Synthesis of single crystal diamond and its applications

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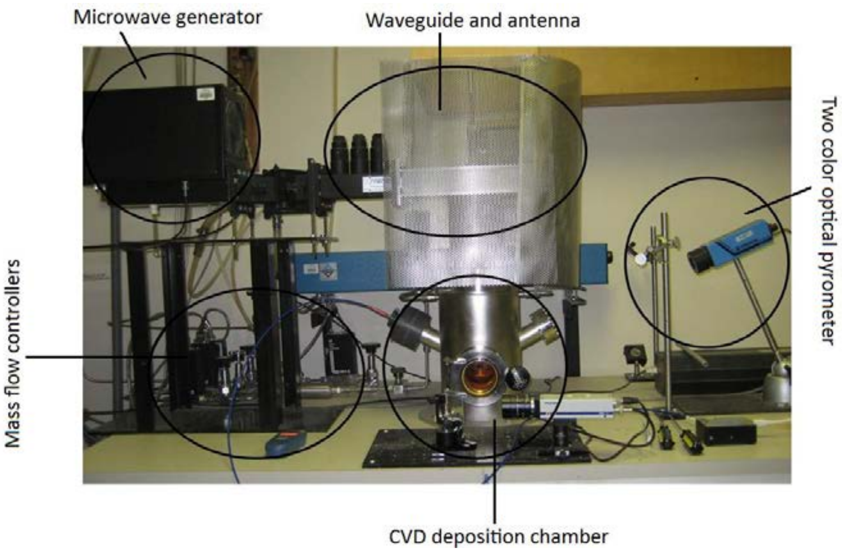
Sources of diamond

Nature

Diavik diamond mine, Canada

Laboratory



1.2 kW Chemical Vapor Deposition system

Synthesis of Diamond

- Growth of diamond from vapor phase
  - Pressure → 70 to 200 torr
  - Temperature → 850 to 1400 C
- Advantages of CVD
  - Possibility of growing diamond over large area substrates
  - No metallic impurities
  - Control over doping can produce p-type and n-type diamond
- Typical gaseous components include hydrogen and a hydrocarbon (e.g., methane).
- Gaseous components are “activated” to produce growth radicals.
- A variety of surface reactions result in the formation of diamond lattice.

Natural diamond

- Less than 3% of natural diamonds are truly inclusion free and colorless.
- Obtaining device grade diamond with required geometry is both time consuming and costly.
- Loss of valuable material during microfabrication step.

CVD Single crystal diamond

- Fully controllable CVD process allows for production of high quality diamond with excellent repeatability.
- A single substrate can be used for multiple growth cycles.
- Price is cheaper compared to natural diamond.
- Provides the ability to change the characteristics of diamond during CVD processing step.

Recent advances in growth of diamond by CVD

Very high growth rate chemical vapor deposition of single-crystal diamond

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Contributed by Russell J. Hemley, August 2, 2002

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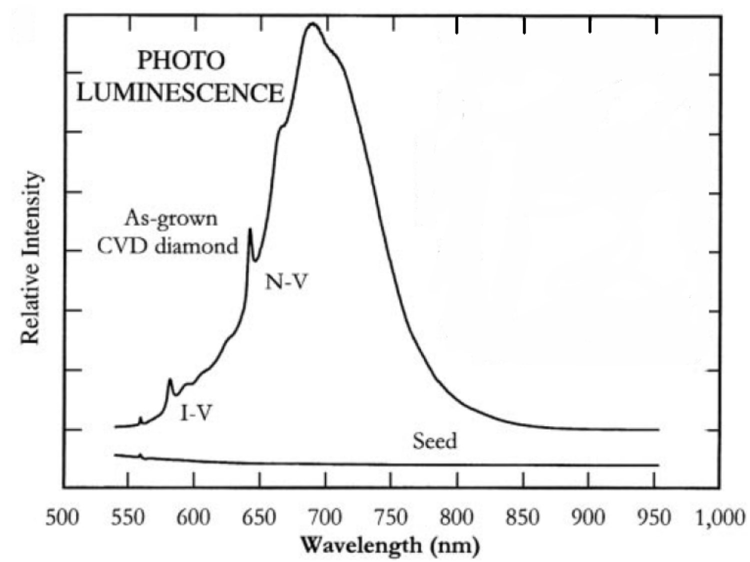
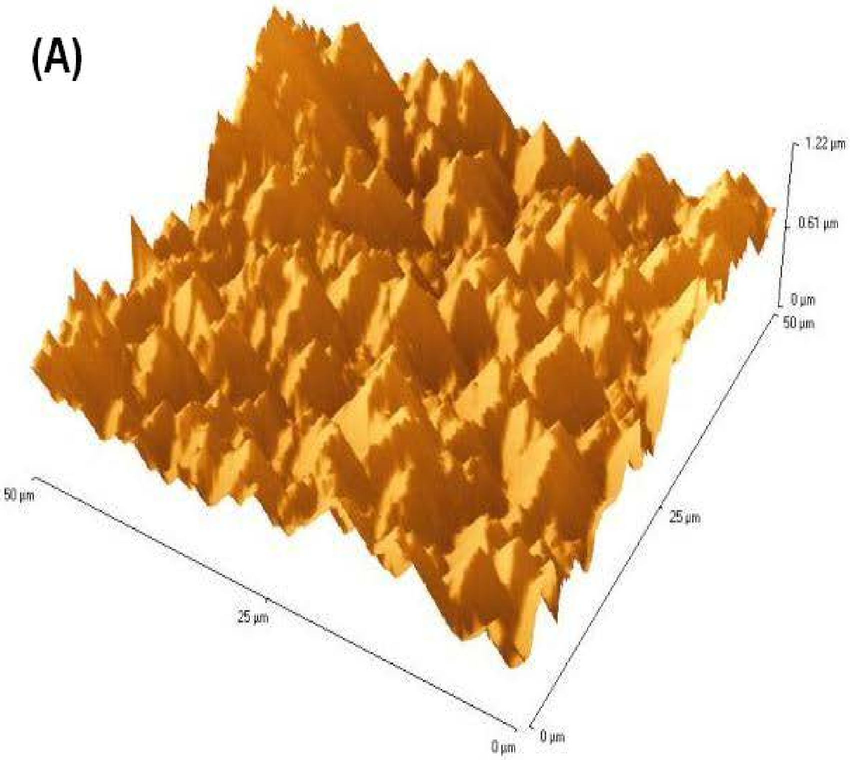
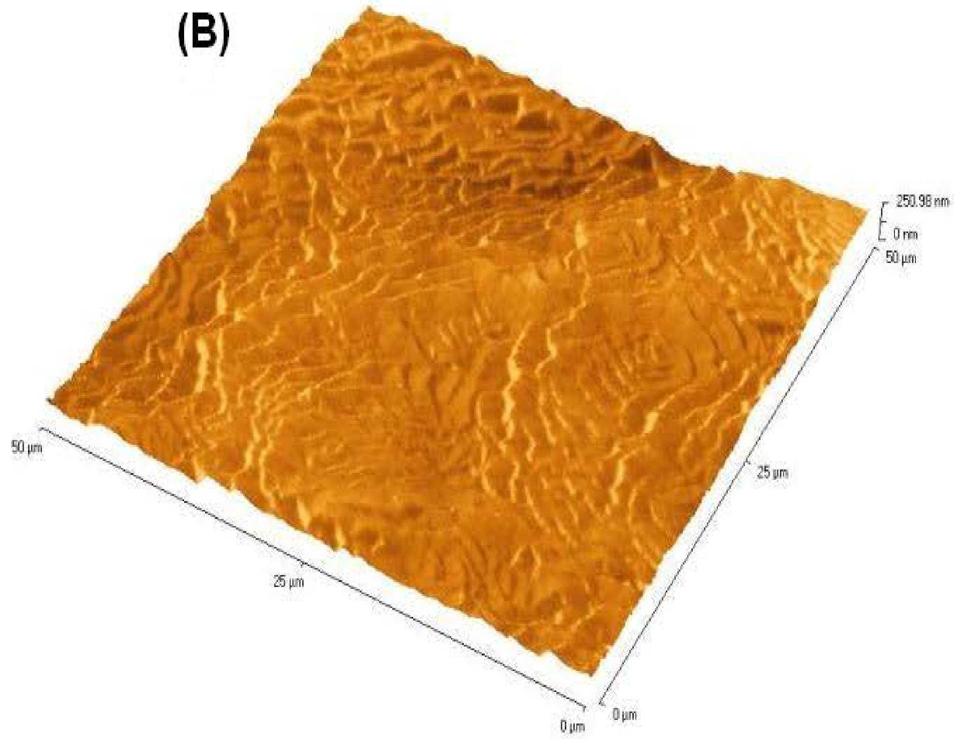
- High growth rate (~ 150 microns/hr) has been achieved by adding nitrogen to the gaseous chemistry.

- As a result, strong presence of nitrogen vacancy centers can be seen in the CVD grown bulk crystal.







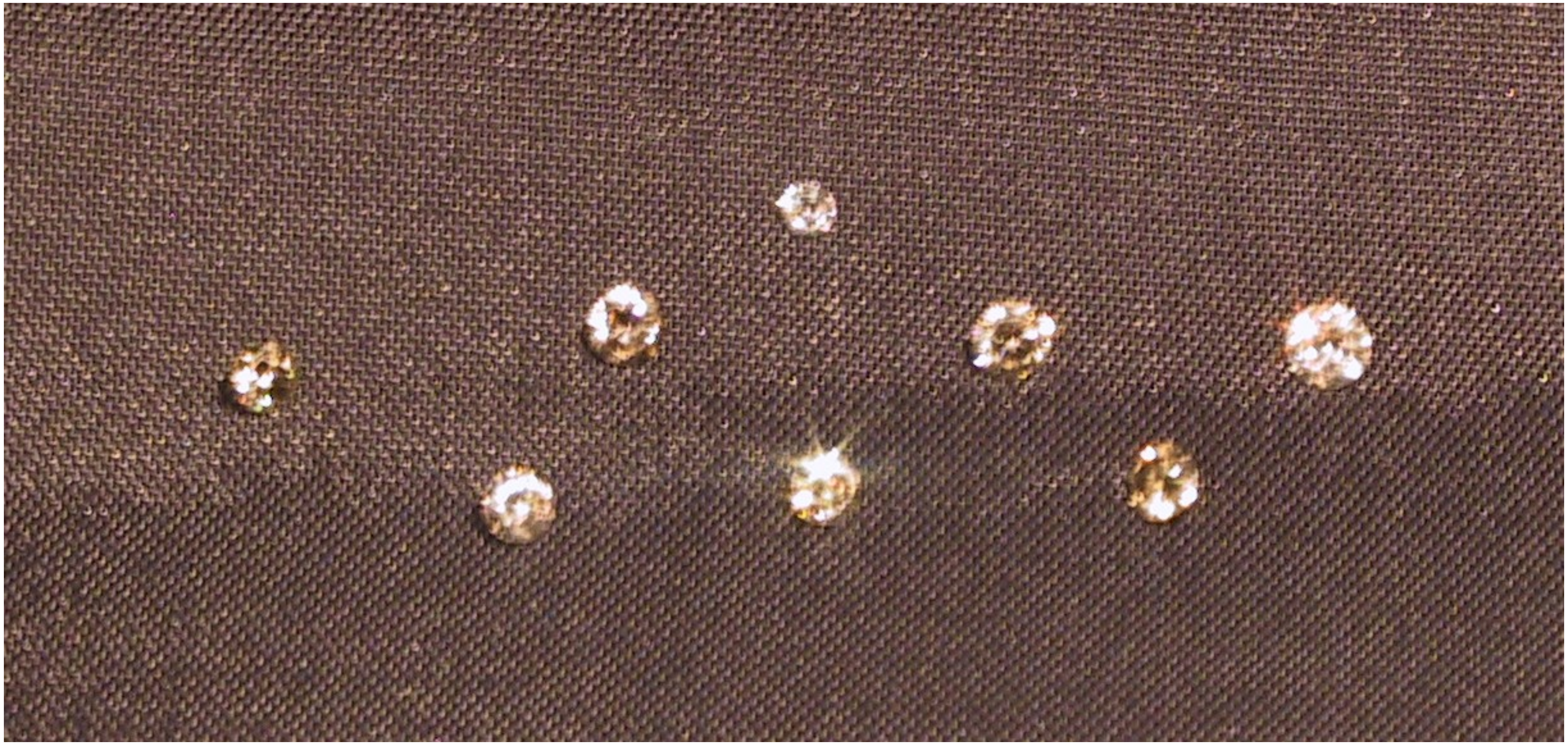
(A) Sample prepared without any nitrogen in plasma.

(B) Sample prepared with 1000 ppm nitrogen in the plasma.

Growth of large flawless diamonds

- Although the addition of nitrogen allows for the growth of large crystals, such diamonds are not of device grade.
- Research in the past few years has been geared towards modifying CVD reactor geometry, and towards achieving uniform plasma power density distribution across the surface of diamond substrate.
- Nearly colorless and colorless diamonds have been produced as a result. Diamonds that have a slight hue have been annealed in order to obtain colorless diamond crystals.

Brilliant Cut Diamonds Using High Growth Rate $H_2/CH_4/N_2$ Chemistry (0.1 – 0.3 Carat)



Brilliant Cut Diamond for High Pressure Research Using CVD

2 mm

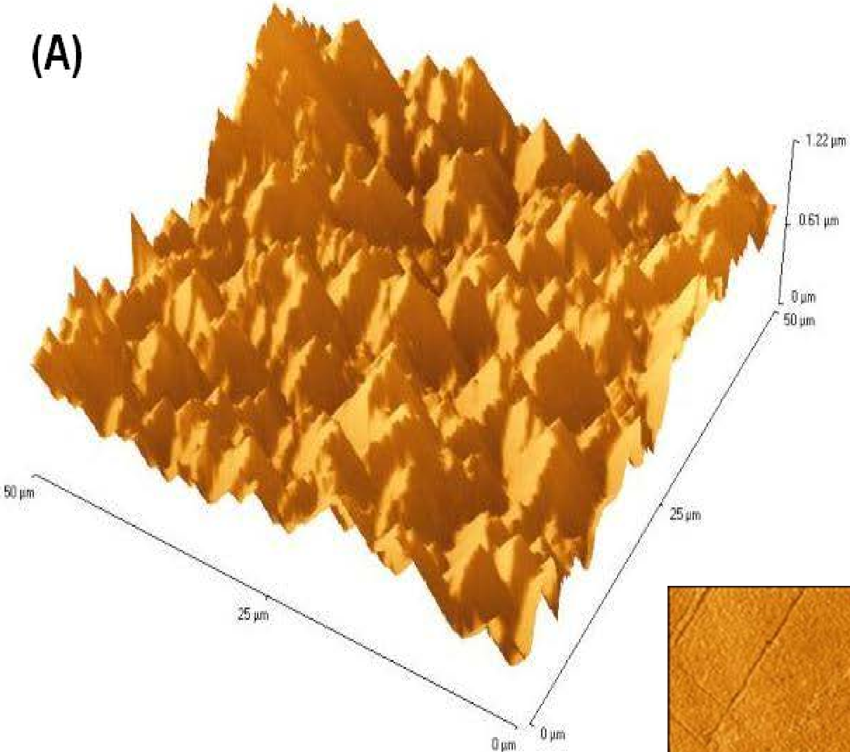
CVD Diamond at UAB

- At UAB, the CVD growth of diamond is being utilized in the following areas.
- Fabrication of designer diamond anvils for high pressure research.
- Production of electrically conducting single crystal diamond, achieved by boron doping.

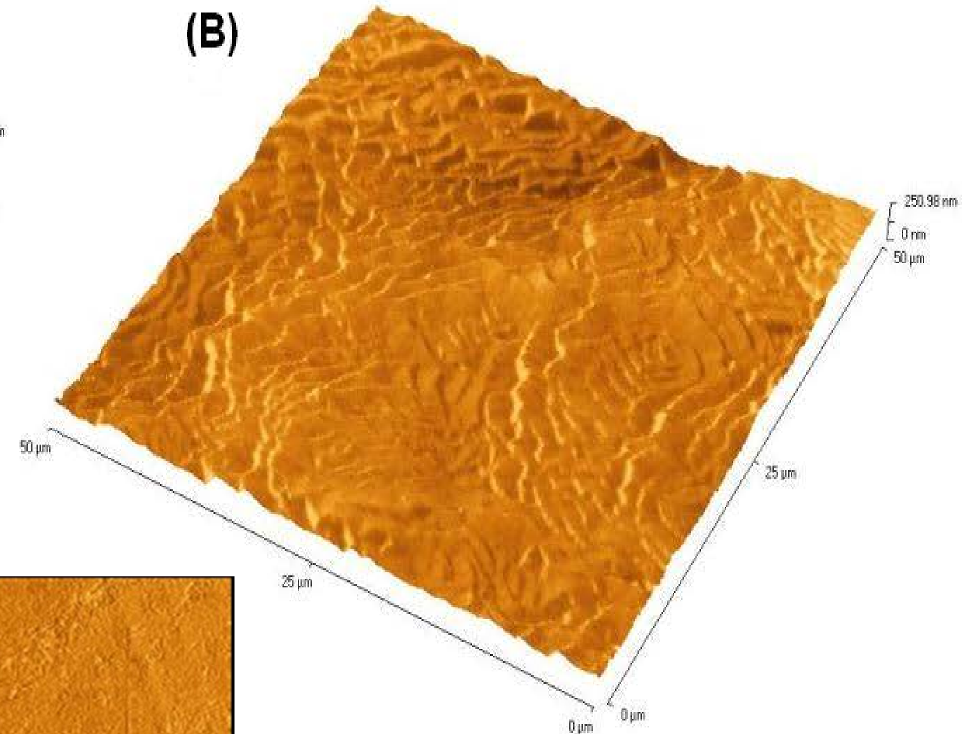
(A) Sample prepared without any nitrogen in plasma.

(B) Sample prepared with 1000 ppm nitrogen in the plasma.

(A)



(B)



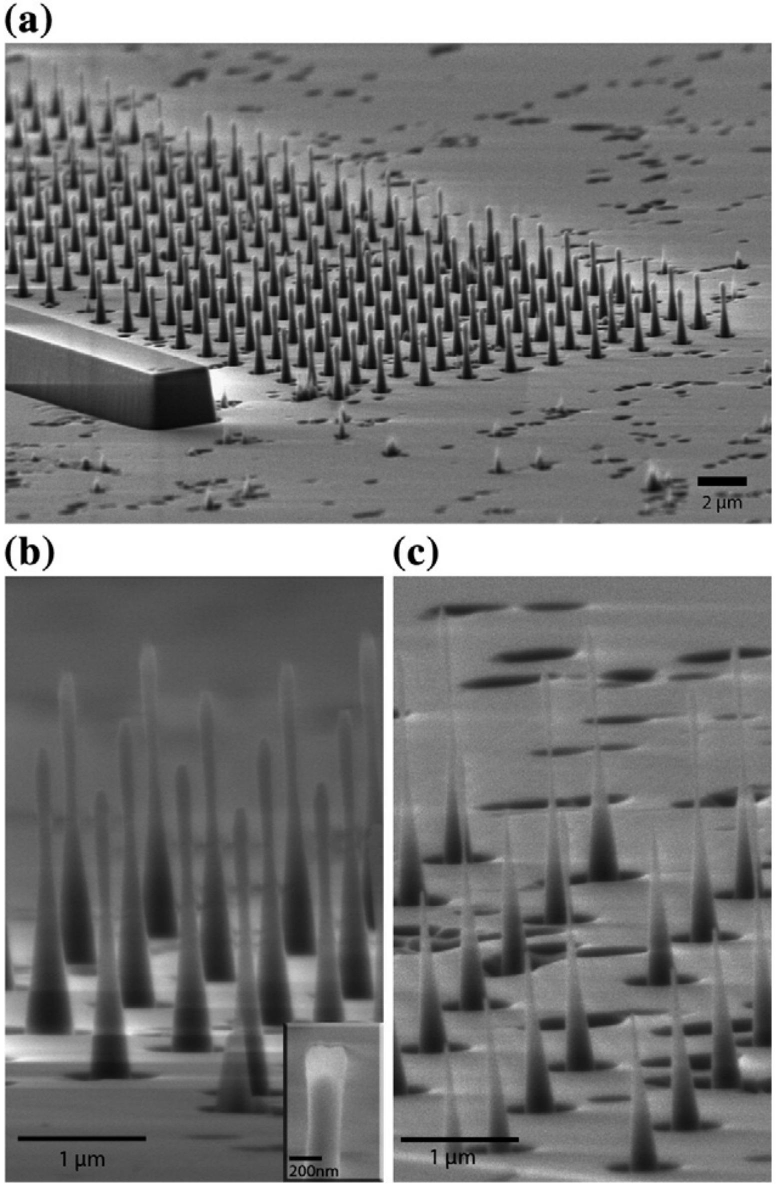
50 X 50 µm^2 AFM image of boron doped diamond film surface

Single crystal growth at UAB

- Electrically conducting diamond anvils have been fabricated. These anvils will be utilized as heating elements in a diamond anvil cell.

- Research efforts are underway to better understand the effects of using multiple dopants such as nitrogen and boron in a single CVD deposition step.

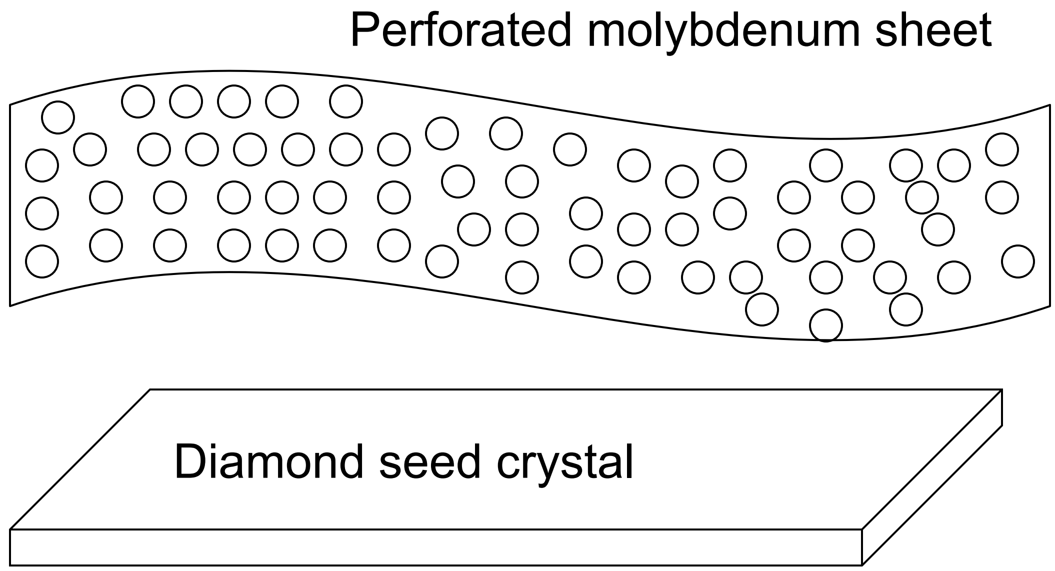
- Currently exploring the possibility of growing micro and nano features using CVD by selective masking of the substrate.



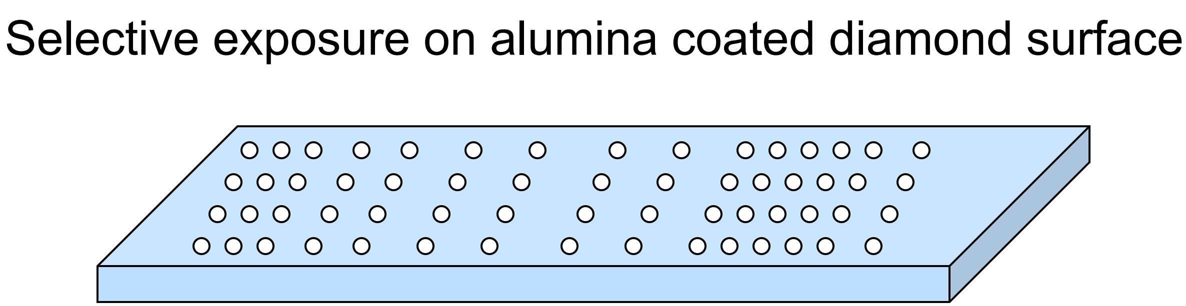
Single crystal diamond wires formed in a Ib HPHT diamond

B.J.M. Hausmann et al. / Diamond & Related Materials 19 (2010) 621–629

Approach 1 →

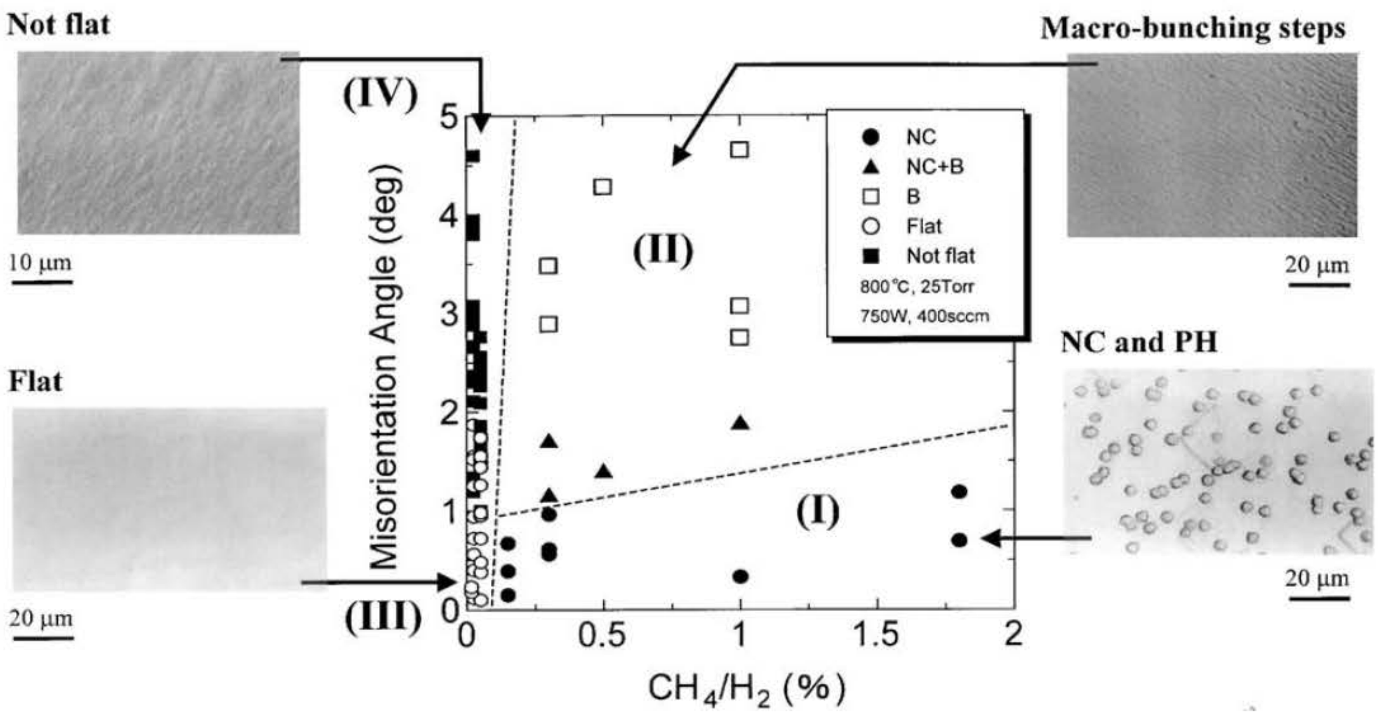


Approach 2 →



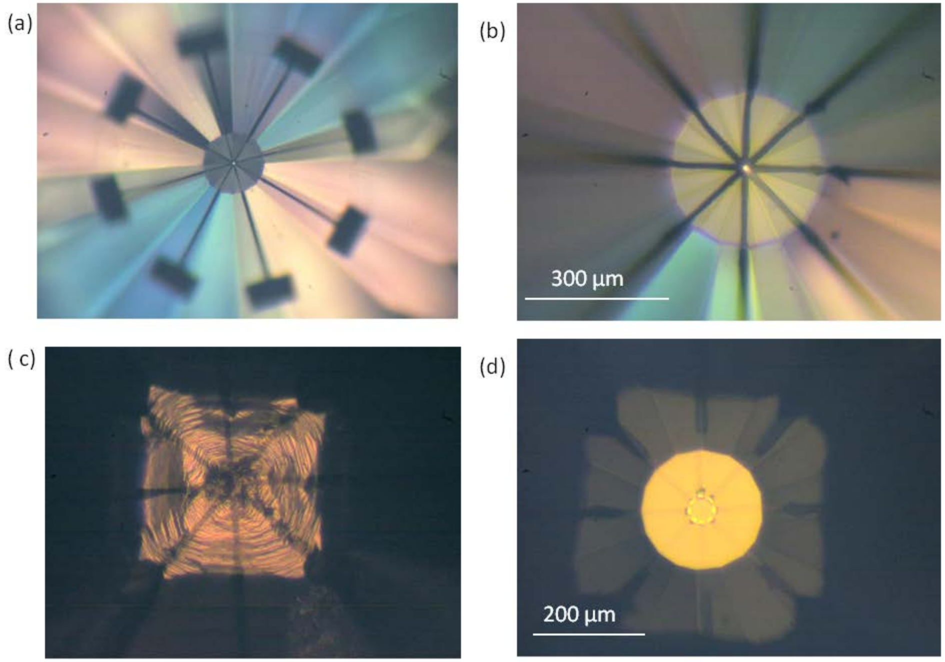
Device grade diamond grown in a lab

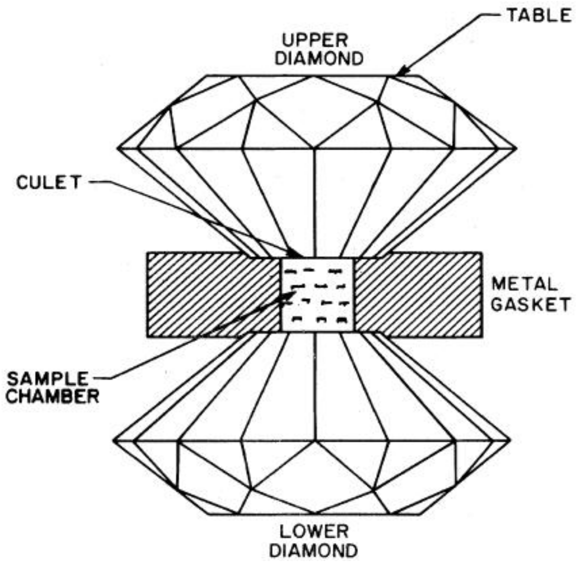
- Laboratory synthesized diamond is a cost effective solution.
- Stringent requirements in terms of impurity levels and surface roughness can be addressed effectively in a laboratory.
- Unmatched ease and versatility of CVD process allows the production of high quality single crystal diamond over large areas.



A map of surface morphologies as a function of both the misorientation angles and the CH_4/H_2 ratios [11]. The dotted lines in the figure serve as a guide to the eye and divided into for region I–IV.

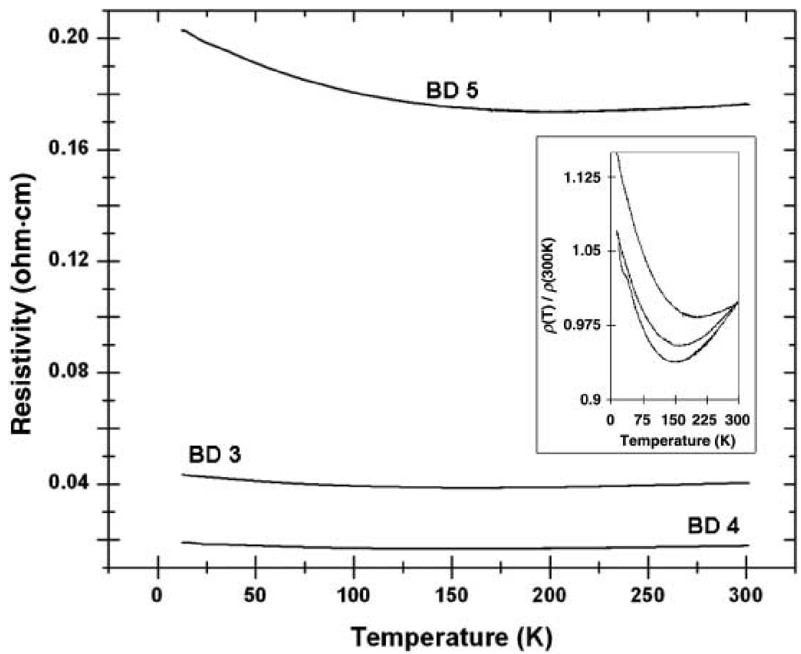
Stages in fabrication of designer diamonds





(a), (b): Sputtered tungsten probes on brilliant cut diamond
(c): Encapsulation of probes by Chemical Vapor Deposition
(d): Polishing to expose the tips of the probes

Doped diamond and its applications



The measured resistivity values for samples BD 3, BD 4 and BD 5.