Plasma-Assisted CVD Grown Single Crystal Diamond for Swift-Heavy Ion Beam Detectors

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Introduction:

Diamond has several superior properties in comparison to other contemporary semiconductors. It is a wide bandgap semiconductor (5.5 eV) with a high breakdown electric field strength, a large atomic displacement energy, a high thermal conductivity and high carrier mobility. These exclusive properties make diamond an excellent candidate for radiation detector material in harsh environment. For particle colliders, the near future goal is to reach higher particle fluence (~10^{16}/cm^2). Diamond has high radiation tolerance to possible meet such requirements.

Single crystal diamond is grown at Michigan State University (MSU) by microwave plasma assisted chemical vapor deposition (MPACVD) system, which is a very efficient process of growing good optical and electronic grade diamonds. In this study, the lab grown single crystal diamonds are applied as a detector for swift heavy ion beams. The eventual goal is to understand the degradation mechanism of diamond and the lifetime of the detectors in swift heavy ion beams.

Growth parameters:

	A	B	C	D
H_2 (sccm.):	400	400	400	400
CH_4 (sccm.):	20	20	20	20
N_2 (ppm.):	0	0	0	0
Growth pressure (Torr)	180	180	180	180
Total growth time (hr).	48	48	48	48
Growth rate (Avg.) (µm/hr)	15.5	16.0	15.8	16.5
Avg. thickness: CVD (µm.)	726	720	711	785

The table shows the parameters used for growing single crystal diamonds in microwave plasma assisted chemical vapor deposition (MPACVD) system at MSU.

Optical properties:

Characterization of optical properties of diamond is important to ascertain the purity of the single crystalline diamond samples. The UV-VIS spectroscopy in fig. (b) and FTIR spectroscopy in fig. (c) show no significant presence of nitrogen impurity and high transmittance of the type IIa diamond samples (in fig . (a)) used for this study.

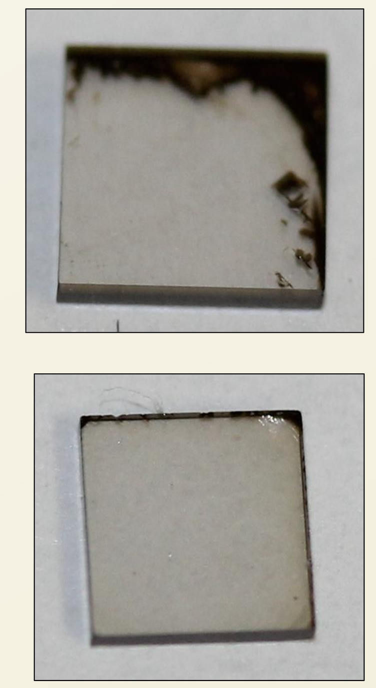


Fig.(a) SCD samples.

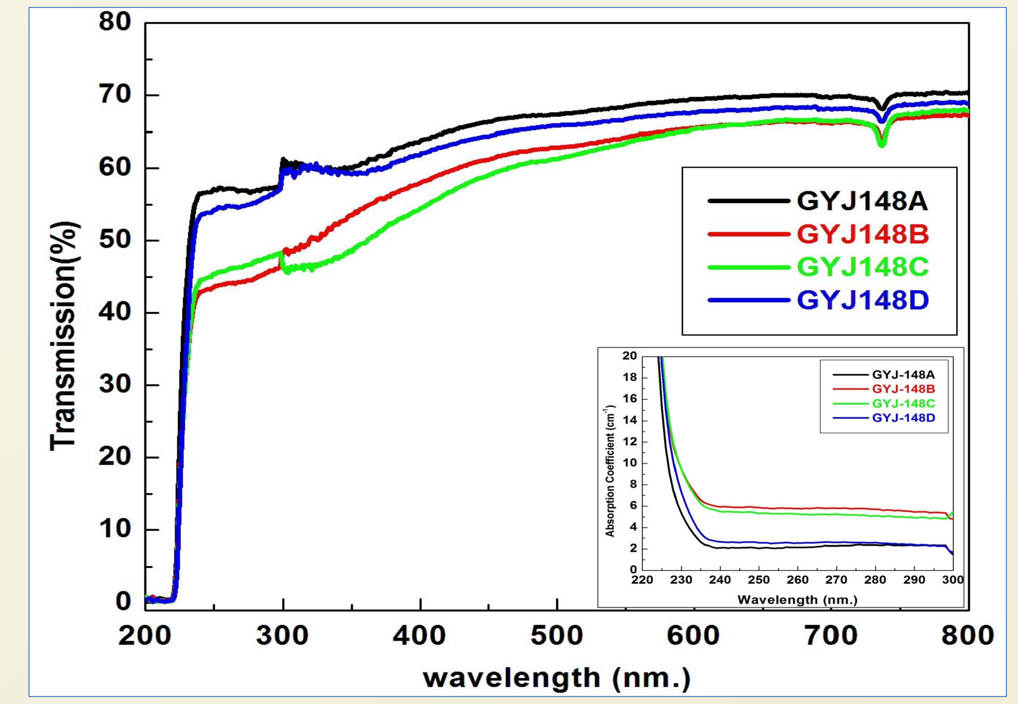


Fig. (b) The transmission and absorption of diamond sample at UV-VIS range

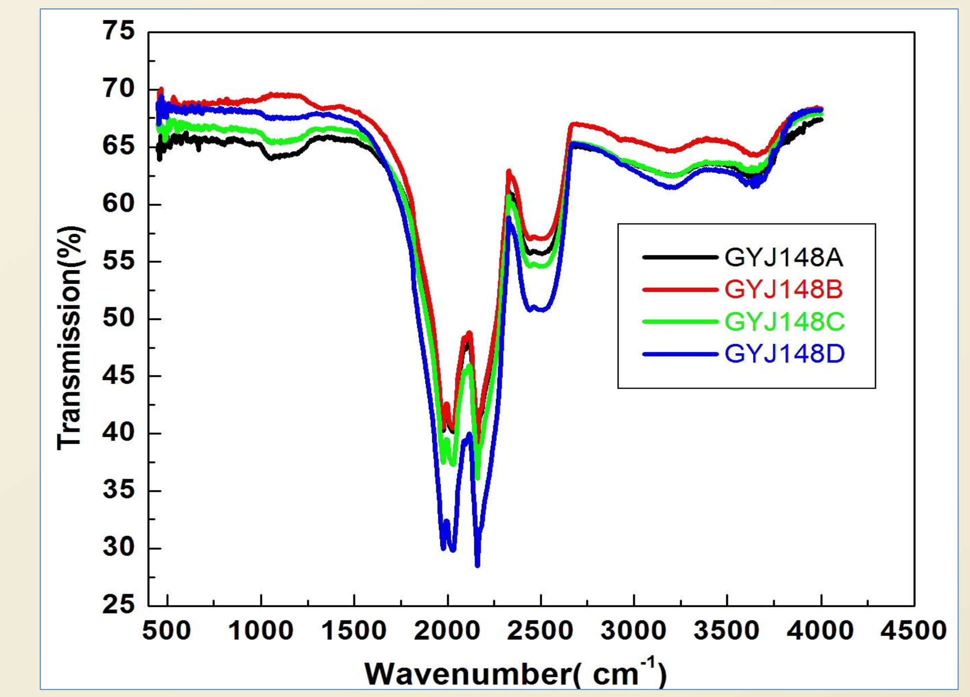
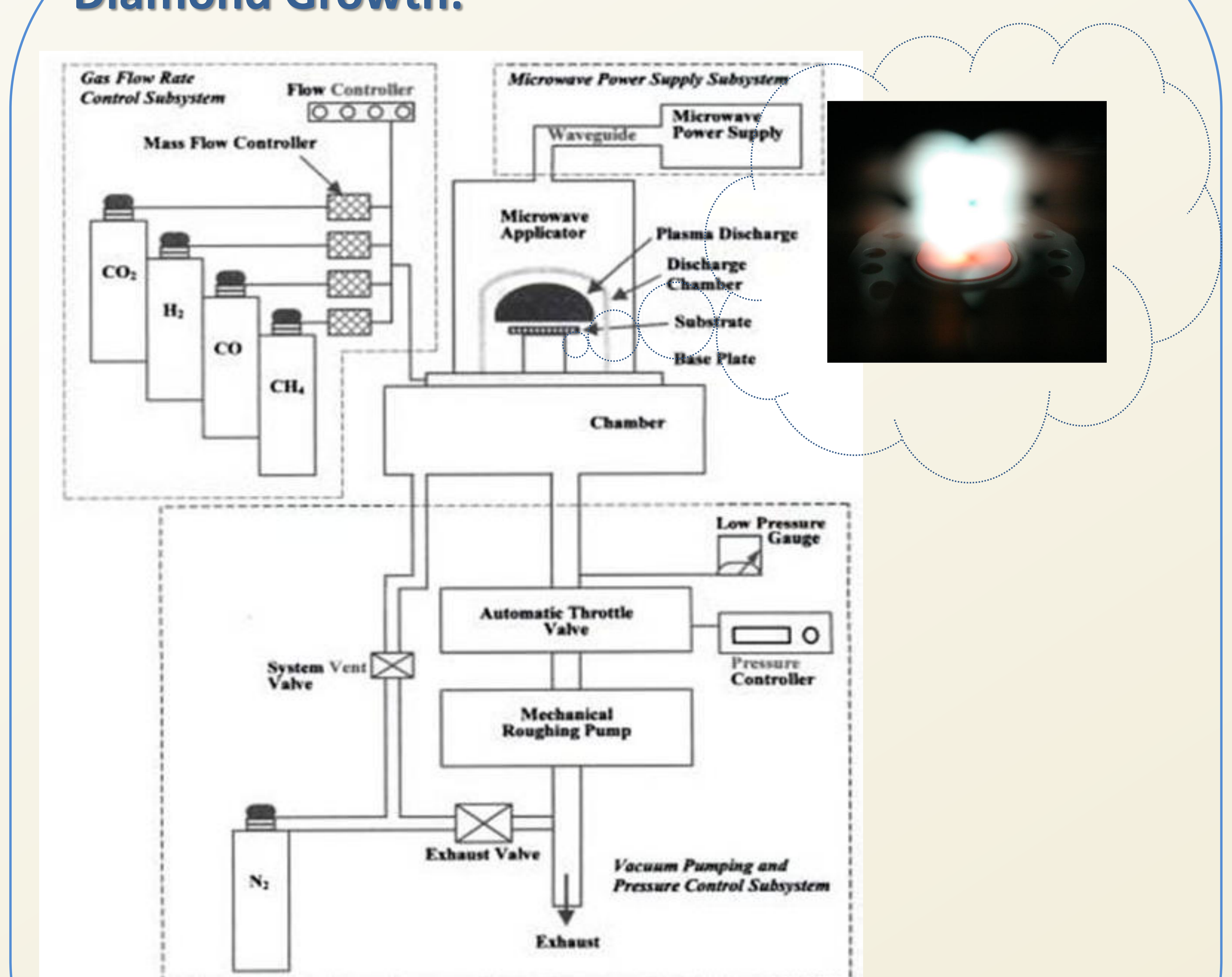


Fig. (c) FTIR spectroscopy of diamond samples

Diamond Growth:



Schematic of Microwave plasma assisted chemical vapor deposition (MPACVD) system (Chapter 7, pg 216, Diamond Films Handbook, J.Asmussen , D.Reinhard) and a CH_4/H_2 plasma at 240 Torr (image courtesy : Dr. Yajun Gu, MSU).

Detector Testing:

In a detector, charges (Q) are generated based upon the ratio of intensity of absorbed radiation and energy required to form e-h pair. The response of the detector is measured by the output current/voltage as the charges move under the influence of an applied electric field.

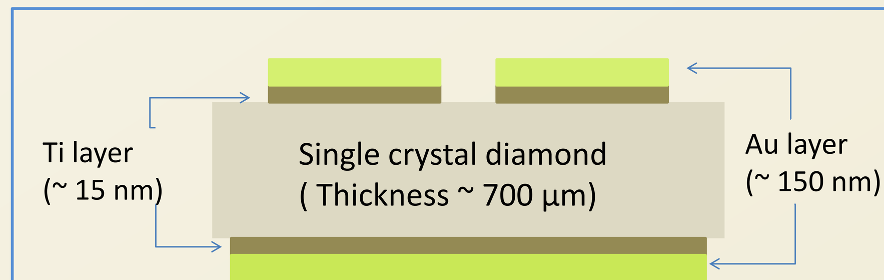


Fig. (d) Cross section diagram of detector.

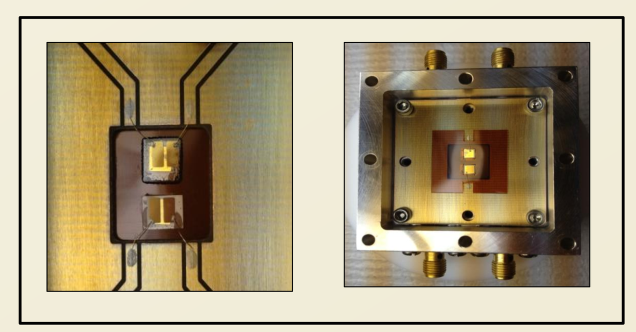


Fig. (f) The electrodes and detection housing

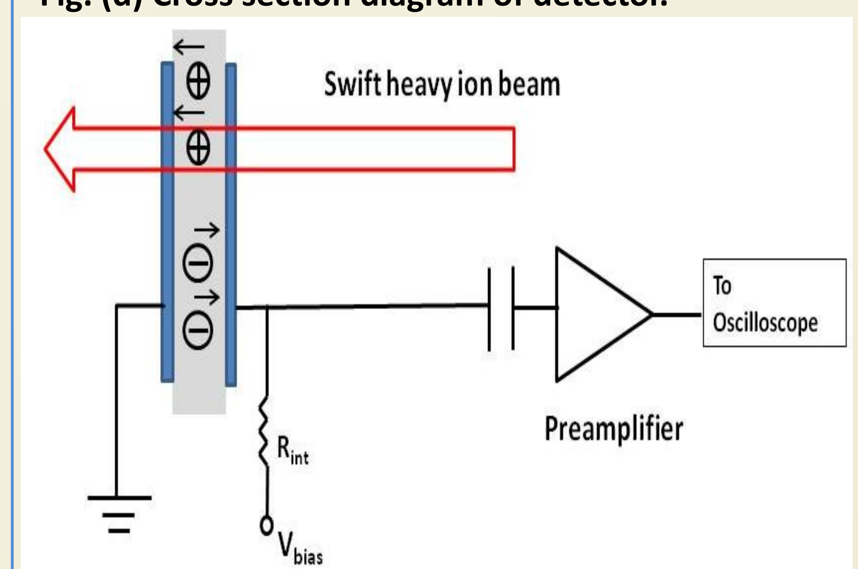


Fig. (e) Schematic of diamond detector

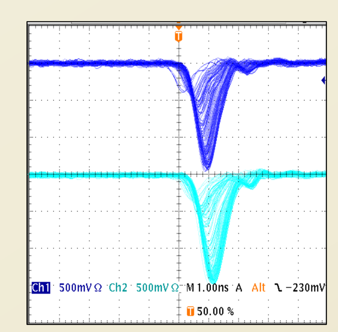


Fig. (g) Voltage read at oscilloscope

Preliminary observations:

The following figures show the performance of the diamond detectors while irradiating with $^{124}Sn^{45+}$ and $^{96}Zr^{37+}$ beam of 120MeV/u at NSCL,MSU.

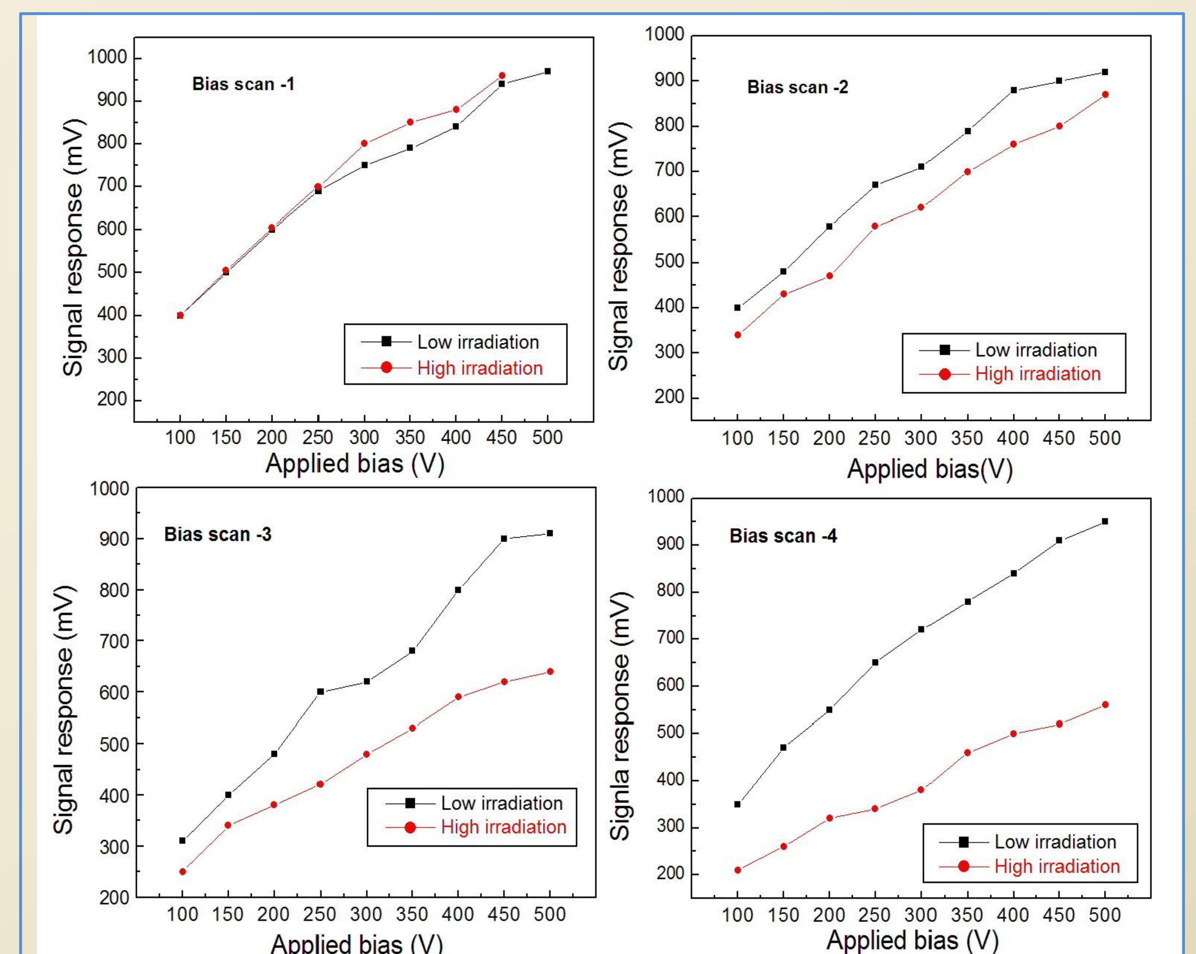


Fig. (h) The figure shows the relative change in the response of heavily irradiated detector with respect to lightly irradiated detector at different phases of the irradiation experiment.

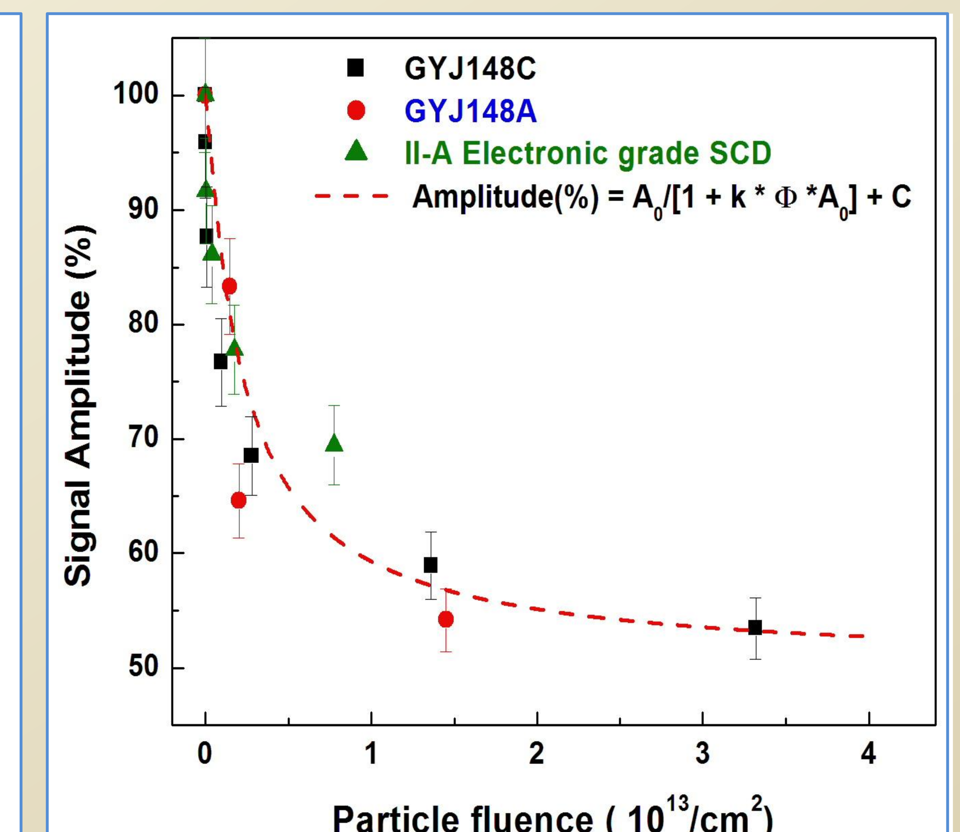


Fig. (i) This figure shows the relative degradation of the detectors built on diamonds grown at MSU (GYJ148A & 148C) in comparison with detector built using a commercial electronic grade diamond (II-A Enterprises, Singapore). The degradation follows a hyperbolic relationship.

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Future work:

The initial results show that the degradation of the diamond detectors follow a hyperbolic relationship under both irradiation by ^{124}Sn and ^{96}Zr beams. Post irradiation diamond samples will be characterized in terms of charge collection distance(CCD) and transient current signal to have a deeper understanding of degradation mechanism. Also UV-VIS, FTIR spectroscopy, birefringence and dielectric properties measurement will be conducted on the irradiated and non-irradiated segment of the sample to compare and understand the change in strain and defect concentration in the samples.