DOSE ENHANCEMENT EFFECTS NEAR METAL INTERFACE IN SYNTHETIC DIAMOND X-RAY DOSIMETERS

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- ☐ METHODS & RESULTS
  - Monte Carlo simulation
  - Encapsulation design
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OBJECTIVE

Interface between High Z material (electrodes) and nearly tissue equivalent material (diamond) is important factor to consider in radiation detector design.

➡

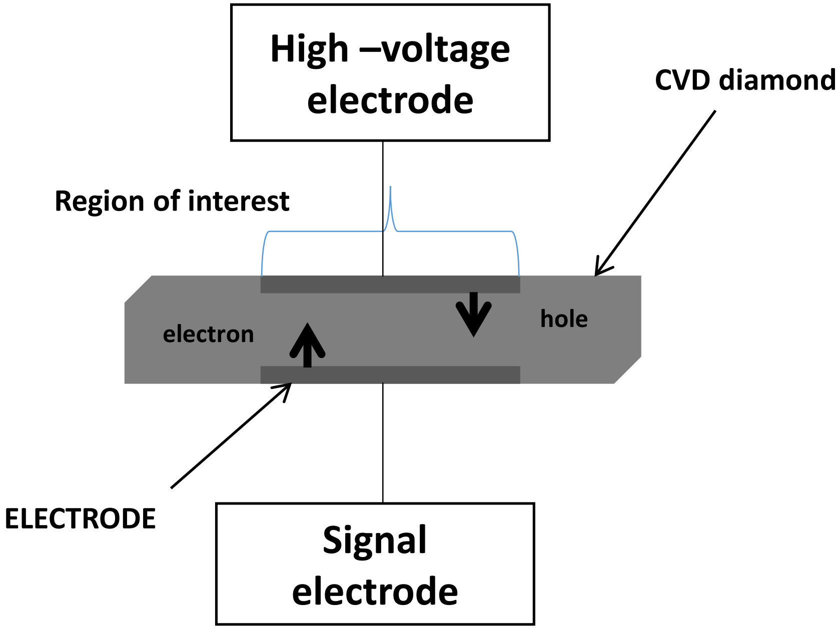
Studying dose enhancement effect near metal interfaces as a function of high atomic number (Z) within CVD diamond whether disturbing the environment with higher Z materials changes the charge collection behaviour of the device.

RADIATION DOSIMETERS

Ideal dosimeter properties must shows the following characteristics:

- **Accuracy and precision.**
- **Dose response.**
- **Dose rate dependence.**
- **Energy Response and tissue equivalence.**
- **Directional dependence.**
- **Convenience of use.**
- **Spatial resolution and physical size.**
- **Dynamic response and stability.**

PRINCIPLE OF OPERATION IN SOLID-STATE DOSIMETERS



- In principle, to create free electrons within a crystal, the carriers need to be given energy, equal to at least the band gap (E_g=5.5 eV), to move an electron from valence to the conduction band.

- **In case of solid–state dosimeters, the dependence of the photocurrent (I) on the dose rate (D) can be evaluated using Fowler's relationship:**

$$\boxed{I = I_{dark} + RD^{\Delta}}$$

***Where I_{dark} is the dark current, R is the sensitivity and the exponent Δ, sometimes referred to as the fitting coefficient or the linearity index is a constant describes the deviation from linearity.**

$$\boxed{I \propto D^{\Delta}}$$

WHY DIAMOND?

- **Radiation hardness.**
- **High mobility, thermal conductivity and potential resolution.**
- **Wide band gap (E_g = 5.5 eV).**
- **Low atomic number (Z=6).**
- **Direct read-out.**

Diamond is an attractive material for medical dosimetry

SYNTHETIC DIAMOND WITH OTHER SEMICONDUCTOR MATERIALS

	Si	Natural Diamond	CVD Diamond	Potential device application benefit
Bandgap (eV)	1.1	5.47	5.47	High temperature
Electron mobility	1450	200-2800	4500	
Hole mobility	480	1800-2100	3800	
Thermal conductivity	1.5	22	24	High power

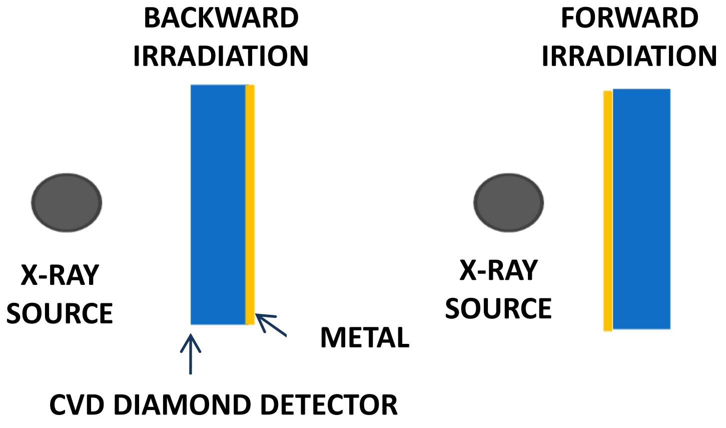
METHODS & RESULTS

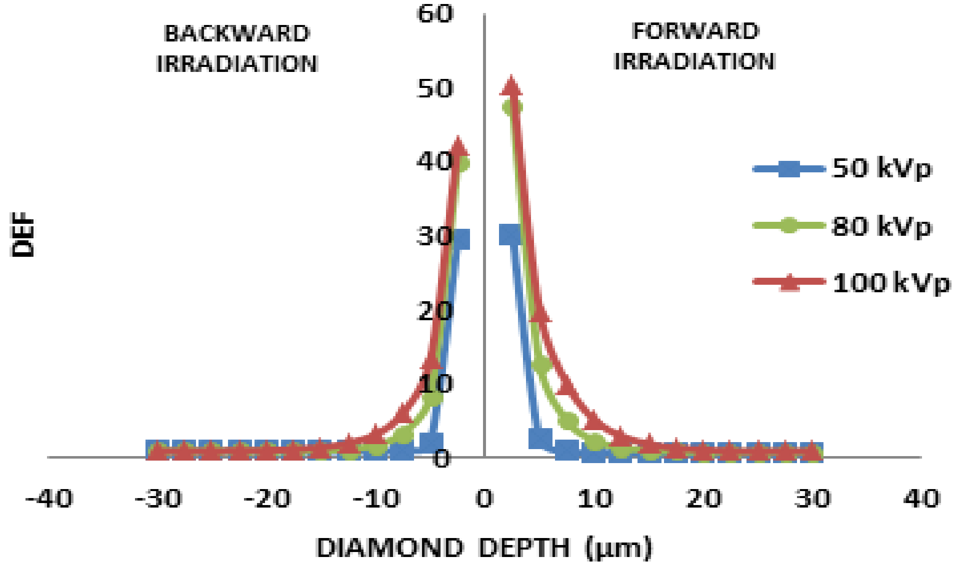
MONTE CARLO SIMULATION

MC simulations (BEAMnrc code) have been used to study the dose enhancement effect near metal interfaces as a function of high atomic number (Z). In order to compare with the experimental investigation.

MONTE CARLO SIMULATION

Simulation of thin (negligible X-ray intensity reduction due to absorption effects) Au layers on top of the detector on 1 side shows that the DEF is approximately symmetric for X-ray irradiating in either direction.

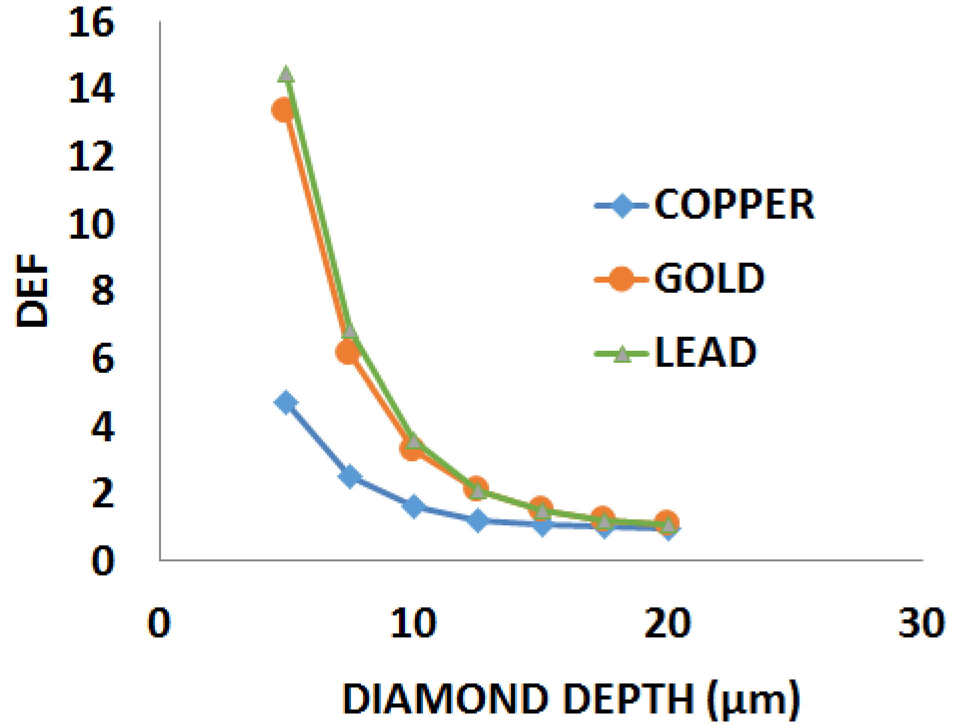




MONTE CARLO SIMULATION

Energy (kVp)	50	100
Metal type	DEF	DEF
COPPER (1 cm)	1.03 ± 0.6%	1.13 ± 0.9%
LEAD (1 cm)	1.33 ± 0.6%	1.50 ± 0.9%

$$\text{DEF} = \frac{\text{AVERAGE DOSE IN SENSITIVE REGION OF DEVICE}}{\text{EQUILIBRIUM DOSE}}$$

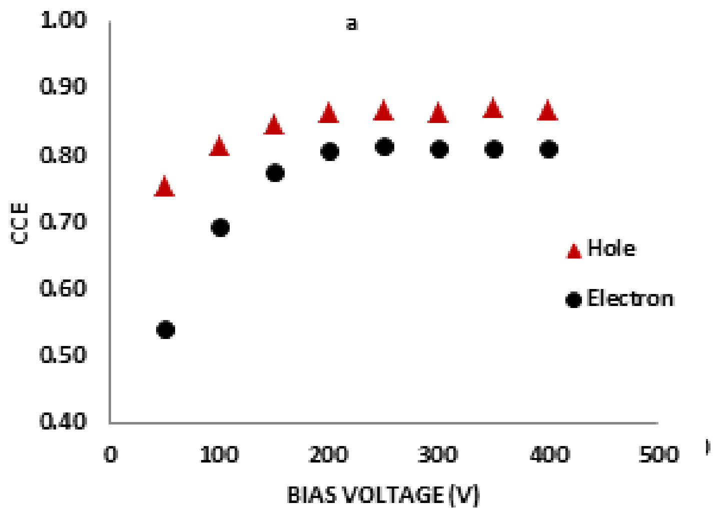


The sensitive region for photocurrent generation and the absorbed dose distribution at micrometre distances from the interface.

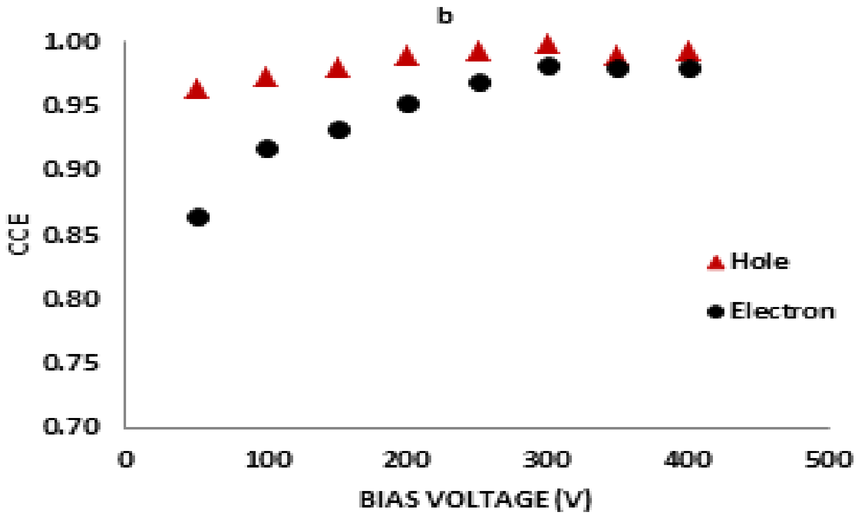
METAL-LESS ELECTRODE CVD DIAMOND

- Three types of metal-less CVD diamond have been used : SC (C) single crystal implanted with Carbon, SC (B) single crystal implanted with Boron and PC (B) polycrystalline implanted with Boron => Fabricated by Hussain Albarakaty [4].

❖Transport properties of holes are better than electrons for both SC detector.



SC (C)



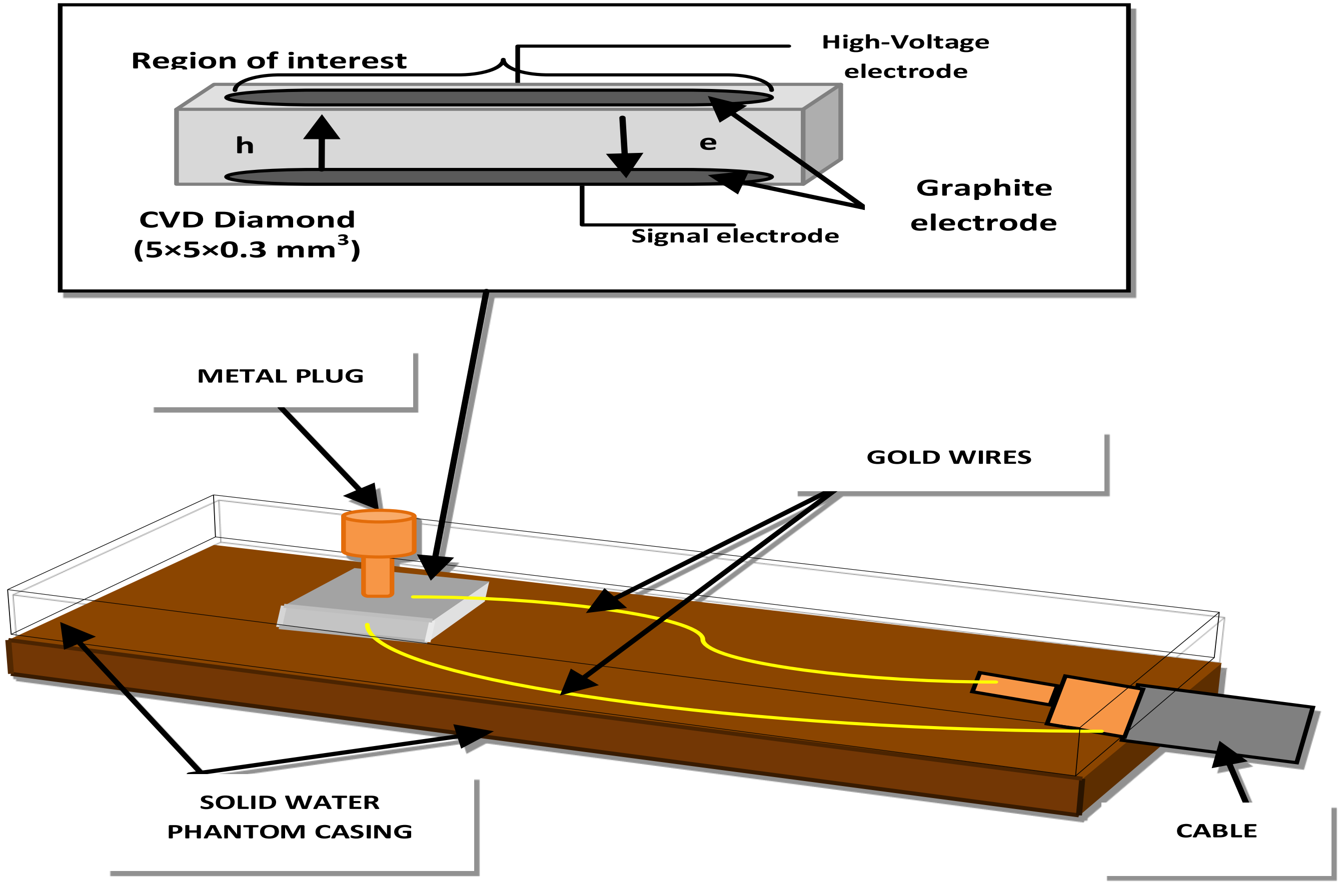
SC (B)

TISSUE-EQUIVALENT ENCAPSULATION DESIGN

The CVD diamond samples are used as radiation detectors are :

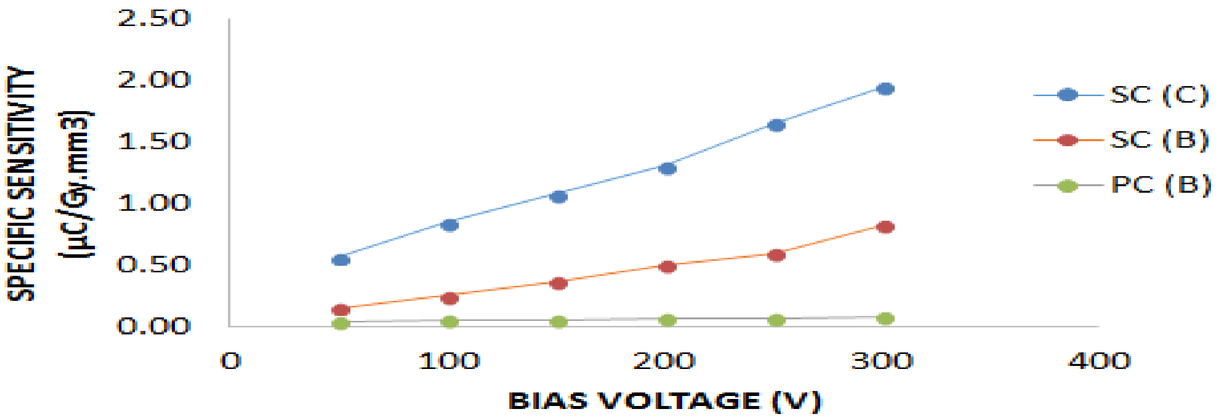
- **Contacted to electrodes using gold wires for readout.**
- **Mounting is inside a solid water phantom, in order to minimize fluence perturbations.**

- **A 3 mm diameter plug on the top half part of solid water phantom was created, to allow replacing the solid water plug with different high Z materials near the detector.**



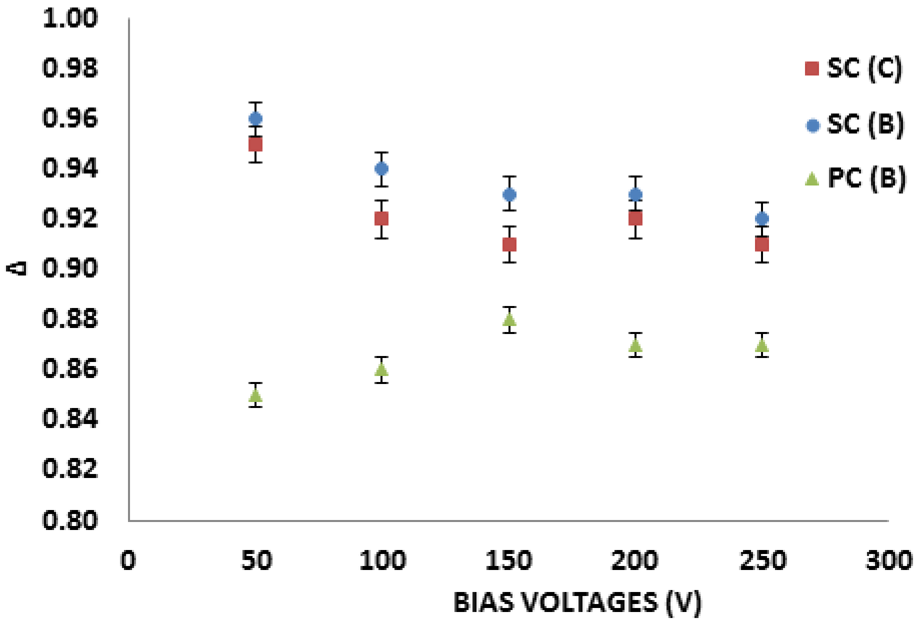
CHARACTERIZATION OF CVD DIAMOND DETECTORS

The sensitivity for the three samples has increased with the bias voltages and both SC detectors have show higher value than PC detector, this is because the CCE in SC detectors is much better than PC detector.

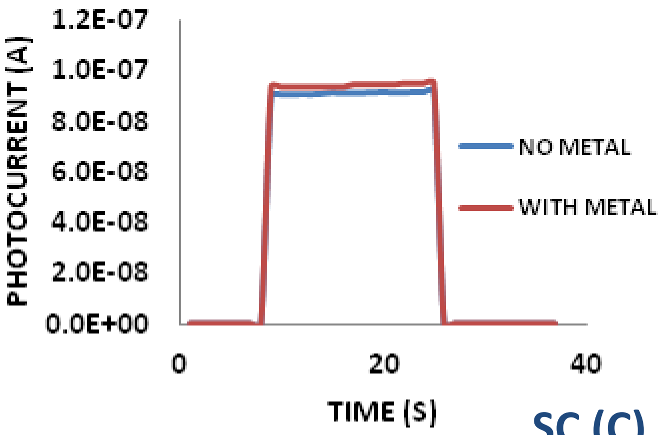


Δ factor used to measure homogeneity of traps within crystal structure.
(0.5< Δ< 1)

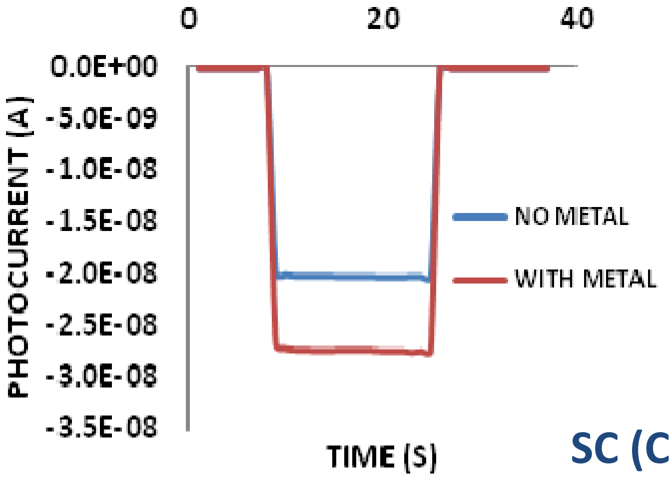
Δ in SC (C) between 0.95 and 0.91
Δ in SC (B) between 0.92 and 0.96
Δ in PC (C) between 0.84 and 0.88



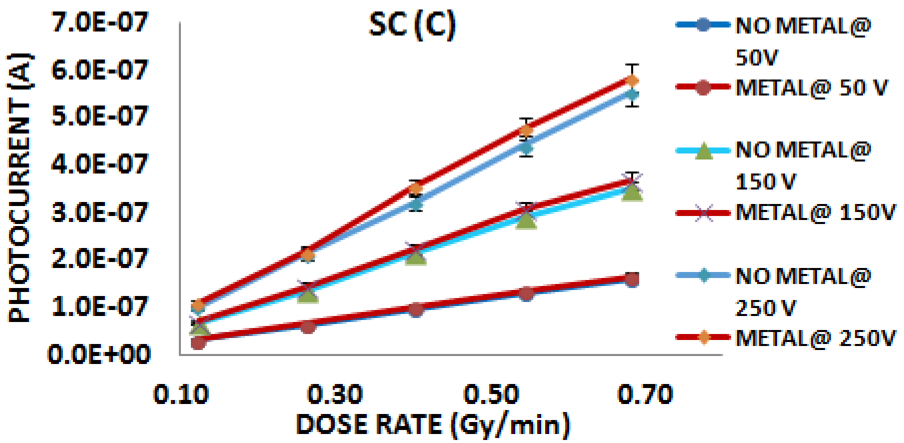
EFFECT OF METAL ON PULSE SHAPE AND DOSE RATE DEPENDENCE OF THE CVD DIAMOND

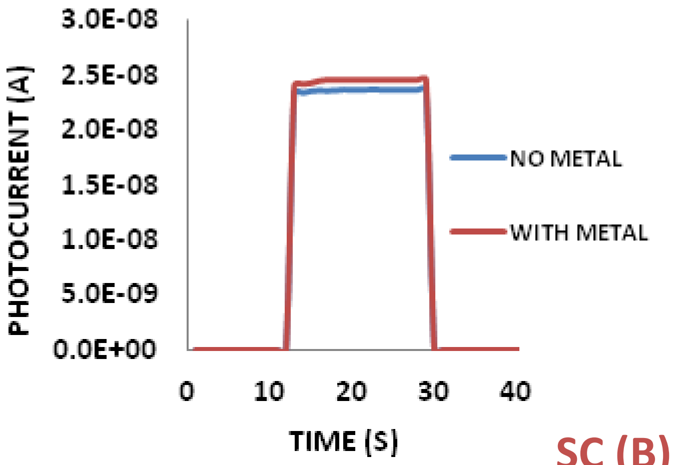


SC (C)

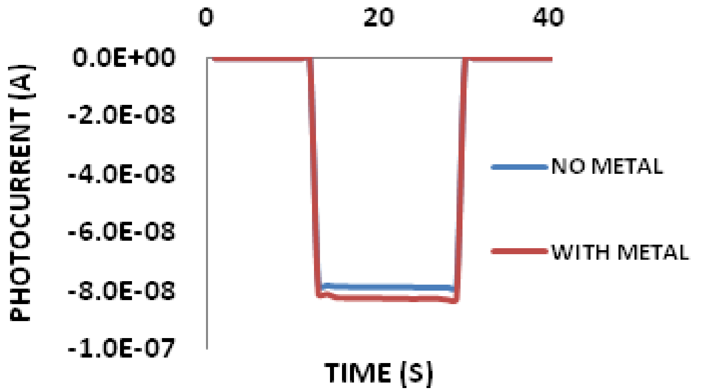


SC (C)





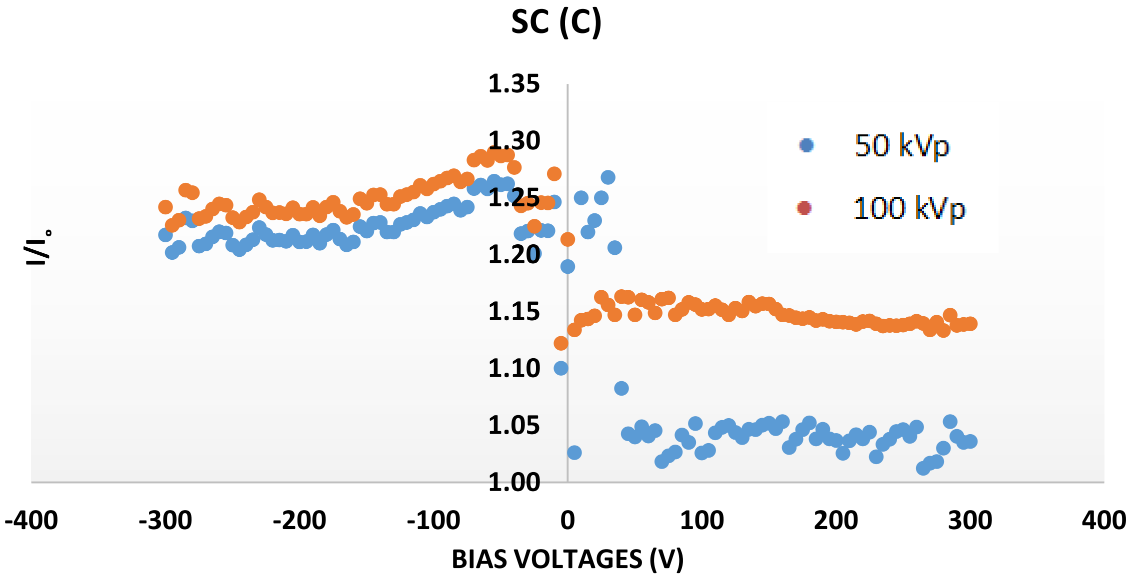
SC (B)

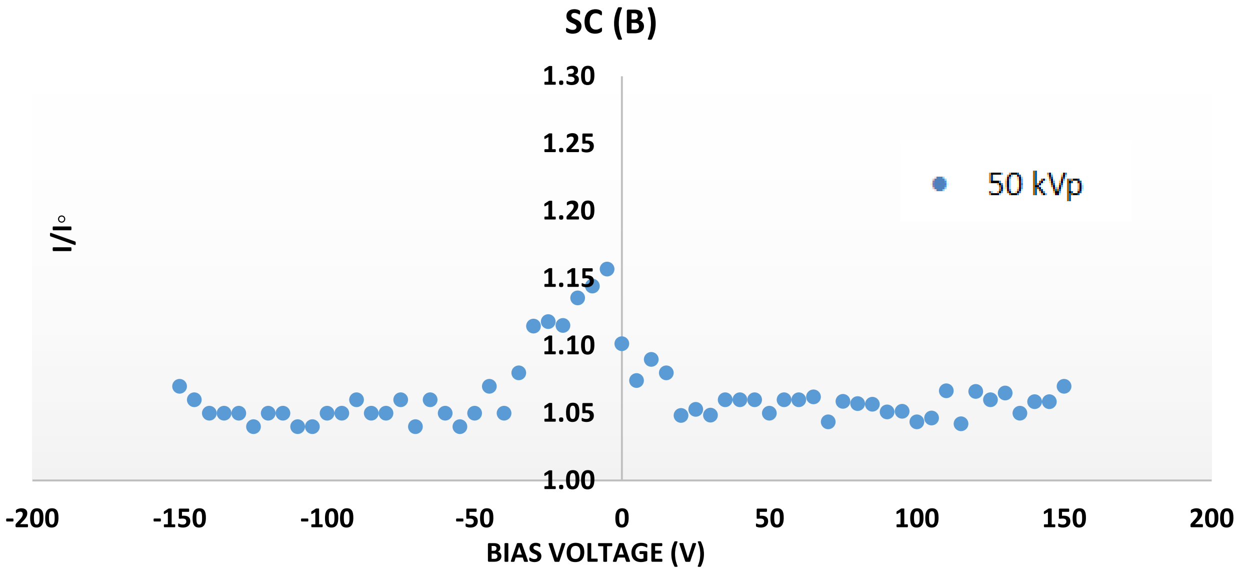


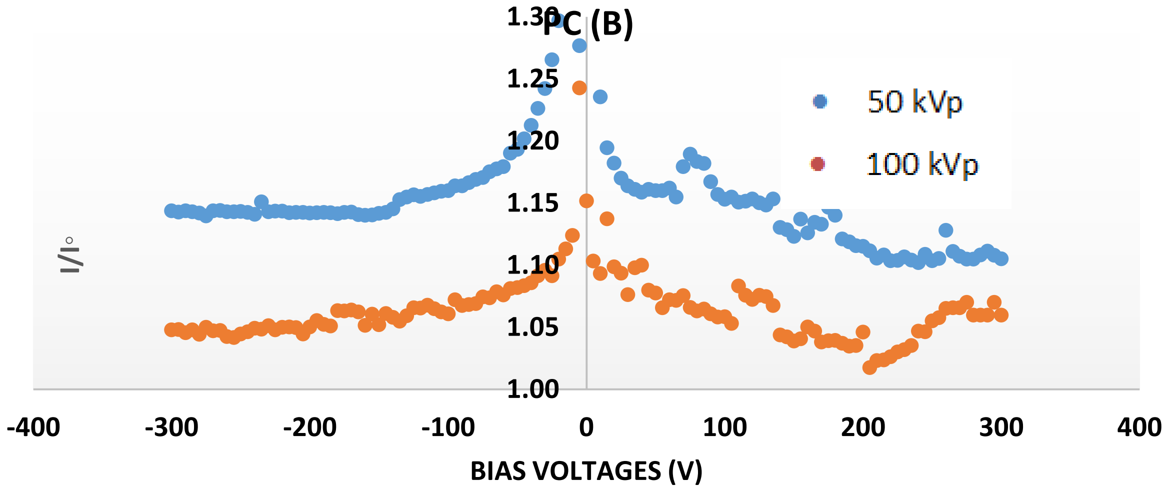
SC (B)

Pulse shape for two signal crystals with/without metal front the SC(C) & SC (B) detectors, at 50 kV$_P$, 68 cGy/min dose rate and ±50 V bias voltage.

MEASURING THE RATIO OF PHOTOCURRENT WITH/WITHOUT METAL







Energy (kVp)	50	100
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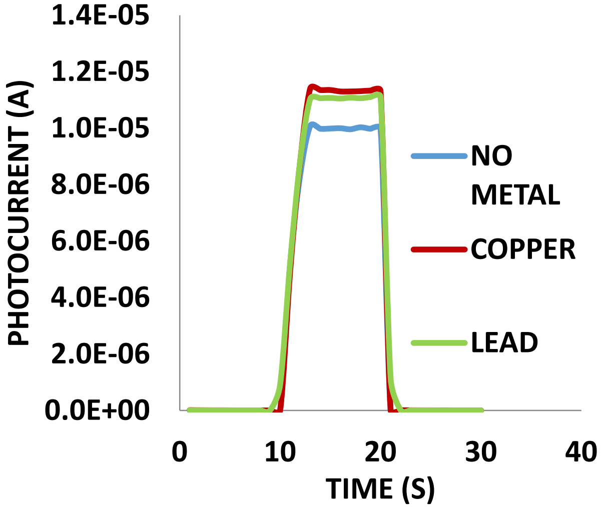
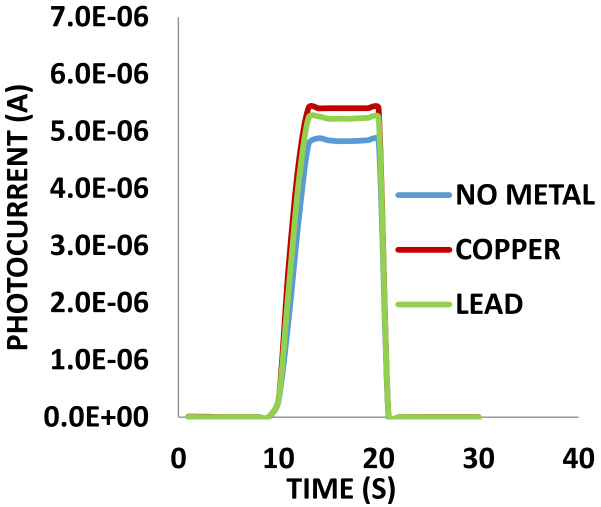
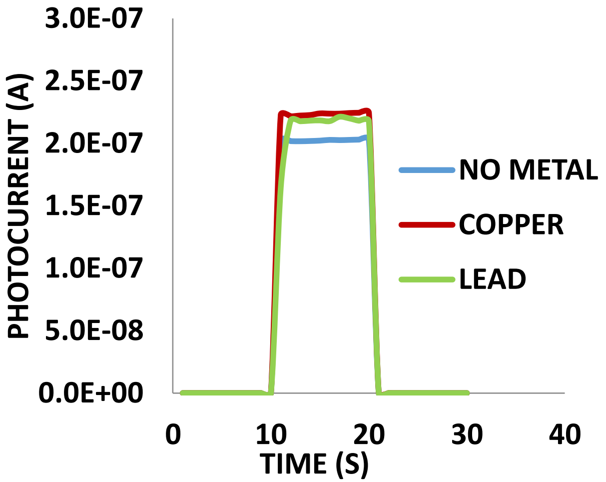
RESPONSE OF DETECTORS WITH DIFFERENT METALS


SC (C) @ 150V


SC (B) @ 150V


PC (B)@ 150 V

Using metals as Lead or Gold enhance the photocurrent response but do not match the expected value from Monte Carlo simulations

SUMMARY

- **Tissue-equivalent design to encapsulate the detectors in order to minimize fluence perturbations.**

- **From MC simulation study, strong enhancement in the absorbed dose in the diamond occurs near the surface of the CVD diamond device and decreases as the distance to the metal/diamond interface increases. (sensitive region from both side of the detectors≈ at few micrometre distances from the interface).**

- **Experimentally , from the backward irradiation, the fluence of the backscattering electron increases with photon energy => lead to increase the photocurrent response of the detector.**

- **CVD diamond with Boron ion implantation shows a symmetric photocurrent ratio measurement by applying positive and negative bias voltages comparing to the diamond with Carbon ion implantation.**

FUTURE WORK

- Understating the behaviour of the photocurrent response of the CVD diamond (fabricate different sizes of region of interest) near different higher Z metals (higher than copper).
- Focusing on the behaviour of the photocurrent response near high Z metals at low bias voltages (less than 50 V).
- Experimentally, studying the effect of photocurrent response by adding metals (different thicknesses in range of nm or µm) on the top of the detector.
- Testing and comparing between metal-less synthetic diamond and the available natural PTW diamond dosimeters for the development of a tissue equivalent dosimeters .

REFERENCES

[1] Wort, C.J.H. and R.S. Balmer, *Diamond as an electronic material.* Materials Today, 2008. 11(1–2): p. 22-28.

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[3] Górka, B., et al., *Influence of electrodes on the photon energy deposition in CVD-diamond dosimeters studied with the Monte Carlo code PENELOPE.* Physics in Medicine and Biology, 2006. 51(15): p. 3607-3623.

[4] Albarakaty, H., *Fabrication and Characterization of Graphite Electrodes for Diamond X-ray Dosimeters*, 2011, University of Surrey, UK.

[5] Long, D.M., Dose Enhancement Effect in Semiconductor Devices. Science Applications, Inc, 1982, IEEE.

Thank you !

Questions?