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Growth of Diamond film by MPCVD Process for Detector Applications

by

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Topics

- Why diamond?
- Comparison of Silicon and Diamond
- Diamond as Time of flight detector
- Issues with Diamond
- Growth of Diamond film by MPCVD Process
- Future Plan

Why Diamond?

- LHC (2008), $L = 10^{34} /cm^2 sec$
- 14 TeV pp Collider, 25 ns bunch spacing

$\xrightarrow[500\ fb^{-1}]{\text{10 Years}} \phi(r = 4\ cm)$

$\sim 3 \times 10^{15}\ /cm^2$

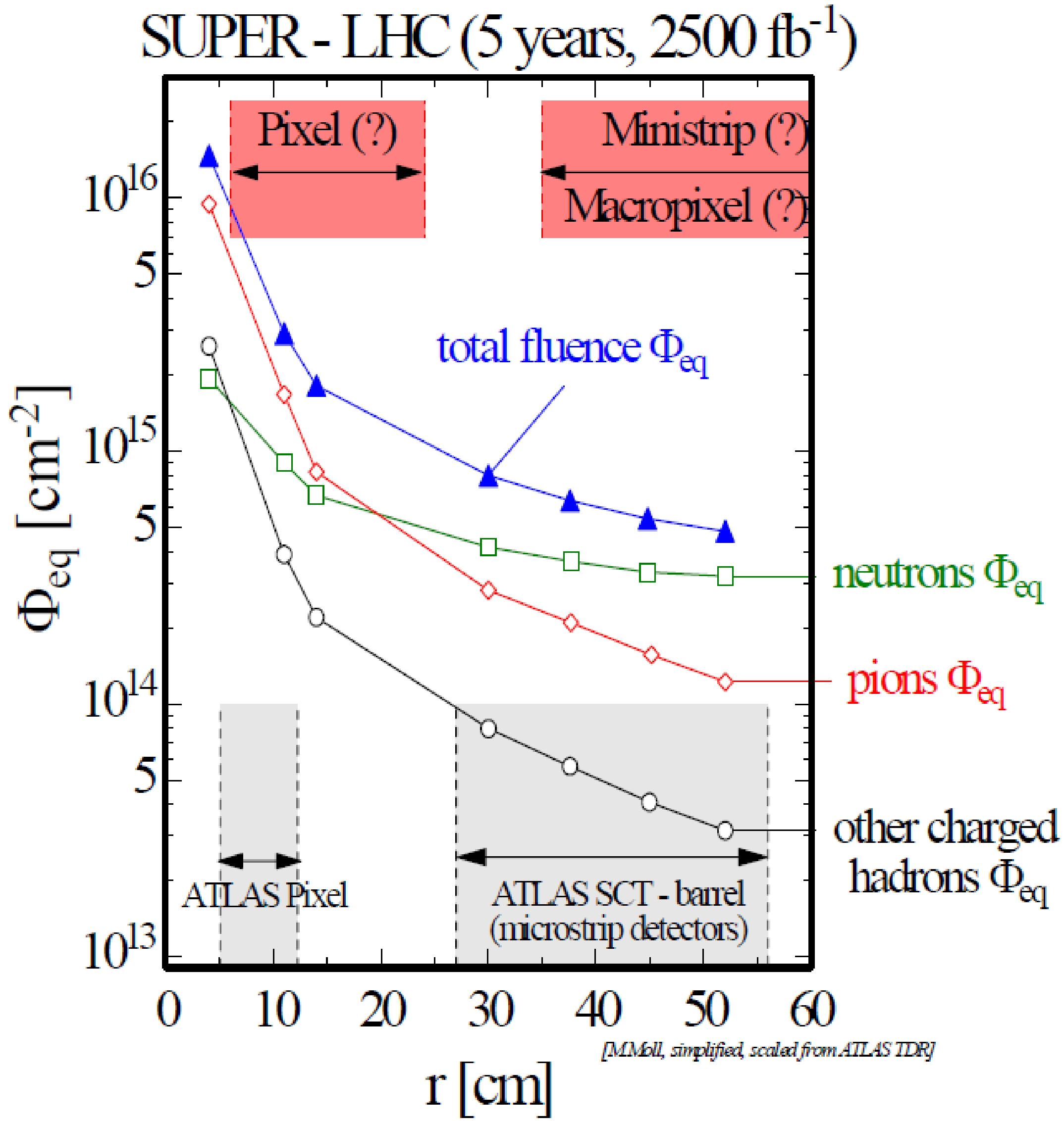
LHC upgrade: Super LHC

$L = 10^{35}/cm^2 sec$

$\times 5$

$\xrightarrow[2500\ fb^{-1}]{\text{5 Years}} \phi(r = 4\ cm)$

$\sim 1.6 \times 10^{16}\ /cm^2$



- Radiation hard detector with High rate capabilities is required=>Diamond

Ref: Development of Radiation Hard Si Detectors, Dr. Ajay K. Srivastava Hamburg, D-22761, Germany

Comparison of Silicon and Diamond

Property	Silicon	Diamond	Effect in Diamond
Band gap [eV]	1.12	5.45	Leakage current is very small and No cooling required
Electron mobility[cm^2/V-sec] Hole mobility[cm^2/V-sec]	1450 500	2200 1600	Signal is very fast
Dielectric constant	11.9	5.7	Low Capacitance and noise
Atomic displacement energy [eV]	21	43	Radiation hardness is high
Electron-hole pair creation energy[eV]	3.6	13.6	Smaller signal
Mean electron-hole pair by MIP (Minimum Ionizing Particle) in 1 μm	89	36	Smaller signal
Charge collection efficiency (%)	100 (Single crystal)	100% for Single Crystal & 50% for Polycrystalline	Smaller signal
Thermal conductivity [W/cm-K]	1.5	22	No cooling required

Ref: Application of sCVD diamonds as beam condition monitors, BI Seminar ,23 rd Nov 2012

- Two pieces of Si and Diamond of thickness d= 300 μm and area 1× 1 cm^2 and apply 100 V after making Ohmic contact

$$R = \frac{\rho d}{A} \quad \text{and} \quad \mathrm{I} = \frac{\mathrm{V}}{\mathrm{R}}$$

- For Silicon: $\rho = 6.4 \times 10^2 \Omega m \ at \ 20\ ℃$

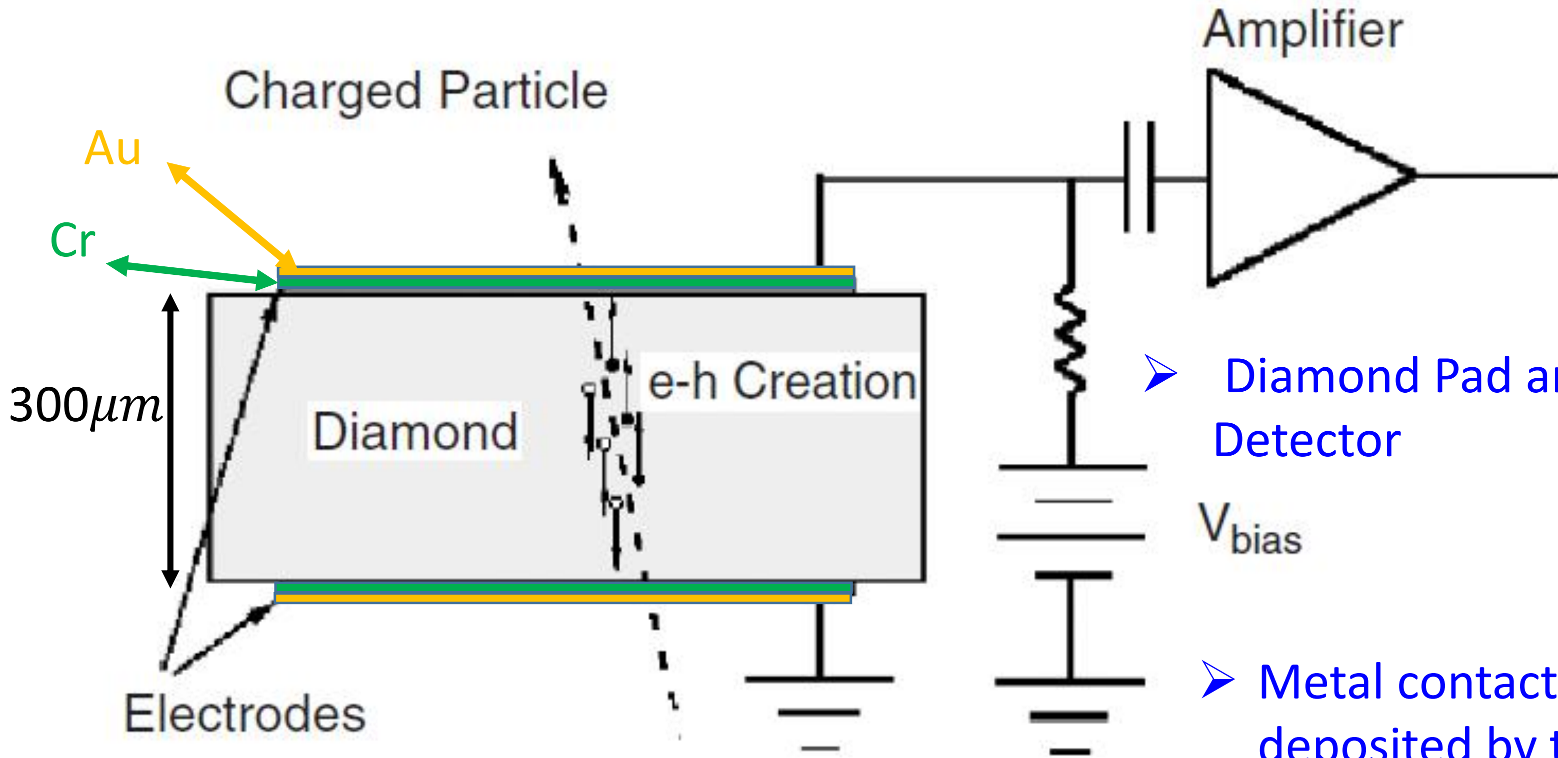
$$R = \frac{6.4 \times 10^2 \times 300 \times 10^{-6}}{10^{-4}} = 1920\ \Omega$$

Leakage current $I = \frac{100\ V}{1920\ \Omega} = 0.0521\ A = 52.1\ mA$

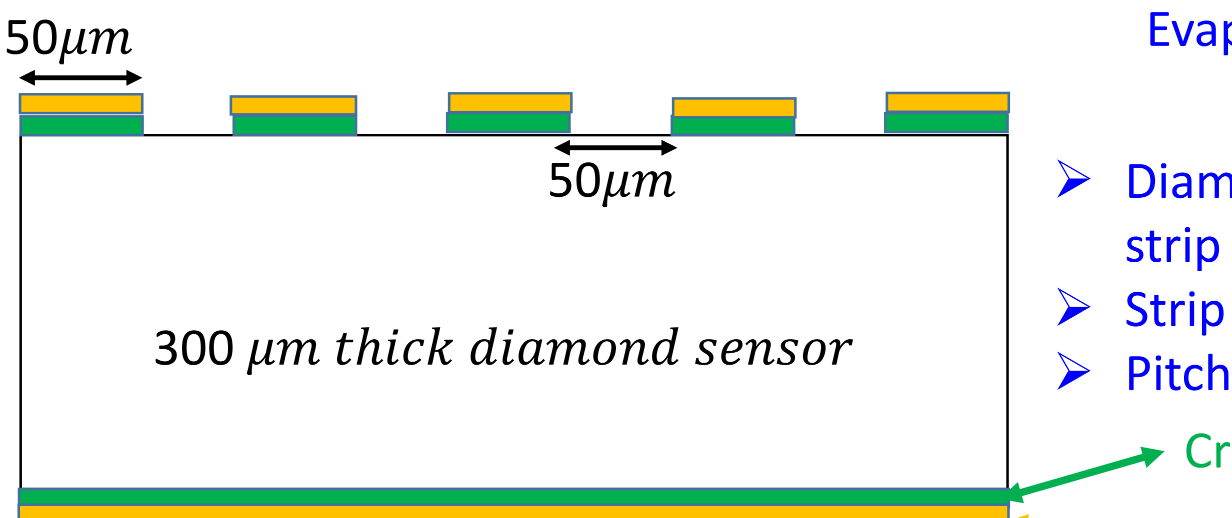
- For Diamond: $\rho = 1 \times 10^{12} \Omega m \ at \ 20\ ℃$

$$R = \frac{1 \times 10^{12} \times 300 \times 10^{-6}}{10^{-4}} = 3 \times 10^{12} \Omega$$

Leakage current $I = \frac{100\ V}{3 \times 10^{12}\ \Omega} = 33.33 \times 10^{-12} A = 33.33\ pA$



- Diamond Pad and Pixel Detector
- Metal contacts can be deposited by thermal Evaporation technique



- Diamond Single Sided Micro strip Detector
- Strip width= 50 μm
- Pitch = 50 μm

"Ref: First measurements with a diamond microstrip detector",
F. Borchelt et al, Nuclear Instruments and Methods in Physics Research A 354 (1995) 318-327

- Higher resistivity of diamond => No P-n Junction required as in case of Silicon
- Average Energy for e-hole pair creation is larger for diamond ($\epsilon = 13.6$ eV) than Si ($\epsilon = 3.6$ eV)=> Probability of creation of delta electrons will be small (not much disturb of charge center of gravity)
- Effective radiation length $\frac{d}{X_0}$ for diamond sensors ($X_0 = 12.14\ cm$) will be smaller than Silicon ($X_0 = 9.37\ cm$) for the same thickness (d) of sensors
- Radiation Damage in Silicon are of two types
- Surface Damage (due to Ionizing energy Loss)
- Bulk damage (due to Non-Ionizing energy Loss)
- In diamond there will be no Surface damage as there is no SiO_2 layer
- The Bulk damage will also be small due to large atomic displacement energy than Si

Particle Identification: different Methods

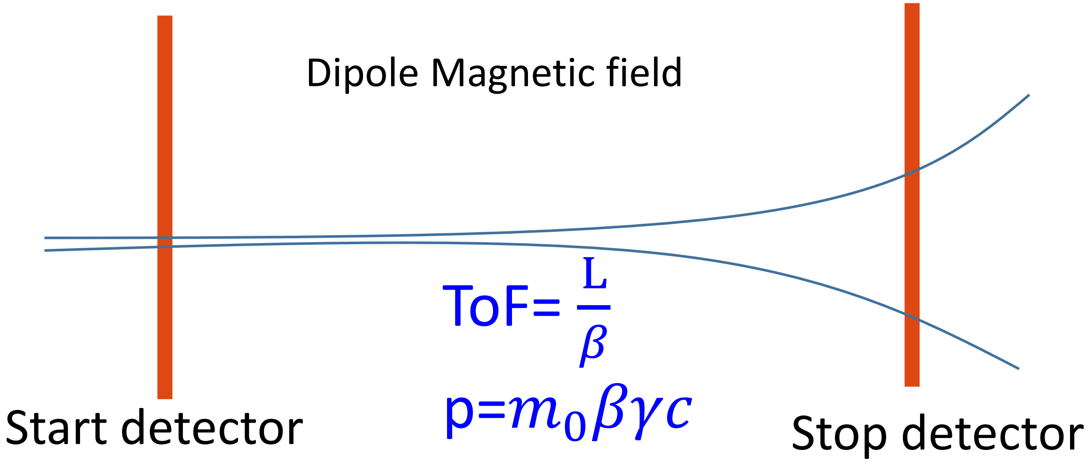
- dedx vs p -up to maximum 1 GeV
- Time of flight method (β *vs* p or m_0^2) - up to maximum 3 GeV or more depends on detector time resolution and track length
- Cherenkov radiation (θ_c *vs* p or m_0^2)- for High Momentum
- Transition Radiation detection -In much higher Momentum range

- Diamond can also be used as the sensor in time of flight PID detector as (time resolution<100 ps)
- Dedx vs Momentum in diamond

$$Separation\ (Sigma) = \frac{\left(\frac{\mathrm{dE}}{\mathrm{dx}}\right)_{\mathrm{A}} - \left(\frac{\mathrm{dE}}{\mathrm{dx}}\right)_{\mathrm{B}}}{\left(\frac{\mathrm{dE}}{\mathrm{dx}}\right)_{res}}$$

- Energy resolution in diamond will not be good because of small charge

Diamond as Time of flight detector



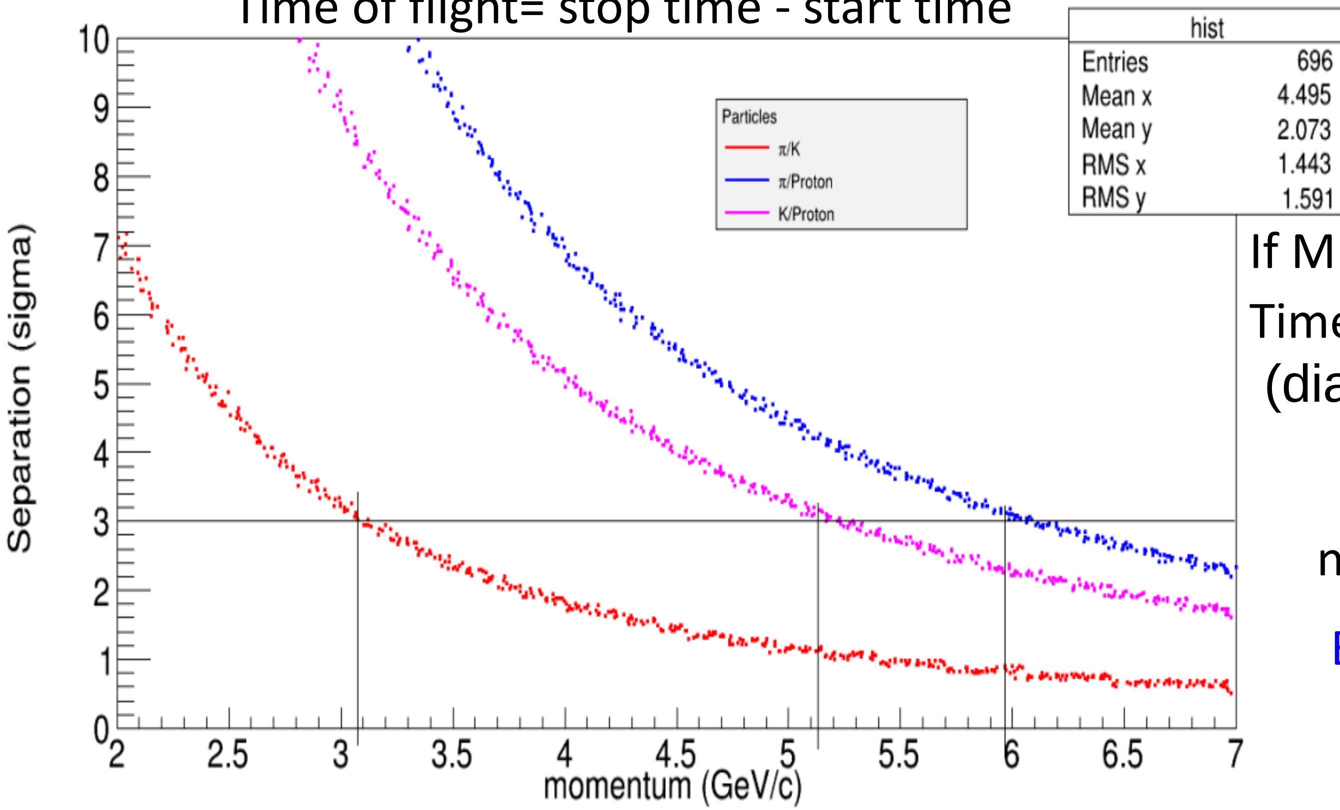
Time of flight difference

$$\Delta t = \frac{L}{pc^2}(E_1 - E_2)$$

L-> Track length
p-> Momentum

Diamond as ToF detector

Time of flight= stop time - start time



If MP track length = 7.8 m &
Time resolution (σ) <100 ps (diamond)

$$\Delta t \geq n\,\sigma$$

n- Separation plotted

Better separation for Pion-Kaon and Protons

Issues with Diamond

- The comparison of Charge in 300 μm thick Si and Diamond by MIP

- For Silicon:

The mean charge created in 300 μm = 89×300 =26700 e-h pairs

- We have silicon single crystal (CCE=100%) wafer of larger size

- For Diamond:

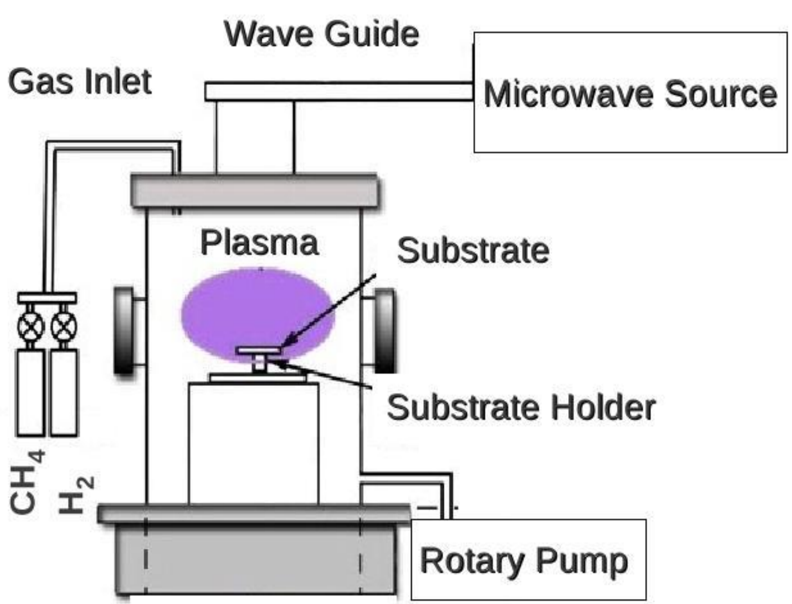
The mean charge created in 300 μm= 36× 300= 10800 e-h pairs

- We have single crystal diamond (CCE=100%) of $1 \times 1\ cm^2$, but Polycrystalline diamond (CCE=50%) are of larger size
- So In diamond Extraction of signal from low charge is big issue !

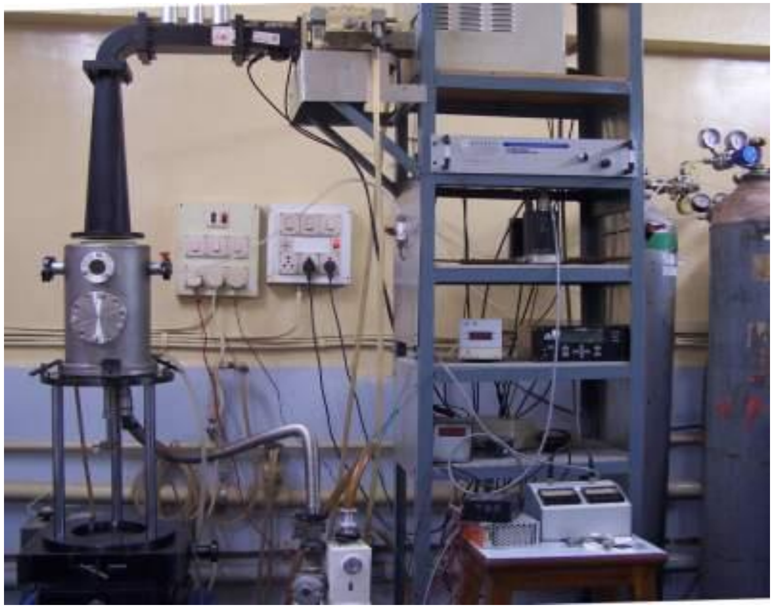
Growth of Diamond film by MPCVD Process

MPCVD : Microwave Plasma Chemical Vapour Deposition

- ➢Electrode less process =>small sheath potential
- ➢Plasma density is high
- ➢Stability of Plasma up to many days
- ➢Ability to scale up the process over large substrates



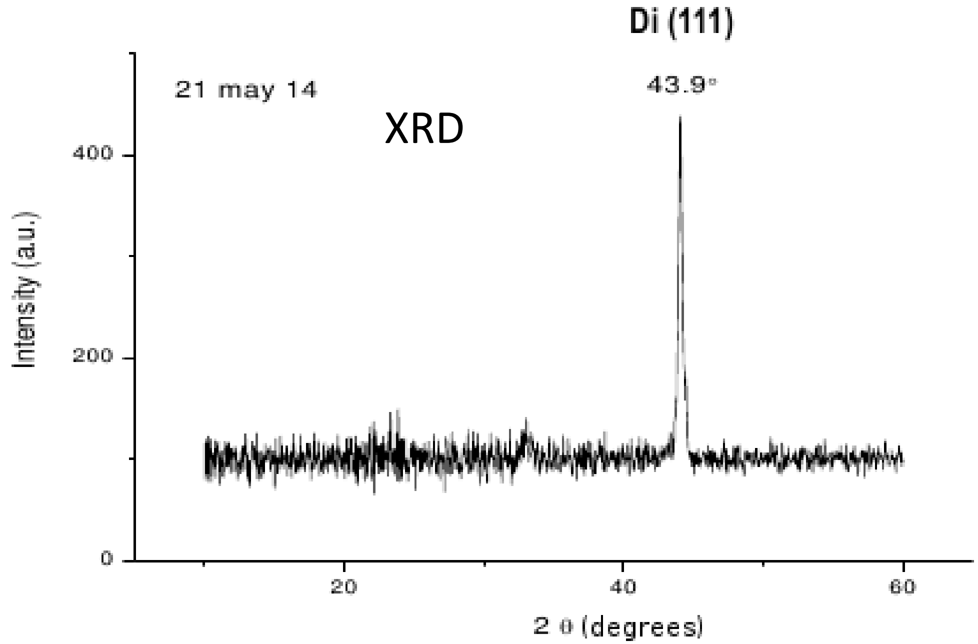
Schematic of MPCVD System

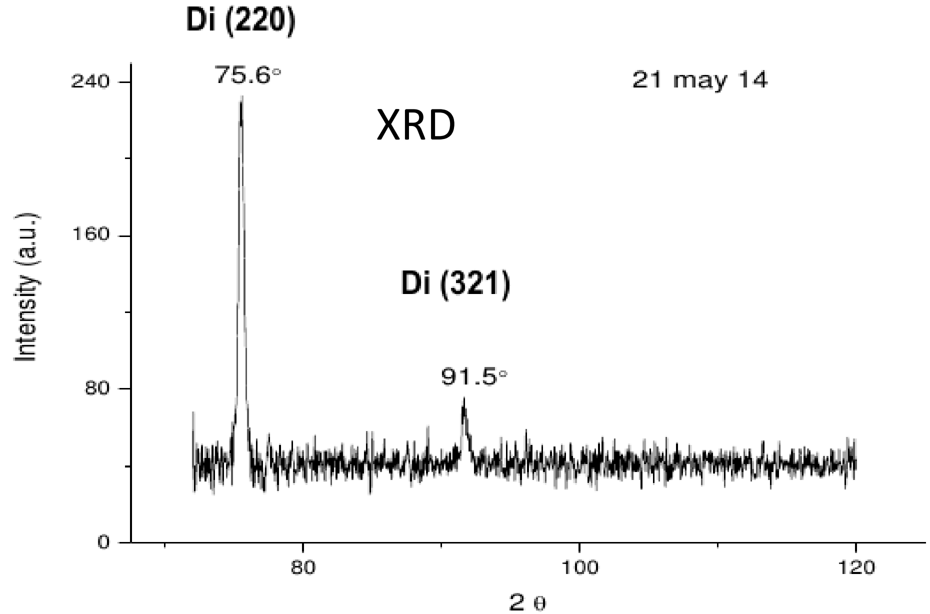


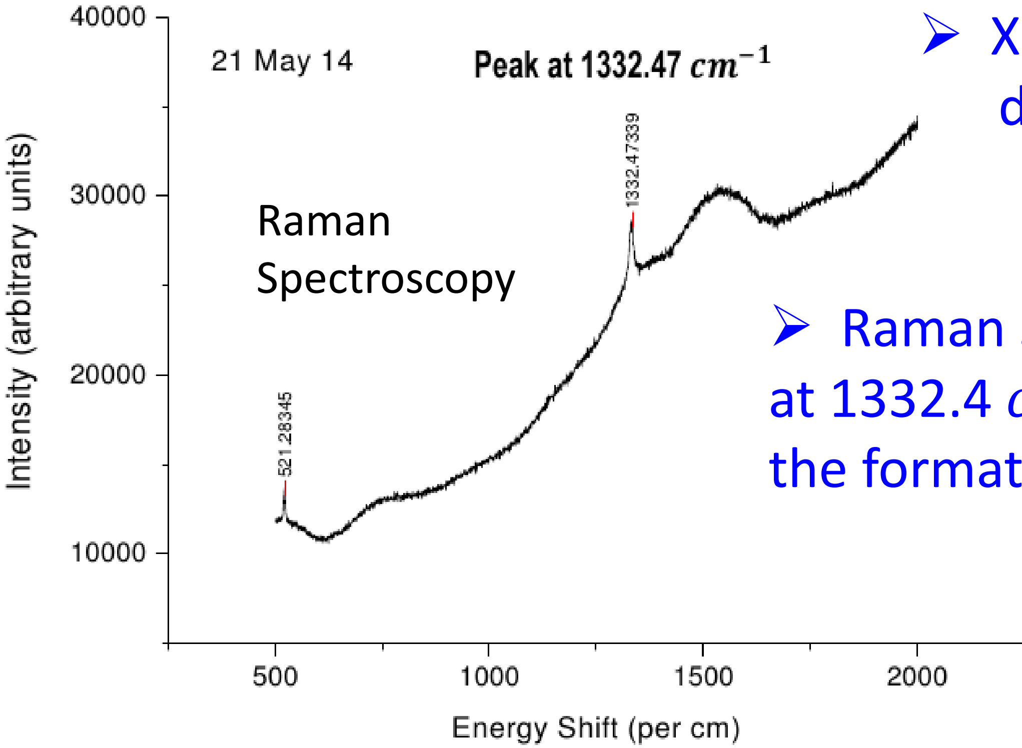
Home made MPCVD System

- Growth Parameter of Film:
- Diamond Film Growth on Si (100)
- Methane = 2 sccm
- Hydrogen = 250 sccm
- Pressure =77-91 torr
- Substrate temperature = 840-877 ℃
- Power Input = 0.5-0.6 kW
- Power Reflected = 0 kW
- Deposition Time = 16 hrs
- Thickness of film = 10 μm

Film Grown in the Laboratory is characterized by X-ray diffraction (XRD), Raman Spectroscopy , Scanning Electron Microscope (SEM) and Energy dispersive X-ray Analysis (EDAX)

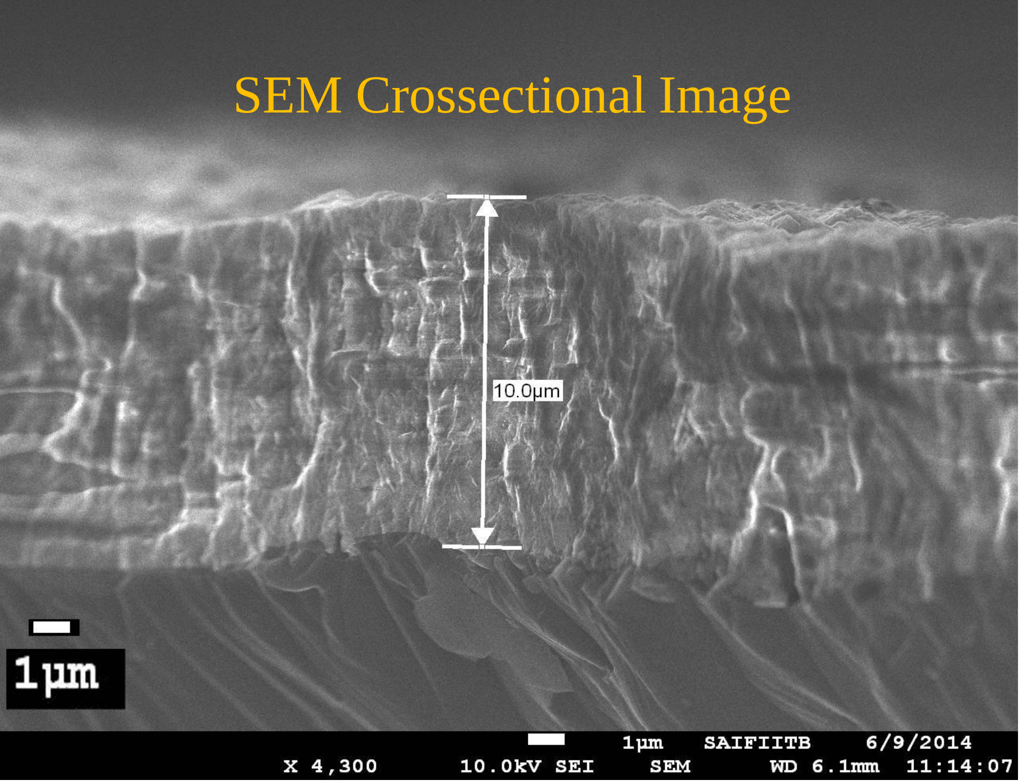






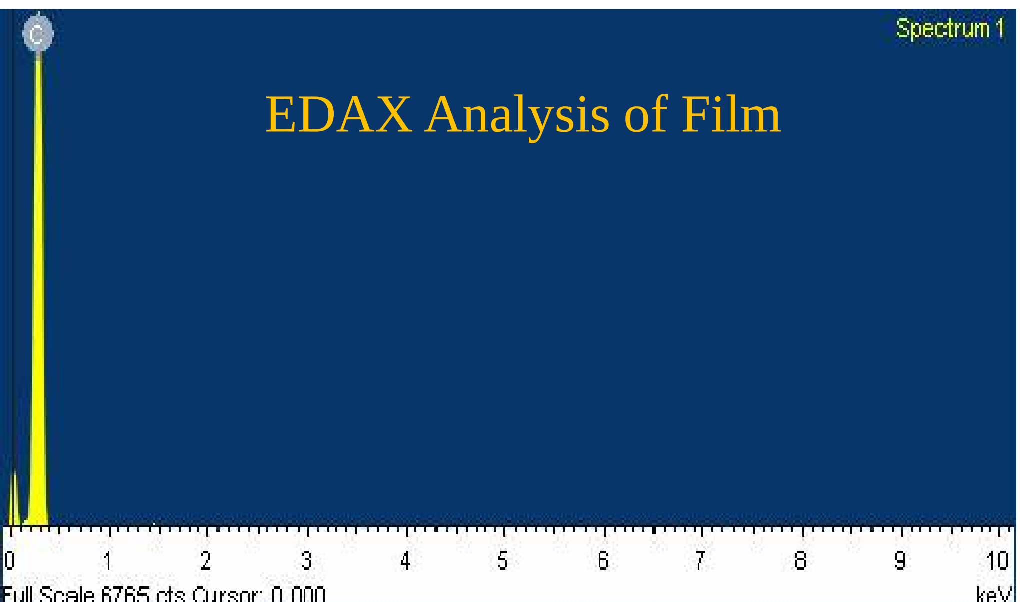
- X-Ray diffraction Shows the peaks of diamond (100), (220) and (321)

- Raman spectroscopy shows a sharp peak at 1332.4 cm^{-1} which confirms the formation of cubic form of diamond



- SEM Crossectional image shows the thickness of grown film = 10 µm

- EDAX analysis shows the elemental composition of the film only carbon is present in the film



Element	Weight%	Atomic%
C K	100.00	100.00
N K	0.00	0.00
O K	0.00	0.00
Si K	0.00	0.00
Totals	100.00	

Future Plan

- Diamond shows excellent properties only charge CCE is low (50%) for large size diamond (polycrystalline)

- Diamond will be the future material for colliders where luminosity is very high but still R&D is required

- Doing simulation by using diamond as Tof detector in Pandaroot

- We have grown polycrystalline diamond film on Si (100) up to thickness 10 μm

- We are also trying to grow single crystal diamond up to thickness 300 μm so that we can use it for detector applications

Thank You