Institute Lecture

Fundamental Discovery of New Phases and Direct Conversion of Carbon into Diamond andhBN into cBN and Properties

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16thDecember 2015, Time: 4.30 PM, Venue: L-1

Abstract

We review the discovery of new phases of carbon (Q-carbon) and BN (Q-BN) and address critical issues related to direct conversion of carbon into diamond and hBN into cBN at ambient temperatures and pressures in air without any need for catalyst and presence of hydrogen. The Q-carbon and Q-BN are formed as a result of quenching from super undercooled state by using high-power nanosecond laser pulses. We discuss the equilibrium phase diagram (P vs. T) of carbon, and show that by rapid quenching kinetics can shift thermodynamic graphite/diamond/ liquid carbon triple point from 5000K/12GPa to super undercooled carbon at atmospheric pressure in air. Similarly, the hBN-cBN-Liquid triple point is shifted from 3500K/9.5GPa to as low as 2800K and atmospheric pressure. It is shown that nanosecond laser heating of amorphous carbon and nanocrystalline BN on sapphire, glass and polymer substrates can be confined to melt in a super undercooled state. By quenching this super undercooled state, we have created a new state of carbon (Q-carbon) and BN (Q-BN) from which nanocrystals, microcrystals, nanoneedles, microneedles and thin films are formed depending upon the nucleation and growth times allowed for the formation. The large-area epitaxial diamond and cBN films are formed, when appropriate planar matching or lattice matching template is provided for growth from super undercooled liquid.

The Q-phases have unique atomic structure and bonding characteristics as determined by high-resolution SEM and backscatter diffraction, HRTEM, STEM-Z, EELS, and Raman spectroscopy, and exhibit new and improved mechanical hardness (harder than diamond), electrical conductivity, chemical and physical properties, including room-temperature ferromagnetism (RTFM) and enhanced field emission. The properties of Q-carbon are summarized as follows: (1) The Q-carbon is amorphous and it can be semiconductor or metallic, and it has robust ferromagnetism with Curie temperature over 500K; (2) The Q-carbon has very high electron emission (negative electron affinity), needed for a variety of display devices; (3) Q-carbon can be harder than diamond as average bond length in Q-carbon is shorter C-C length than that in diamond; (4) Q-carbon can be converted into diamond rather inexpensively in the form of nanodots, microdiamonds, nanoneedles and microneedles, and large-area single-crystal films; and (5) diamond can be doped both n-type and p-type, creating a new frontier in high-power devices and high-temperature transistors.

We have also deposited diamond on cBN by using a novel pulsed laser evaporation of carbon and obtained cBN/diamond composites, where cBN acts as template for diamond growth. Both diamond and cBN grown from super undercooled liquid can be alloyed with both p- and n-type dopants. This process allows carbon to diamond and hBN to cBN conversions and formation of useful nanostructures and microstructures at ambient temperatures in air at atmospheric pressure on practical and heat-sensitive substrates in a controlled way without need for any catalysts and hydrogen to stabilize sp^3 bonding for diamond and cBN phases.

References

1. J. Narayan, VP Godbole and CW White, Science 252, 416 (1991).
2. J. Narayan and A. Bhaumik, APL Materials 3, 100702 (2015).
3. J. Narayan and A. Bhuamik, J. Appl. Phys. (In Press Nov 30, 2015 Online)
4. J. Narayan and A. Bhaumik, Science Advances (In Press)

About the speaker

Professor Jagdish (Jay) Narayan is the John C. C. Fan Family Distinguished and Distinguished University Professor in the Department of Materials Science and Engineering at North Carolina State University. After graduating with B. Tech. (Distinction and First Rank) from IIT, Kanpur in 1969, Prof. Narayan established an extraordinary academic record at UC Berkeley by finishing MS (1970) and PhD (1971) degrees in a record time of two years. His pioneering research on defects and diffusion and novel materials laid foundations for materials processing needed for systems ranging from nano to micro and macroscale. Narayan's work has been cited over 21,200 times with h-index of over 72, and he has published nine books and more than 500 papers in scholarly journals. His honors include, 2014 North Carolina Science (Highest Civilian Honor of the State of North Carolina), Award O. Max Gardner Award (Highest UNC System Honor), Holladay Medal and RJ Reynolds Prize (NC State's highest honors for excellence in research, teaching and extension), ActaMaterialia Gold Medal and Prize given for pioneering contributions and leadership in materials science worldwide, ASM Gold Medal, TMS RF Mehl Gold Medal, US DOE Outstanding Research Award, Three IR-100 Awards in addition to Fellow Honors from two academies and seven professional societies. Professor Narayan's research has been duly recognized by the American Institute of Physics (AIP) in this year's Nobel Prize in Physics on Blue Light Emitting Diodes (LEDs) made from Gallium Nitrides (III-nitrides) based materials. The AIP has singled out Narayan's highly cited paper (J. Appl. Phys. 87, 965 (2000) with over eleven hundred forty citations) on the development of GaN based materials used in the Nobel Laureates' work.

Tea at 4.15 PM

All interested are welcome.

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