Fabrication and Characterization of Diamond as Detector for Future Collider

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Introduction

The Large Hadron Collider (LHC) has already set a bench mark for future accelerators both in terms of luminosity and energy. It has already exceeded its design luminosity and would further go up during the long shut-down-II. Any future machine is bound to have luminosity greater than or equal to LHC. With high luminosities the inner tracking system made of Silicon of most of the collaborations would need frequent replacement. Diamond is a wide band semi-conductor and recently there has been a lot of interest in investigating its use as a tracking detector. This is primarily because of its fast response time and radiation hardness. Also because of large band gap it has minimal thermal noise. Furthermore, it needs minimal processing as compared to Silicon to transform it into a particle detector. To be ready to cater to the demands of the future experiments, we have grown high quality diamond in our physics lab using an indigenous custom built setup of Microwave Plasma assisted Chemical Vapor Deposition (MPCVD) in IIT Bombay. In this paper we elaborate on the details of diamond film fabricated successfully to a quality factor better than 60%. These were characterized by X-ray diffraction (XRD), Raman Spectroscopy, Scanning Electron Microscope (SEM) among other characterization techniques.

MPCVD Process

The MPCVD system contains a microwave generator of frequency 2.45 GHz. The microwave is carried by rectangular waveguides and coupled to a vacuum chamber through a quartz window. Gas flow into the chamber is fine-controlled by mass flow controllers calibrated in standard cubic centimeter per minute (sccm). The substrate temperature is controlled by microwave power and monitored by an infrared pyrometer. The position of the substrate holder is fine-tuned to form standing waves of the microwave and due to presence of hydrogen gas it leads to creation of hydrogen plasma [1].

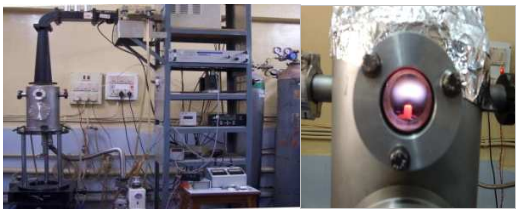

FIG. 1 MPCVD set up & Hydrogen Plasma inside vacuum chamber

Diamond Growth

We use Diamond as a seed substrate to grow a fresh Diamond film using MPCVD process. The substrate is cleaned ultrasonically and glued to a molybdenum substrate holder which is uploaded in the vacuum chamber. A small fraction of methane is mixed with molecular hydrogen in the chamber. When the gas mixture is ionized Carbon based radicals are reduced and settle on the substrate which progressively link together with σ-bonds into a diamond lattice [2]. The quality of diamond thus grown depends on the purity and ratio of gas mixture, temperature and pressure. Although this is an easy principle, the growth process is extremely difficult to control in order to grow material suitable for detector application, since the parameters are not constant throughout the process. We typically get a growth rate of 1 μm/hr. After the growth process, the substrate is etched out from the film.

Growth Parameters of film

Our seed substrate had the dimensions of $5\times5\times0.3\ mm^3$. We have made five films with different growth conditions. Here we report the results from film 03 that was thickest and hence could be most easily processed. The growth conditions attempted by us for various Diamond films are listed in Table 1.

Film No.	H2: CH_4	Press. (Torr)	Temp. (^oC)	Time (Hour)
01	100:2	75-77	757-780	7
02	100:2	80-81	904-928	48
03	100:2	75-76	921-966	168
04	100:1	68-70	920-937	24
05	100:1	68-70	920-925	63

Table 1 Growth parameters of diamond films

.Crystallinity of film

The XRD study confirms the formation of single crystal diamond. Our grown film has crystal orientation in [111] and [220] directions corresponding to diffraction angles 44.2^o and 75.7^o respectively. We scanned through the range of 10^o - 110^o in these XRD studies.

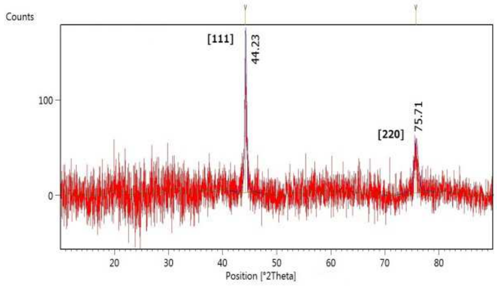

Fig. 2 XRD peaks for diamond [111] and [220]

Estimating Diamond content

The Raman Spectroscopy presents a very sensitive test to the bonds present in the material. We used the Raman spectra of our film to estimate the quality factor (q) of diamond. This is a measure of the relative content of diamond to graphite in the film. We used UV for this study and estimated the quality factor by Eq. 1

$$q = \frac{I_d}{(I_d + I_{nd})} \times 100 = \frac{1406}{1406 + 936} \times 100 \quad (1)$$

Where I_d and I_{nd} are the intensities of diamond and non-diamond (Graphite) peaks respectively. Due to stress in the film, some bonds show up at slightly different energy shifts. To accommodate all such diamond and graphite content, we have considered the area under the respective peaks instead of its intensity. This yields a quality factor of 60%.

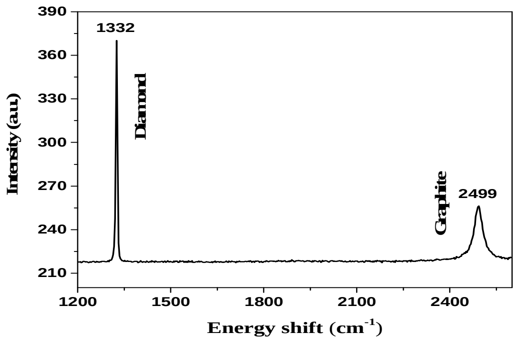

Fig. 3. Raman peaks of diamond and graphite corresponds to 1332 and 2499 cm^{-1} respectively.

Surface characterization

SEM study on our grown film also shows the formation of crystalline diamond with very few grain boundaries, showing uniformity over whole film. Fig. 4 shows the SEM with a zoom of 50,000 showing only few graphite patches.

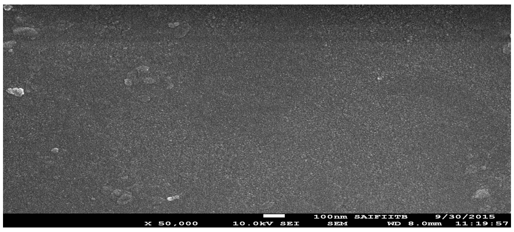

Fig. 4. SEM morphology of diamond film

Conclusions

The best results were obtained at substrate temperature between 925-966 ^oC and methane contents up to maximum 2%. We are able to grow diamond films in the laboratory up to 300 µm thickness at a growth rate of ~2 µm/hr. The quality factor of the diamond film number 03 is estimated to be 60.0%. We will further metalize the film and observe its I-V/C-V characteristics.

References

[1] Growth of Diamond by MPCVD Process Shyam Kumar et-al, Proceedings of the DAE Symp. on Nucl. Phys. 58 (2013).
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