outstanding feature observed from these hBN MSM detectors is the exceptionally high responsivity in the long wavelengths measured up to 800 nm. However, the observed DUV to visible rejection ratio in hBN MSM detectors is still 2–3 orders of magnitude lower than that of AlN based detectors. This corroborates the fact that the crystalline quality of hBN is not yet as good as those
of high quality AlN, as confirmed by the XRD results shown in Fig. 1(a). The relative responsivity increases almost linearly with the bias voltage, as illustrated in Fig. 3(a), which suggests that hBN MSM detector has a gain. This may be attributed to the presence of dislocations or impurities in the epilayers. However, the photocurrent kinetics of hBN MSM detector measured at room temperature shown in Fig. 3(b) exhibit no persistent photoconductivity (PPC) effects. The presence of PPC is generally regarded as an indicative of existence of deep metastable charge trapping centers or local potential fluctuations caused by material inhomogeneity.\(^{32,33}\)

One other important parameter of a semiconductor for detector applications is the dielectric strength or the breakdown field (\(E_B\)) in the \(c\)-direction. A previous study has obtained \(E_B = 7.94\) MV/cm for ultrathin hBN layers mechanically exfoliated from powder crystals.\(^{34}\) Since our hBN epilayers were grown on sapphire substrates, it was necessary to release epilayers from the host sapphire substrate in order to conduct \(E_B\) measurements. We first deposited a bilayer of Ni/Au Schottky contact on a 1.8 \(\mu\)m thick hBN epilayer and then coated the Ni/Au Schottky contact with Ag past. Next, we glued the structure to a second sapphire substrate and then released the epilayer from the host sapphire substrate by mechanical force.\(^{35}\) Finally, another bilayer of Ni/Au Schottky contact was deposited on the back side of the released hBN epilayer. A schematic of the device structure for \(E_B\) measurements is shown in Fig. 4(a).

Figure 4(b) shows the I-V characteristics of the released hBN epilayer in the \(c\)-direction (out-of-plane), which indicates that the breakdown occurs at around 800 V. This translates to \(E_B \sim 4.4\) MV/cm, which is lower than that obtained from ultrathin hBN layers exfoliated from powder crystals having a cross section area in micron scale. Not only our released hBN epilayer used for \(E_B\) measurement has a large cross section area of \(4 \times 4\) mm\(^2\) but also hBN epitaxial layers are grown on foreign substrate and are not dislocation free. It was demonstrated previously in AlN epilayer detectors that \(E_B\) increases linearly with a decrease in the device area (\(A\)), since the number of dislocations decreases linearly with a decrease in \(A\).\(^{31}\) \(E_B\) for dislocation-free AlN epilayers was obtained by extrapolating \(A\) to zero (\(\sim 4.1\) MV/cm).\(^{31}\) Moreover, the backside of the released hBN epilayer contains a 20 nm low temperature buffer layer of amorphous nature, which also reduced the measured value of \(E_B\) of hBN. Our results shown in Fig. 4(b) clearly indicate that hBN epilayers have a higher \(E_B\) than AlN epilayers. If we assume ultrathin hBN layers exfoliated from powder crystals are dislocation free, then the value of 7.94 MV/cm (Ref. 34) may represent the \(E_B\) value of intrinsic hBN. Our results thus suggest that the device performance can be improved by improving...
material quality, mainly reducing dislocation density, and optimizing the device size and geometry.

In summary, we have synthesized high quality hBN epilayers by MOCVD and explored them as DUV detector materials. Based on the graphene optical absorption concept, the estimated band-edge absorption coefficient of hBN is about 7 × 10^5/cm, which is more than 3 times higher than the value for AlN (~2 × 10^5 /cm). The dielectric strength of hBN epilayers exceeds that of AlN epilayers and is greater than 4.4 MV/cm based on the measured result for an hBN epilayer released from the host sapphire substrate. The hBN epilayer based DUV detectors have a sharp cut-off wavelength around 230 nm, which coincides with the band-edge PL emission peak and showed virtually no response in the longer wavelengths measured up to 800 nm. Currently, our understanding of hBN epilayer growth and properties is still in the very early stage compared to the status of AlN epilayers. Much improvement is anticipated for hBN, which ultimately will lead to functional practical devices.

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