Application of Nitrogen-doped Ultrananocrystalline Diamond/Hydrogenated Amorphous Carbon Composite Films to Electronic Devices

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https://hdl.handle.net/2324/1866324

出版情報：九州大学, 2017, 博士（学術）, 課程博士
バージョン：

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Nanostructured carbon films including diamond, diamond like carbon (DLC), single-layer graphene, and carbon nanotubes (CNT), have received a great scientific and technical interest for applications in many fields. Ultrananocrystalline diamond (UNCD) film is a unique formation of diamond, which was grown through a patented microwave plasma-enhanced chemical vapor deposition (MPCVD) technique. The ultra-smooth surface offered by nanometer scale grain sizes of UNCD films, together with other outstanding properties, such as, thermal stability, chemical inertness, high electron field emission, low friction coefficient, as well as the ability to incorporate n-type dopants, have attracted many scientists towards the application of UNCD films in optoelectronics devices, microelectromechanical systems (MEMS), field emission source, and biomedical applications. Over many trials, one of the most challenging issues in the diamond field is the growth of n-type diamond. Although, nitrogen is often used to create n-type conduction, nitrogen doped diamond is an electrical insulator at room temperature due to the deep level of 1.7 eV of the nitrogen impurity. On the other hand, nitrogen dopant in UNCD films (in pure form or as composites of nanocrystalline diamond embedded in an amorphous matrix UNCD/a-C:H) realize n-type conduction with enhanced electrical conductivities.

In this study, nitrogen-doped ultrananocrystalline diamond/hydrogenated amorphous carbon composite (UNCD/a-C:H) films were synthesized by coaxial arc plasma deposition (CAPD) method. Nitrogen doping produces n-type conduction accompanied by enhanced electrical conductivities. The results of temperature dependence of electrical resistivity imply that carriers are transported in hopping conduction. Furthermore, synthesized films were structurally investigated by sensitive spectroscopic measurements employed in Saga Light Source (Saga-LS) synchrotron center, such as, X-ray diffraction (XRD), X-ray photoemission (XPS) and near-edge X-ray absorption fine structure (NEXAFS) spectroscopies. The origin of the n-type conduction of nitrogen-doped UNCD/a-C:H films correlated to the chemical bonding structural evaluation. The results suggested that hydrogen atoms that terminate diamond grain boundaries will be partially replaced by nitrogen atoms and, consequently, π C–N and C=N bonds that easily generate free electrons will be formed at grain boundaries.

Beside their attractive electrical properties, nitrogen-doped UNCD/a-C:H films possess large absorption coefficients of more than 10^5 cm^{-1} at photon energies from 3 to 5 eV. The optical band gap which should be attributable to a-C:H matrix in UNCD/a-C:H films was shrinkage by nitrogen doping, which refers to increase of sp^2 fractions in the films by nitrogen doping.

Heterojunction diodes were fabricated by depositing n-type nitrogen-doped UNCD/a-C:H films onto p-type Si substrates. The resultant diodes were evaluated based on current-voltage (I-V) and capacitance-voltage (C-V) characteristics. Dark I-V characteristics reveal a rectification ratio of more than four orders of magnitude, which confirm that the fabricated junctions are working as typical diodes, and it experimentally demonstrated that nitrogen-doped UNCD/a-C:H is applicable as an n-type semiconductor. C-V measurements afford a valuable information about carrier density and energy band diagram. Moreover, Current transport mechanisms through fabricated diodes were electrically characterized by ***J–V–T*** characteristics method, measured in the temperature range of 80–300 K. The results suggested that the multi-step trap-assisted tunneling is the dominant transport mechanism in this temperature range at low forward bias voltage below 0.45 V.

In our most recent study, photodiode comprising *n*-type nitrogen-doped UNCD/a-C:H film and *p*-type Si substrate was employed as an ultraviolet photodetector. Under 254 nm monochromatic light, photodiode shows a capability of deep ultraviolet light detection, which attributed to the existence of UNCD grains. It was experimentally demonstrated that nitrogen-doped UNCD/a-C:H film works as ultraviolet-range photovoltaic material.