Chemical Vapor Deposition of Diamond Films for Advanced Material Applications

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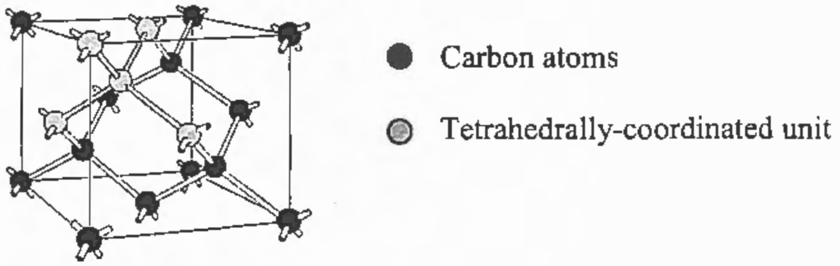
Diamond, the cubic modification of crystalline carbon, has long held a special place in the hearts and minds of both scientists and the public at large. For the latter, the word diamond conjures images of brilliant gemstones and special occasions. To the scientist, however, diamond distinguishes itself with a wide range of unique properties. These properties include the highest bulk modulus, the lowest compressibility, extreme mechanical hardness, the highest room temperature thermal conductivity, the highest sound propagation velocity, and a very low coefficient of thermal expansion.[1,2] The successful exploitation of these properties and others has been made possible by the discovery that chemical vapor deposition (CVD) methods can be used to grow diamond under conditions where it is a metastable phase.

Figure 1



The diamond unit cell consists of two interpenetrating face-centered cubic (fcc) lattices in which every carbon atom has four tetrahedrally-coordinated nearest neighbors as shown in Figure 1.[3] At ambient temperatures and pressures, however, sp^2-bonded graphite is the stable form of carbon, and the conversion of graphite into diamond is characterized by a large activation energy of 728 ± 50 kJ/mol.[4] Two divergent strategies have been used to surmount this barrier and synthesize diamond in a laboratory environment: 1) mimicry of geological diamond formation by use of a high temperature, high pressure (HPHT) conditions, and 2) breakdown of hydrocarbon precursors for use as building blocks in atom-by-atom assembly of the diamond lattice. The second strategy, the foundation for the CVD process, has become the preferred method because of lower associated costs and the ability to produce diamond films.

In order to make the development of diamond-based technology more economically feasible, considerable research has been devoted to improving the growth, characterization, and processing of diamond films. Recent advances in film growth have resulted in improved nucleation density and crystallinity control via bias-enhancement techniques as well as patterned film deposition by chemical surface modification.[5,6] Although the exact mechanism of diamond film growth is not well understood, robust, highly surface sensitive techniques such as sum frequency generation (SFG) have made possible improved characterization of the growth surface under CVD conditions.[7] In addition, techniques such as neutron activation analysis are now being used alongside more conventional Raman spectroscopy and x-ray diffraction to evaluate film quality.[8] As laboratory and industrial production of diamond films has increased, greater attention has also been paid to cost-effective improvement of post-growth processing methods such as polishing and planarization.[9,10]

Much of the early interest in the growth of CVD diamond has and continues to focus on the incorporation of diamond films into active electronic devices. Diamond exhibits electronic properties superior to those of many conventional semiconductor and insulating materials; however, the development of diamond-based electronics has been slowed due to several factors.[11] These include reliable and reproducible doping methods, lack of n-type dopants with shallow donor states, and the inability to grow large area diamond single crystals. While recent reports have shed light on potential solutions to these problems, commercially produced "diamond chips" and other active electronic devices remain on a distant if attainable horizon.[12-15] The communications industry, however, has been able to successfully incorporate currently produced films into commercial products. Surface acoustic wave (SAW) frequency filters using polycrystalline diamond films exhibit significant improvement in both range of frequency and power-handling capability compared to conventional structures.[16,17] Continued increases in production and decreases in the price of CVD diamond films, as has been observed in the last decade, will undoubtedly fuel further investigations and promote the development of economically-viable diamond-based technologies.[18-20]

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