DIAMOND THIN FILMS: A 21st –CENTURY MATERIAL

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Diamond has some of the most extreme physical properties of any material, yet its practical use in science or engineering has been limited due its scarcity and expense. With the recent development of techniques for depositing thin films of diamond on a variety of substrate materials, we now have the ability to exploit these superlative properties in many new and exciting applications. In this paper, we shall explain the basic science and technology underlying the chemical vapour deposition of diamond thin films, and show how this is leading to the development of diamond as a 21st century engineering material.

The extreme physical properties of diamond derive from its strong, directional a bonds. Diamond has a wide 5.5 eV band gap, the largest bulk modulus of any solid, the highest atom density, the largest room temperature thermal conductivity, smallest thermal expansion coefficient, and largest limiting electron and hole velocities of any semiconductor. Graphite has strong intra-layer a bonding and weak van der Waals bonding between its layers. A single graphite plane is a zero band gap semiconductor, and in three dimensions it is an anisotropic metal.

Unfortunately, it has proved very difficult to exploit these properties, due both to the cost and scarcity of large natural diamonds, and the fact that diamond was only available in the form of stones or grit. What is required is a method to produce diamond in a form that can allow many more of its superlative properties to be exploited, in other words, as a diamond thin film. It had been known for 200 years that diamond is composed solely of carbon, and many attempts were made to synthesize diamond artificially using as a starting material another commonly occurring form of carbon, graphite.

It proved extremely difficult to synthesize diamond, mainly because at room temperature and pressure, graphite is the thermodynamically stable allotropeof carbon. Although the standard enthalpies of diamond and graphite only differ by 2.9 kJ mol- 1, a large activation barrier separates the two phases preventing interconversion between them at room temperature and pressure. Ironically, this large energy barrier, which makes diamond so rare, is also responsible for its existence, since diamond, once formed, cannot spontaneously convert to the more stable graphite phase. Thus, diamond is said to be metastable, that is, kinetically stable but not thermodynamically stable.

There have recently been very important advances in the science of carbon such as the development of the chemical vapour deposition of diamond. Chemical vapour deposition, as its name implies, involves a gas phase chemical reaction occurring above a solid surface, which causes deposition onto that surface. All CVD techniques for producing diamond films require a means of activating gas phase carbon-containing precursor molecules. This activation can involve thermal methods (e.g. a hot filament), electric discharge (e.g. DC, RF or microwave), or a combustion flame (such as an oxyacetylene torch). While each method differs in detail, they all share a number of features in common. For example, growth of diamond (rather than graphite) normally requires that the precursor gas (usually CH4) is diluted in excess of hydrogen, in a typical mixing ratio of 1%vol. CH4. Also, the temperature of the substrate is usually greater than 700 °C to ensure the formation of diamond rather than amorphous carbon.

With the 21st century upon us, we are still some way from diamond becoming the engineer's dream of being 'the ultimate engineering material'. However, some devices are already in the marketplace, such as diamond heat spreaders, windows, cutting tools, and SAW filters. In the next few years we can expect to see diamond films appearing in many more applications, especially in electronics. Perhaps the most likely 'killer applications' which will firmly establish diamond as a 21st-century material will be in the area of specialized flat-panel displays and high temperature electronics, for which the total available market in the year 2000 has been estimated at $435 million and $16 billion, respectively. In some ways this may be a shame, since familiarity with diamond as just another commonplace material may remove some of the glamour and mystique surrounding the world's most sought-after gemstone.

INFORMATION AND COMMUNICATION TECHNOLOGIES IMPACT ON THE ECONOMIC GROWTH

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The question of information and communication technology's (ICT) impact on economic growth and productivity has fascinated and perplexed governments, academics and business leaders since the ICT "revolution" began. The role of technology in the economy is now a subject of government policy across the globe. There is widespread consensus that ICT does benefit productivity and growth, but exactly how and to what extent remains a matter of debate.

The Economist Intelligence Unit conducted empirical research to investigate the strength of ICT's impact on economic growth, based on a cross-section model of 60 countries including 26 developed countries and 34 less-developed countries. Using this model it is possible to draw a number of conclusions about the economic impact of ICT.

1. **Technology does drive growth — but only after a minimum threshold of ICT development is reached.** Countries with high penetration levels for fixed telephone lines, mobile phones, personal computers and the Internet appear to achieve the greatest economic benefit from ICT. By contrast, the impact of ICT on GDP per head growth was non-existent and in some cases even negative for the developing countries included in the model. One major reason for this appears to be that ICT penetration and usage needs to attain critical mass before it will make a significant positive impact on a country's economy.

2. **There is a time-lag before ICT benefits growth and productivity.** It is the time it takes for organisations to assimilate and adjust to new technology. During this period the adoption of ICT can even retard productivity growth.

3. **ICT accounts for most of the gap in GDP per head growth between the US and euro zone "big three".** The impact of ICT