A Model for Charge Transport in Randomly-Ordered Carbon Nanoclusters

Demonstration of a rudimentary carbon based sensor

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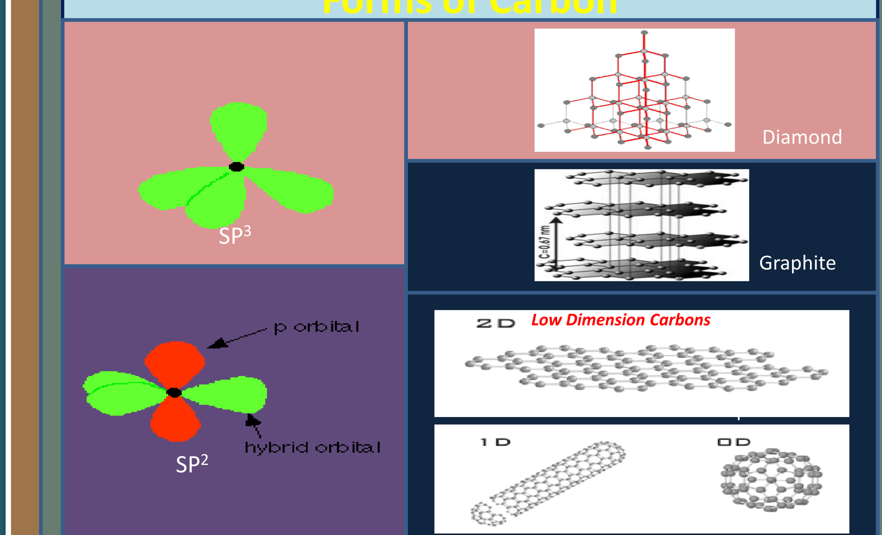
Abstract

The carbon nanofilms on diamond were obtained by irreversible graphitization of diamond at above 1000 0C. The exposure to plasma reduces the surface conductance of the carbon nanofilms on diamond as result of a partial removal of carbon and the plasma-stimulated amorphization. The experimentally observed exponential dependence of conductance G of the carbon nanofilms on temperature T can be well represented by a relation G = A exp (BT). This behavior is explained by a model based on the thermally vibrating energy barriers formed between the carbon nanoclusters constituting the thin carbon nanofilms. The empirical constants A and B relate to the density of the carbon nanoclusters and the energy barrier height between them respectively. A rudimentary temperature and chemical sensor is demonstrated utilizing the electronic properties of resultant carbon system.

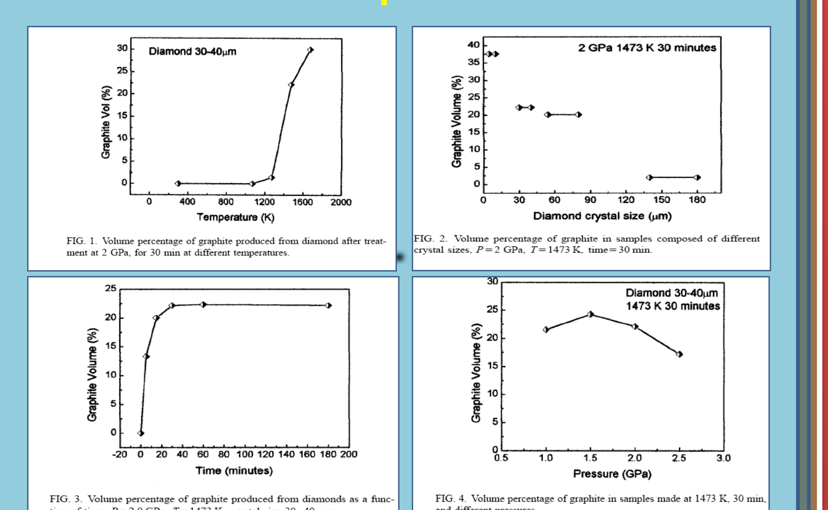
Introduction

Forms of Carbon



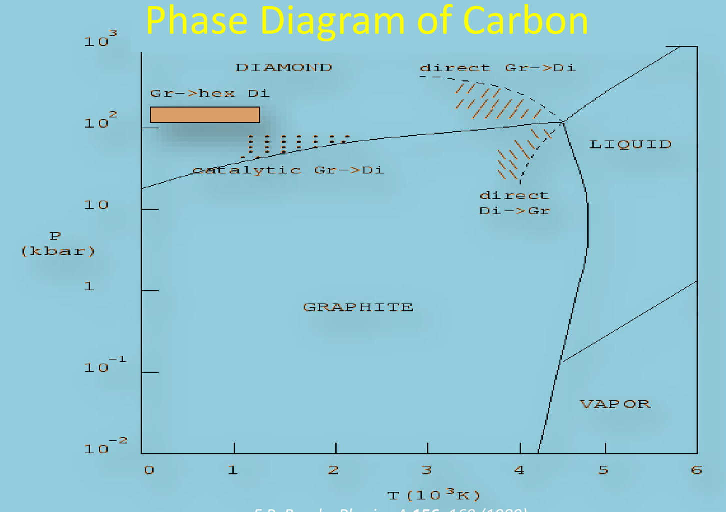
Crystalline, Amorphous & Glassy Carbon

Parameters of Graphitization



Zerda et al. J Chem. Phy. 2001, 90, 1632

Phase Diagram of Carbon



*F.P. Bundy, Physica A **156**, 169 (1989)*

Diamond is a metastable form of diamond and converts into graphite at high temperatures

Thin Films of Carbon

Type	Graphite Like (GLC); Diamond Like (DLC)
Properties	Mixture of crystalline phases and amorphous phases; Different ratios of SP^2 and SP^3; Properties vary, Depends upon method of synthesis; Diamond like or Graphite like properties
Synthesis	Vapor Deposition; Carbonization of Polymers; Fast Ion Beam Lithography; Thermal Treatment of Diamond; Synthetic Methods for Graphene: Mechanical & Chemical

Why Diamond??

Nanoelectronic Application

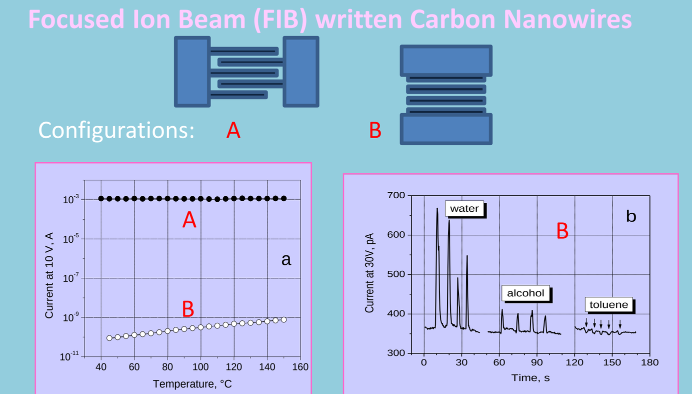
- **Excellent Substrate**
- **Diamond ⇔ Graphite**

- Very Good Insulator
- Excellent thermal conductor
- One of the hardest material
- Thermally stable
- Chemically inert
- Availability of synthetic diamonds

- As insulating substrate in electronic devices
- Employability in harsh conditions
- All-carbon technology
- Lab-on-chip

Past Work

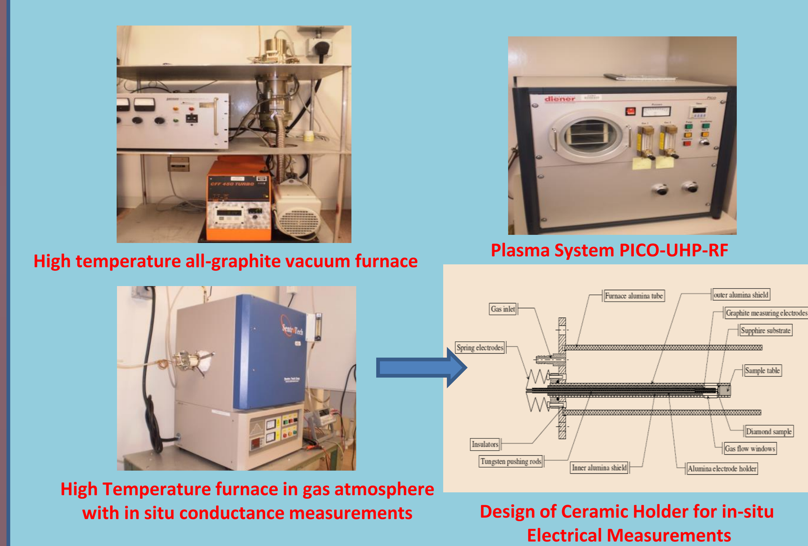
Focused Ion Beam (FIB) written Carbon Nanowires



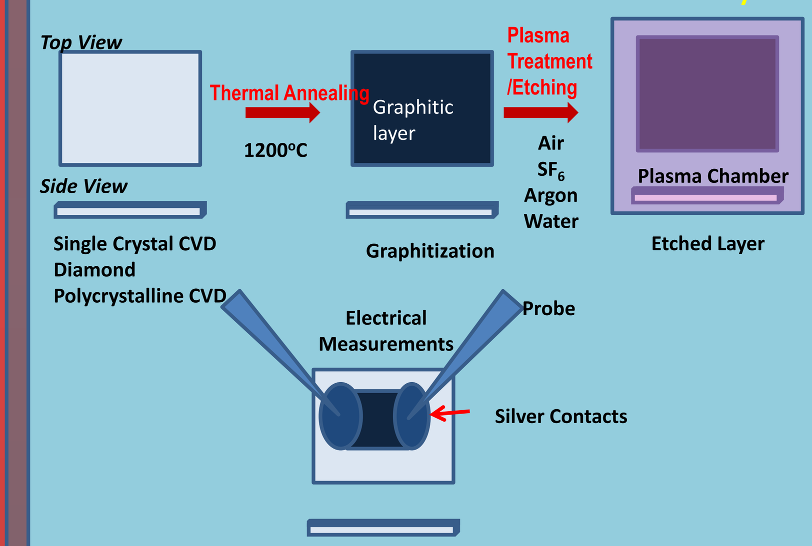
Response to temperature — Response of B to chemical analytes

- **Configuration B is temperature and chemical sensitive**
- **Response is fast and reproducible**

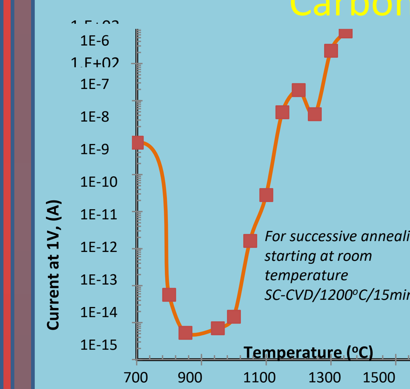
Instruments



Fabrication Scheme: Carbon Nano Layer



Graphitization of Diamond: Carbon Nanolayer



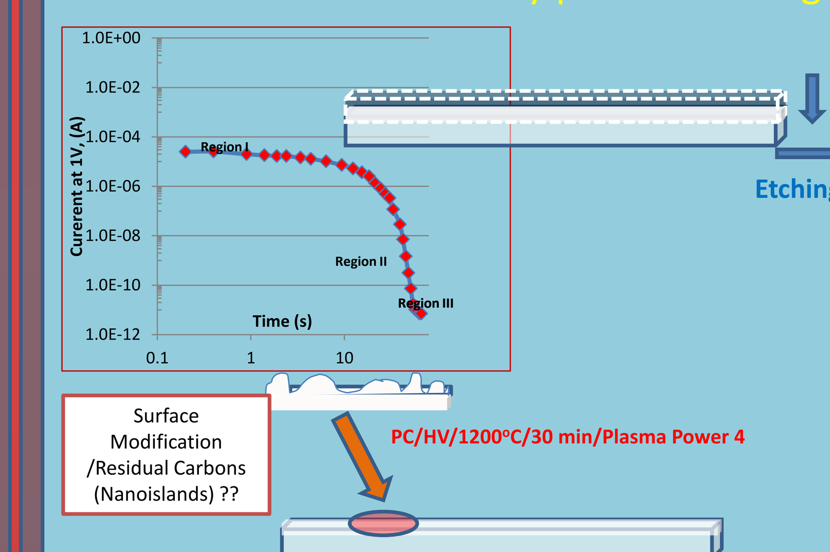
Measured Specific Resistances:
HV film : ~ 2.5 x 10^{-5} Ω.m
LV film: ~ 1.0 x 10^{-6} Ω.m.

Types of Carbon	Specific Resistance
Isotropic graphite*	9.5 x 10^{-6} – 15 x 10^{-6} Ω.m
Extruded Graphite	8.0 x 10^{-6} – 9.0 x 10^{-6} Ω.m
Glassy Carbon	4.2 x 10^{-5} Ω.m

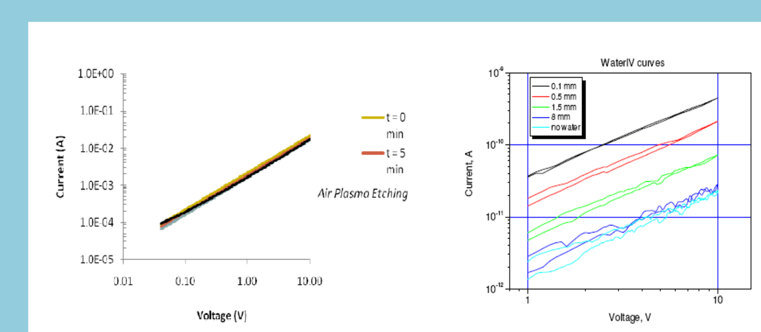
Source: Tokai Carbon Company limited

PC: Polycrystalline, **CVD**: Chemical Vapor Deposition
HV: (2x10^{-5} – 5x10^{-5} mbar), **LV**: (2 x 10^{-2} – 3x 10^{-2} mbar)

Reduction in thickness by plasma etching

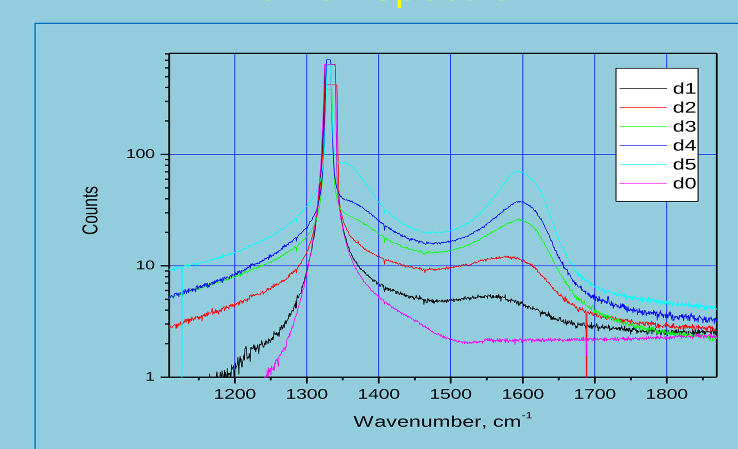


Current-Voltage (I-V) characteristics



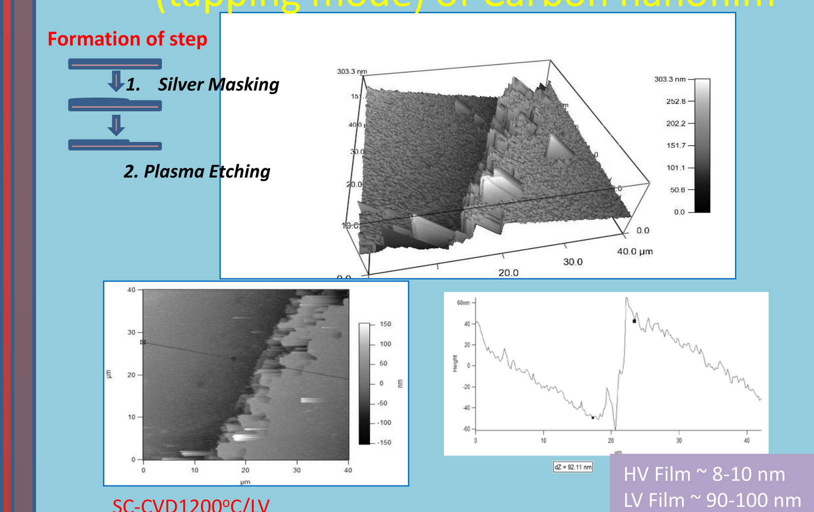
(a) Thick films grown in low vacuum at 1200°C for 30 min: as-grown and after 5 minute plasma etching in air plasma
(b) Thick films grown in Ar atmosphere at 1000°C for 10 min: as grown and exposed to water vapor of different densities (different droplet sizes)

Raman Spectrum

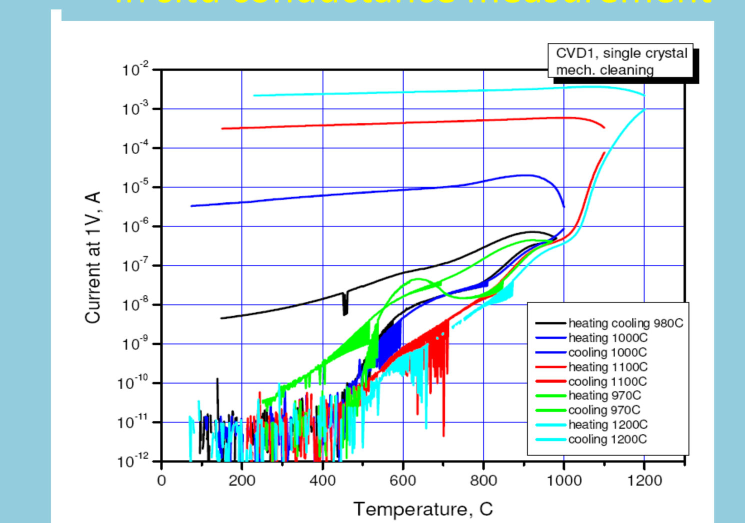


The Raman spectra of a thin carbon film grown on a PC-CVD diamond by annealing at 1200°C for 15 min in high vacuum (5 x10^{-5} mbar) and the films obtained by successive plasma etching of this original film.

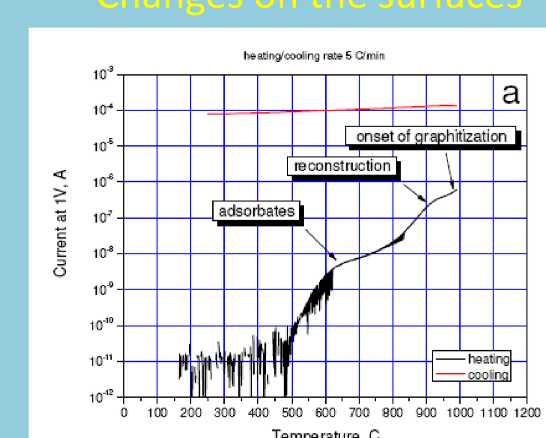
Atomic Force Microscopy (AFM) profile (tapping mode) of Carbon nanofilm



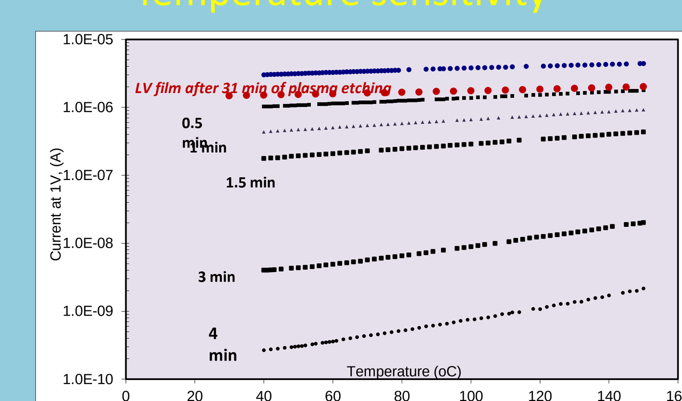
In situ conductance measurement



In situ conductance measurement: Changes on the surfaces

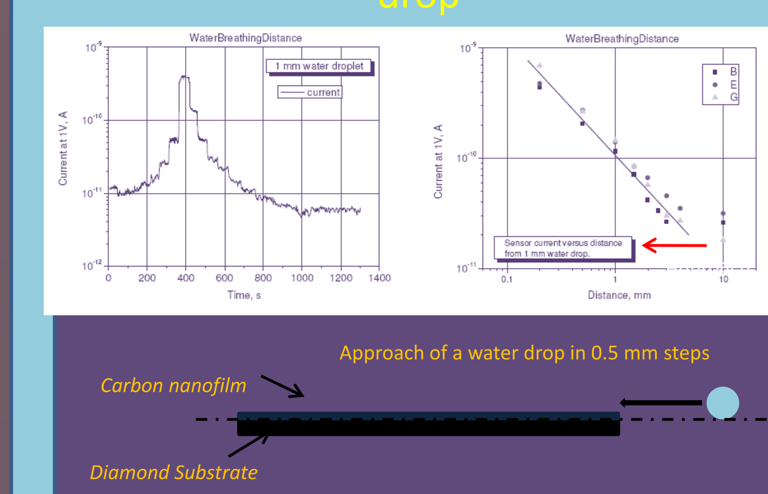


Temperature sensitivity

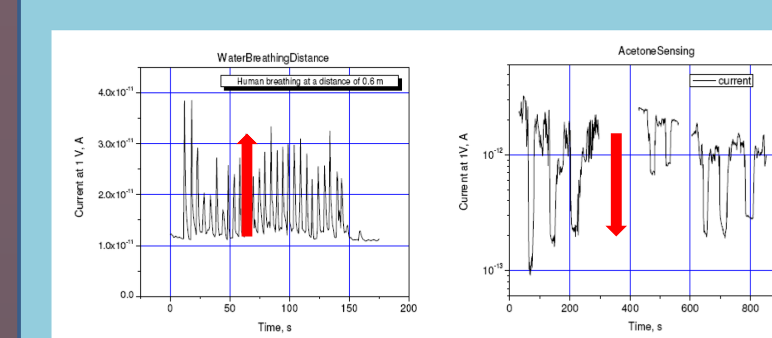


HV Film: • Original Film ▫ Etched Films

Chemical Sensitivity: Response to a water drop



Chemical Sensitivity: Selectivity



- Positive response to water or humane breathing
- Negative response to chemical analytes like acetone

Conclusions

- The temperature and chemical sensitive - few carbon atoms thin films of carbon can be obtained by thermal annealing of diamond films at high temperatures (higher than 1000°C) combined with plasma etching.
- The grown films are amorphous in nature with short range graphitic domains.
- The thin film obtained in high vacuum (5 x 10^{-5} mbar) is about 12 nm thick; while a thick film obtained in relatively low vacuum (2 x 10^{-2} mbar) is about 95 nm.
- The thickness of the thick LV film can be easily reduced to few nm by prolonged plasma etching to give a thin temperature sensitive film.
- Characterization techniques like X- Ray photoelectron spectroscopy (XPS) and X-Ray diffraction measurements (XRD) may give more insight into the material structure of these nano films. Besides, the role of pressure, temperature and annealing time needs to be investigated in more detail.
- Thus, we have an all carbon based technology to grow nano films of carbon for nano temperature and chemical sensor application.

References

1. Lenttington, A. *Carbon* **1998**, 36, 555
2. Robertson, J. *Materials Science and Engineering: R: Reports* **2002**, 37, 129-281
3. Evans, T.; James, *P.F. Prtoc. R. Soc. London* A **1963**, 277
4. Evans, S.; *Prtoc. R. Soc. London A* **1978**, 360, 427
5. Evans, S.; *Prtoc. R. Soc. London A* **1990**, 370, 107
6. A. M. Zaitsev; A. M. Levine, S. H. Zaidi ***Wiley Inter Science***, Published online, **2007**
7. Iijima, S.; Helical *Nature* **1991**, 354, 56
8. Novoselov, S,; et al. *Nature* **2004**, 306, 666
9. Geim, K.; et al. *Phys. Rev. Lett.* **2006**, 97, 187401-4
10. Viculis, M.; et al.; *Science* **2003**, 299, 1361

Acknowledgements

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