Fabrication and Characterization of Graphite Electrodes for Diamond X-ray Dosemeters

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Most of the results are extracted from the PhD thesis of Dr Hussain Al-Barakaty (10/2011)

Talk outline

- Motivation
- Device Fabrication
- IV and charge transport characterization
    - I-V characteristics
    - Alpha Spectroscopy
    - Pulsed X-ray characterization
- X-ray dosimetric characterization
- Ongoing work
- Conclusions

Motivation

Radiotherapy dosimetry requires radiation detectors with the following characteristics:

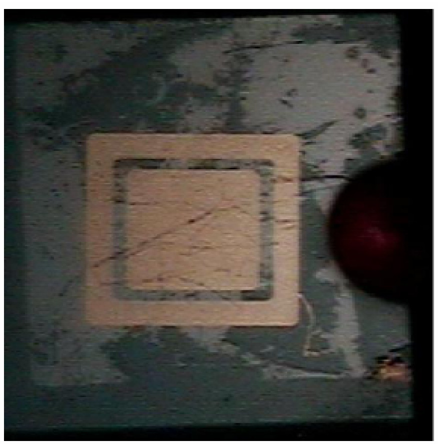
- Radiation hardness
- Tissue equivalence
- Small volume

Graphite contacts fabricated by ion implantation have several advantages over conventional metallic contacts:

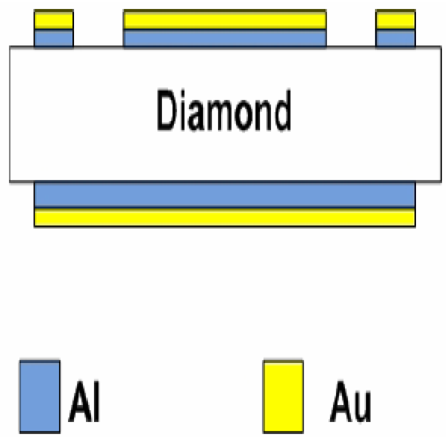
- It maintains the tissue equivalence of the detector
- Very good adhesion and stability
- Potential in use of heavy ion detection due to its low atomic number

Device Fabrication

sample	type	top contact	back contact
PC Al	polycrystalline	Al\ Au	Al\ Au
SC Al	single crystal	Al\ Au	Ti\ Ni\ Au
PC G	polycrystalline	graphite	graphite
SC G(B)	single crystal	graphite(B implantation)	graphite
SC G(C)	single crystal	graphite (C implantation)	graphite



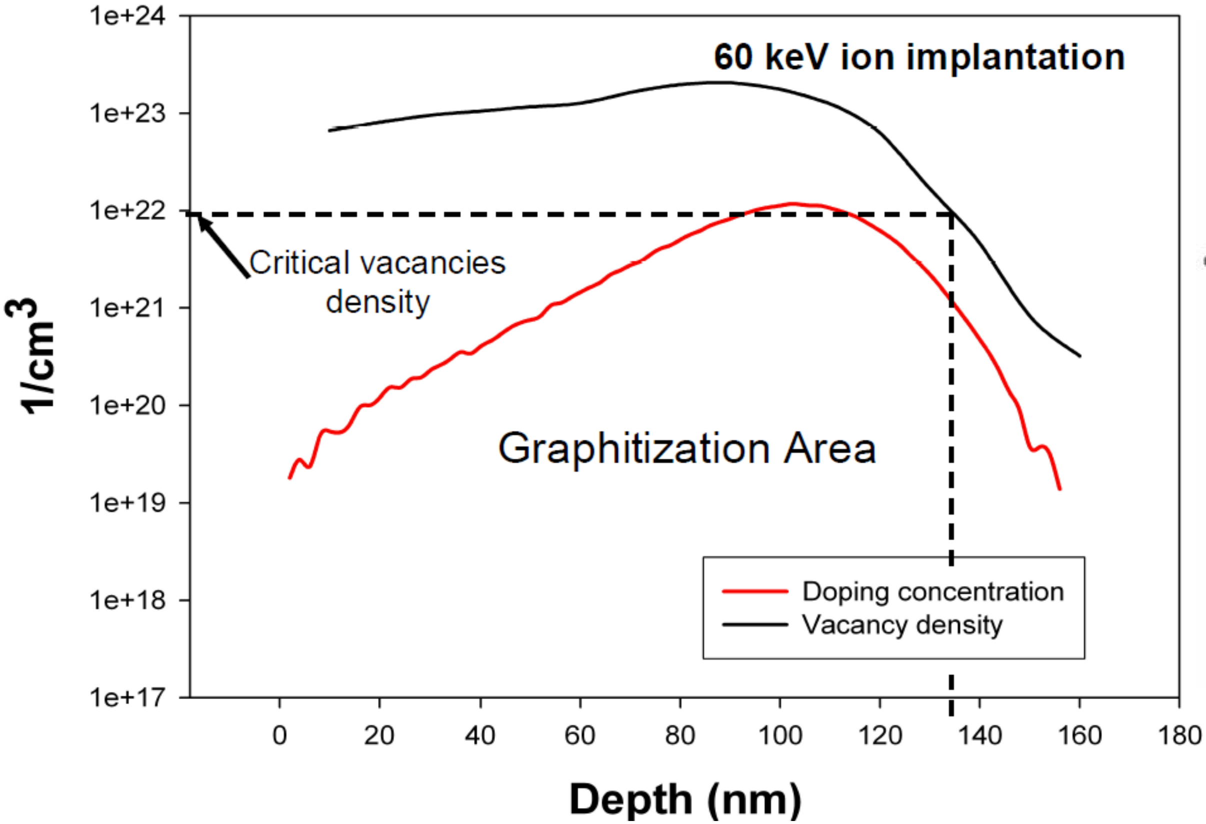
(a)

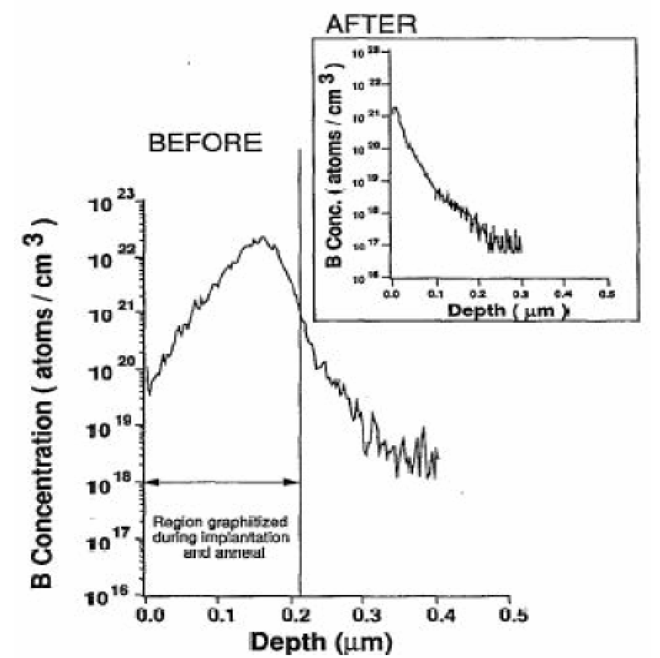


(b)

Samples are electronic grade from ElementSix Ltd with very low impurities. (N < 50 and 5 ppb in pc/sc diamonds respectively; B < 1 ppb in both types.

Metal-free contacts by ion implantation

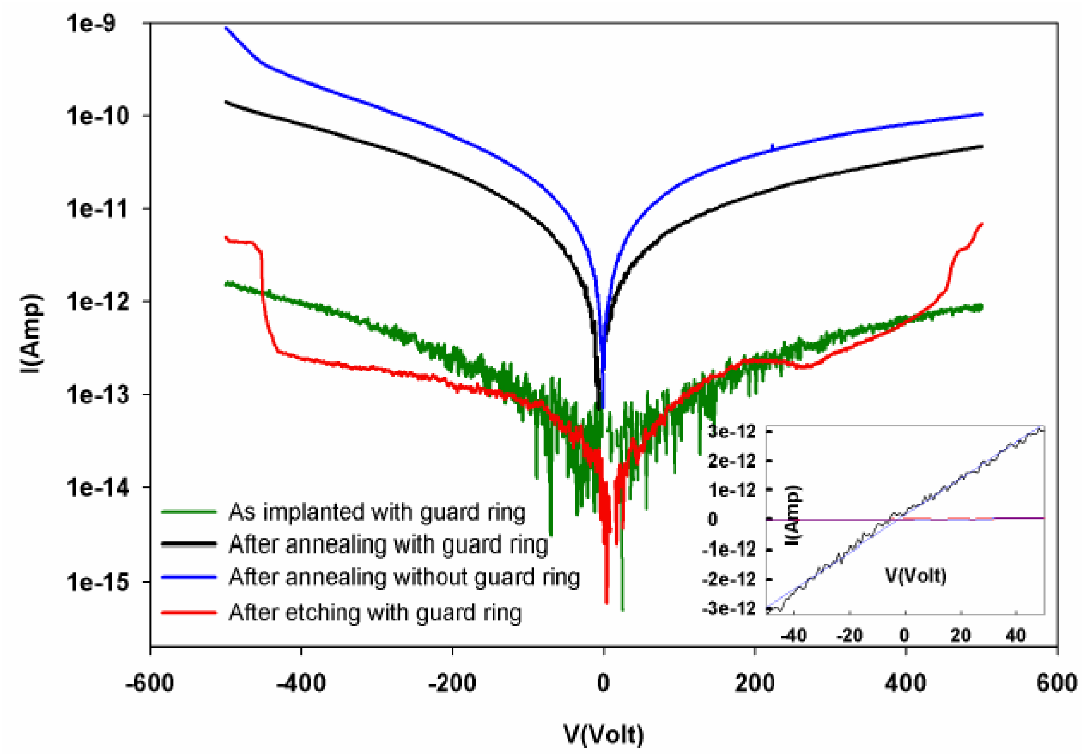




V. Venkatesan, DM Malta, K. Das, and AM Belu. Evaluation of ohmic contacts formed by B implantation and Ti-Au metallization on diamond. *Journal of Applied Physics*, 74:1179, 1993.

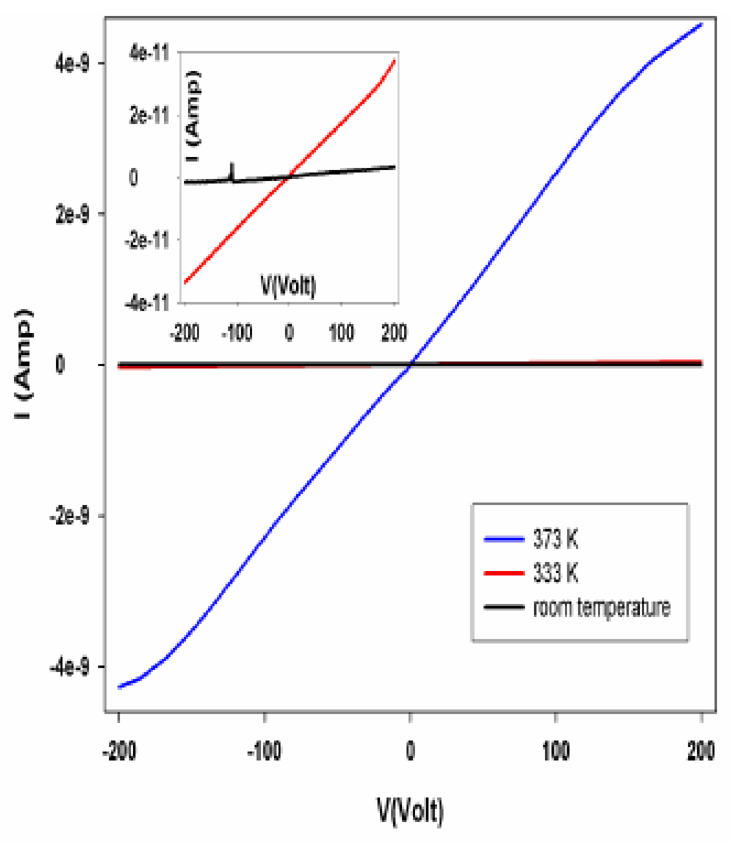
- 60 keV B ions; dose of $5.0 \cdot 10^{16}$ cm^{-2}; A_t = 700 ^{0}C, 5 minutes
- 100 keV C ions; dose of $1.0 \cdot 10^{16}$ cm^{-2}; A_t = 1000 ^{0}C, 5 minutes

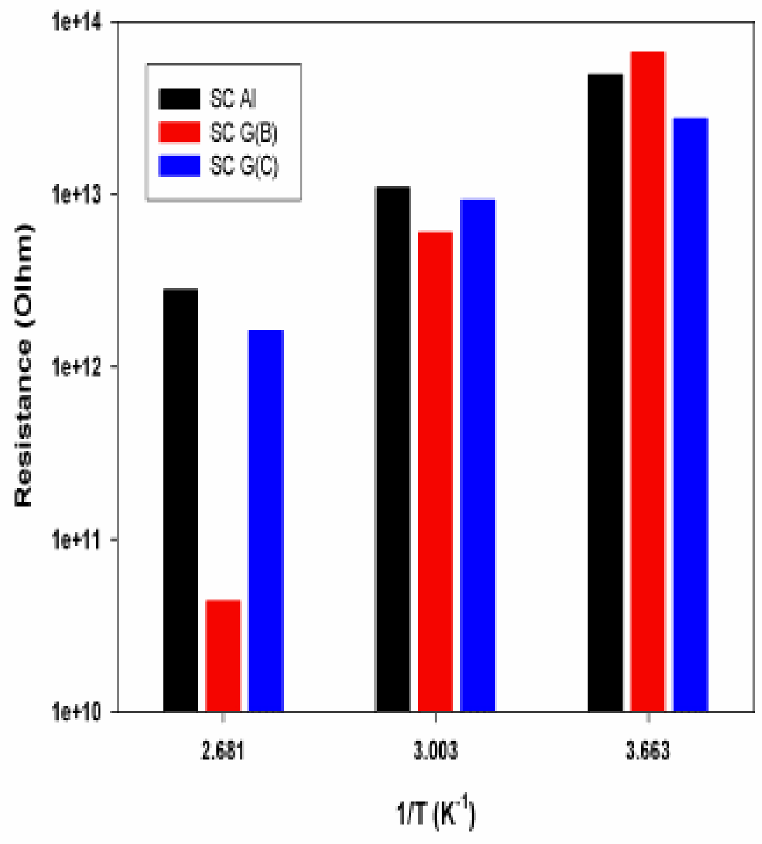
I-V characteristics - PC G(B)



- Before annealing, the measurements were noisy especially at low current.
- After annealing, the leakage current increases but became more stable (the device shows ohmic behavior in the range of -50 to 50 V with R ~ $1.6 \cdot 10^{13}$).
- Guard ring reduces the leakage current by eliminating the surface current.
- Chemical etching increases the resistances.

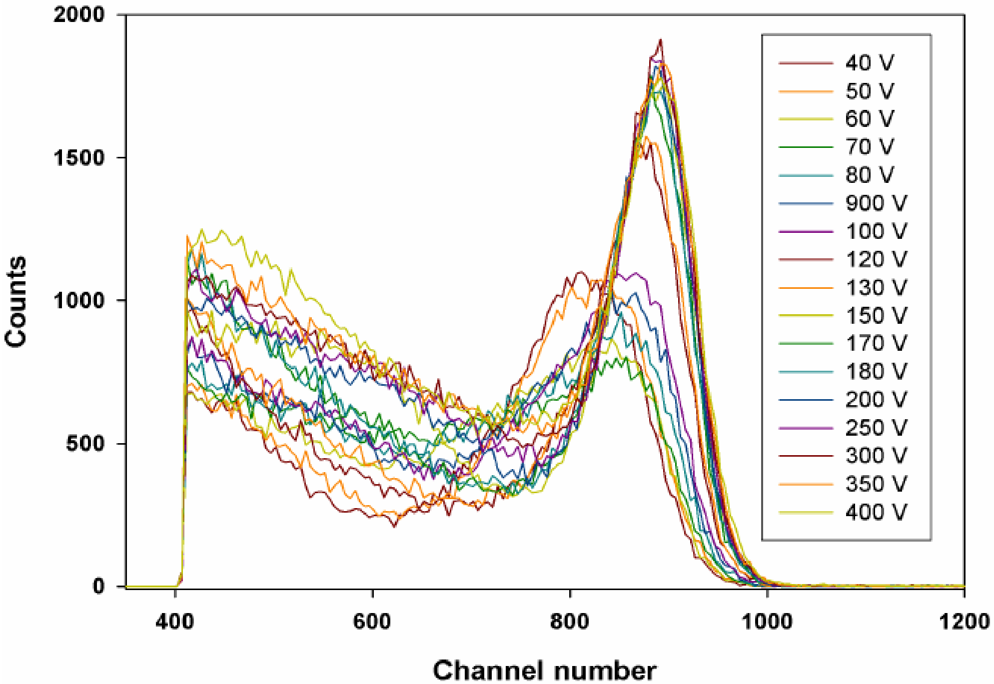
I-V Characteristics - SC



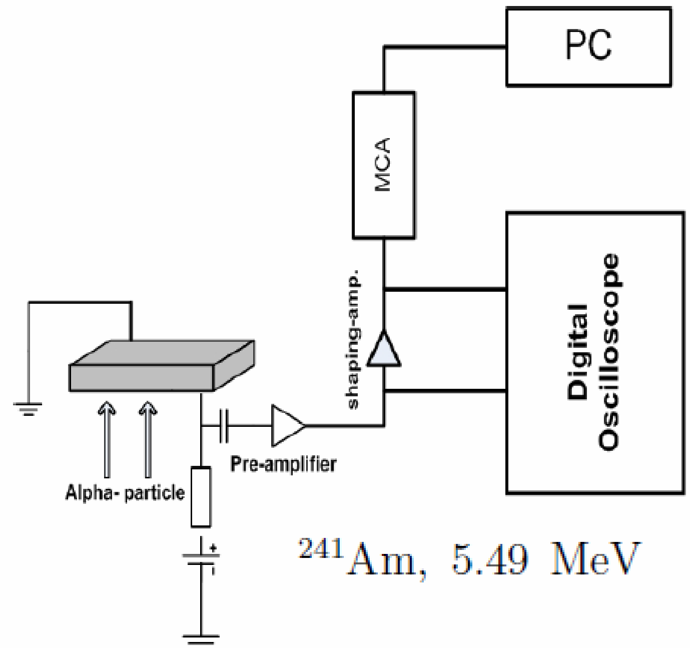


SC G(B) sample resistance decreases faster than the other two devices at higher temperatures. This is believed to be due to the activation of boron impurities at higher temperatures.

Alpha Spectroscopy



^{241}Am alpha particles spectroscopy of the SC G(C) sample.

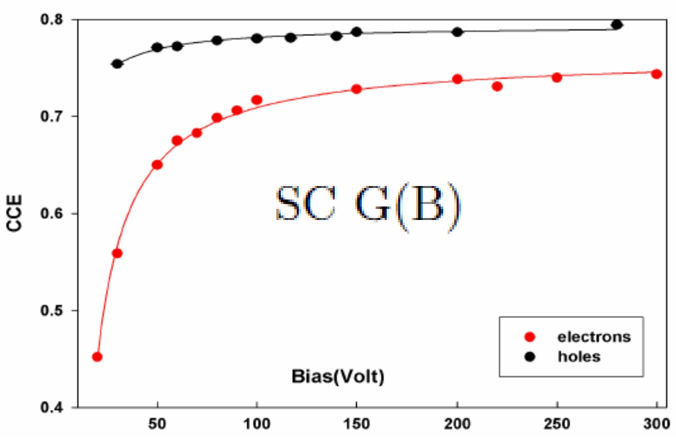


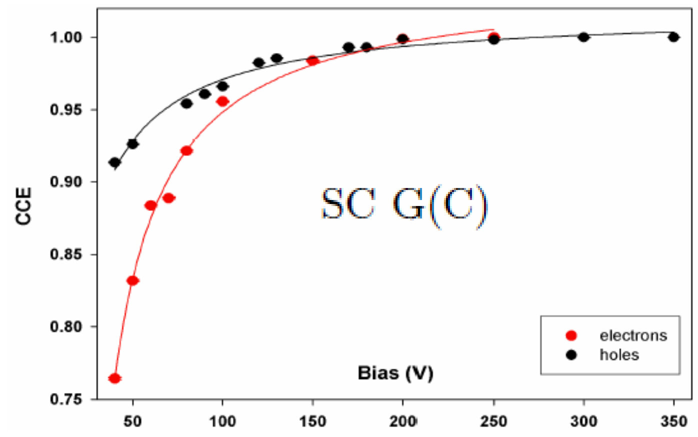
^{241}Am, 5.49 MeV

Alpha particle spectroscopy system

- The centroid and the FWHM of the peaks were determined by Gaussian distribution regression.
- FWHM was limited mainly by the alpha source which has low resolution due to its sealing.
- The FWHM decreases with increasing the bias, which indicates that the charge collection length saturated.

The Hecht equation: (μτ) product





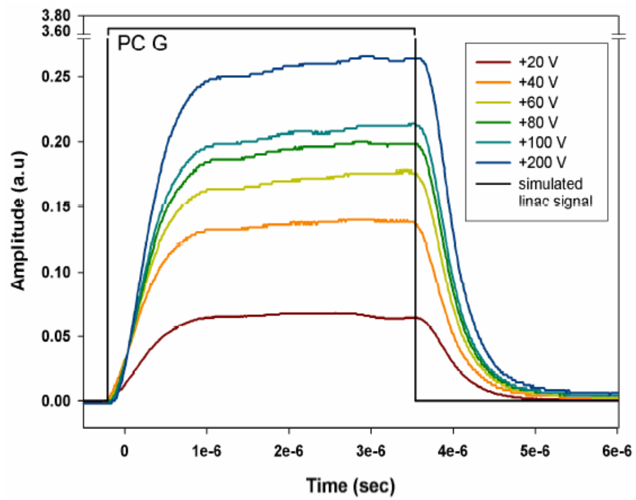
$$CCE_{e,h} = \left(\frac{1}{1+S_{e,h}d/\mu_{e,h}(V-P)}\right)\frac{\mu\tau_{e,h}(V-P)}{d^2}\left[1-exp\left(\frac{-d^2}{\mu\tau_{e,h}(V-P)}\right)\right]$$

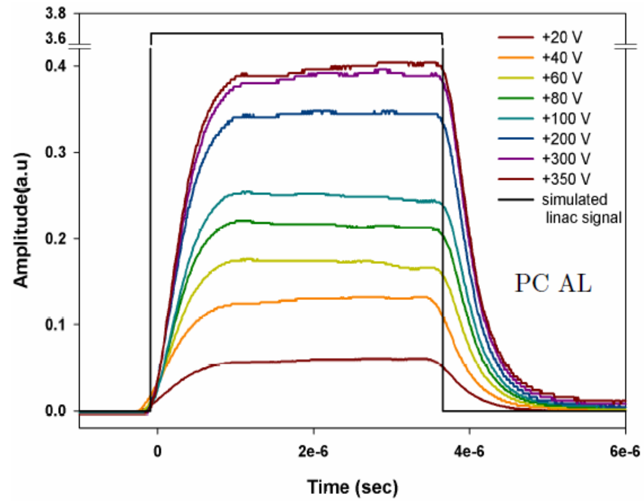
Assumptions:

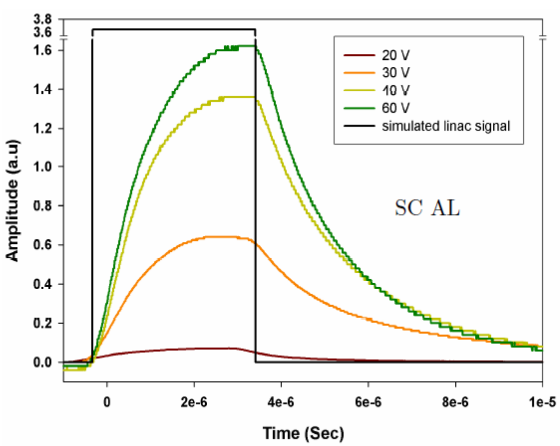
- Single charge carrier sensing
- Limited (constant) lifetime
- Constant electric field } Constant carrier velocity
- Constant mobility } Constant carrier velocity
- No re-emission of trapped charges during the observation time

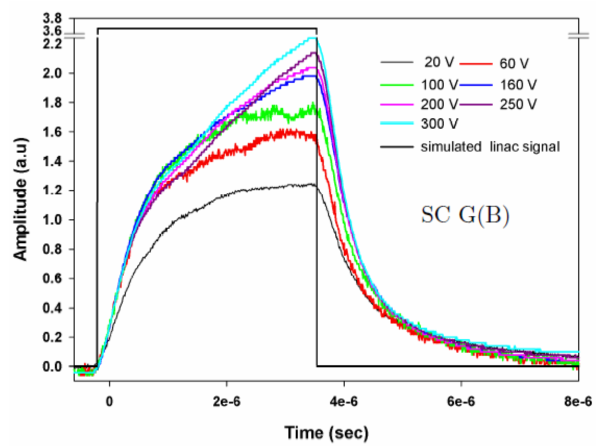
	SC G(C)
$\mu\tau_e(cm^2/V)$	$(1.2 \pm 0.1) \times 10^{-4}$
$\mu\tau_h(cm^2/V)$	$(1.9 \pm 0.1) \times 10^{-4}$
$P_e(V)$	18.2 ± 2.7
$P_h(V)$	$(2.7 \pm 0.3) \times 10^{-14}$

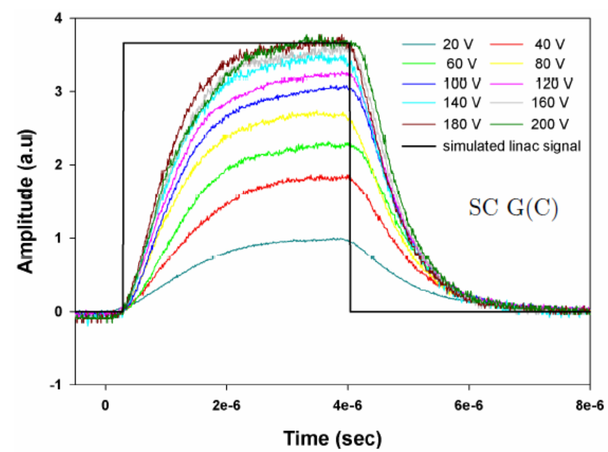
Pulsed X-ray Characterization





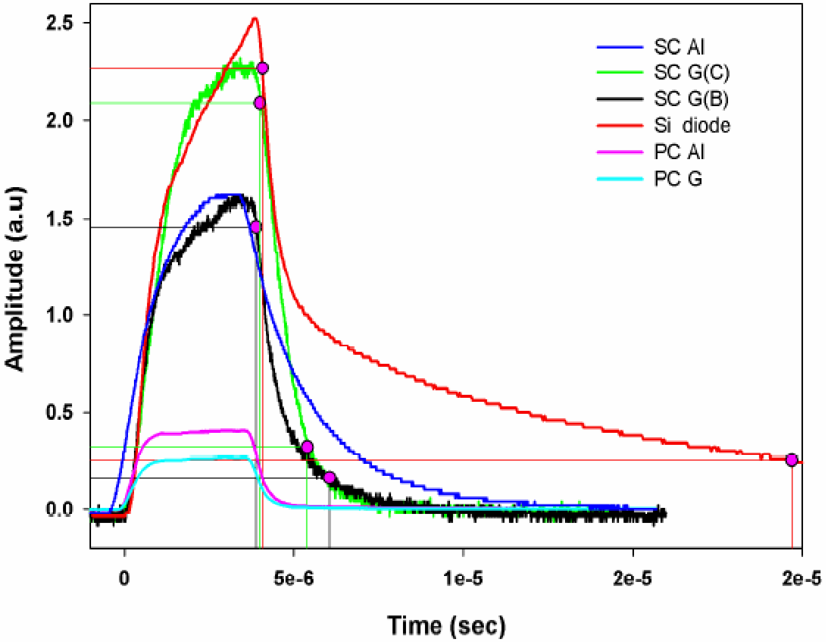


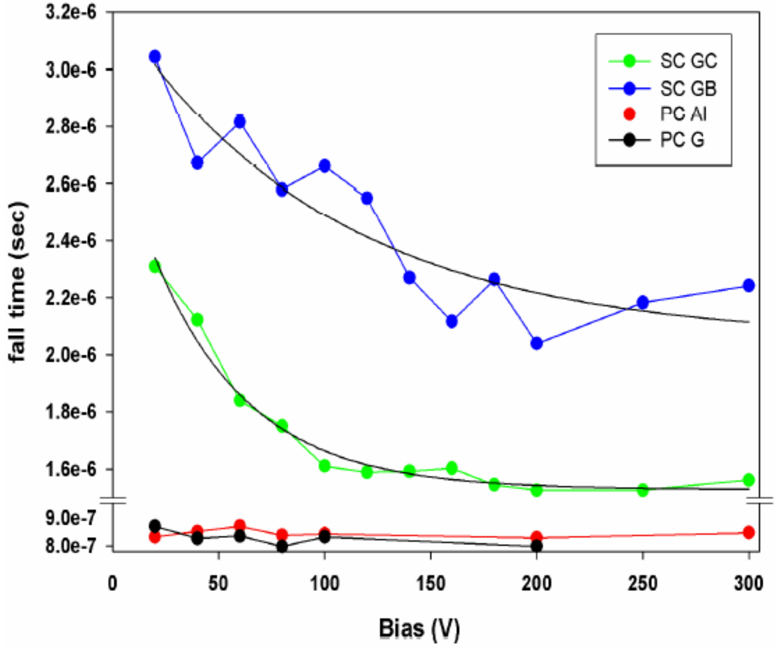




- Signal acquired by the PC samples are almost independent of the contact type.
- SC samples pulse shape is dependent on the contact type in terms of signal shape and collected charge.

Pulsed X-ray Characterization - Fall Time





• SC Al sample has the highest fall time of around 5 μs (is related to the diamond metal interface?).

•The SC G(C) and has a shorter fall time than the SC G(B) which can attributed to a lower trap level density in the SC G(C) sample.

•The PC samples have very short fall time compared to the other samples (multiple detrapping).

• the fall time decreases exponentially with the applied bias in the SC G(C) and the SC G(B) samples (field assisted detrapping phenomenon).

Pulsed X-ray Characterization - Charge

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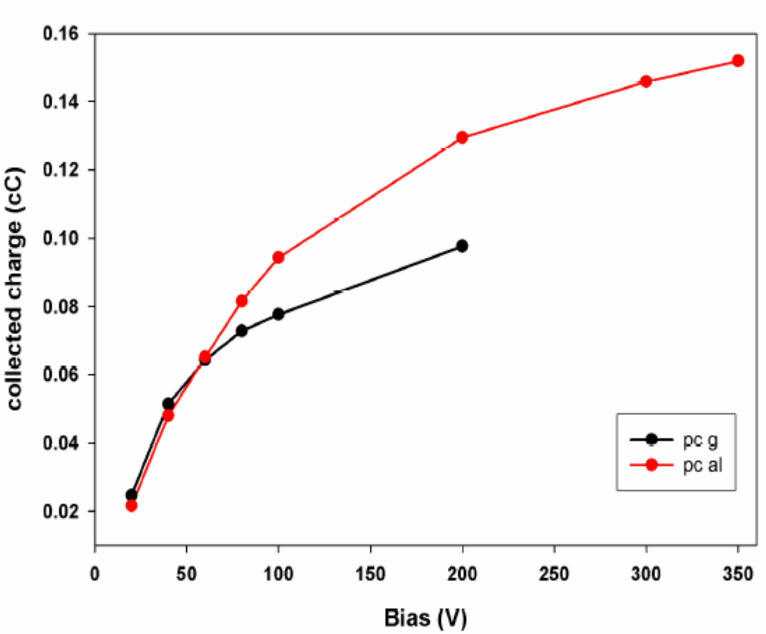

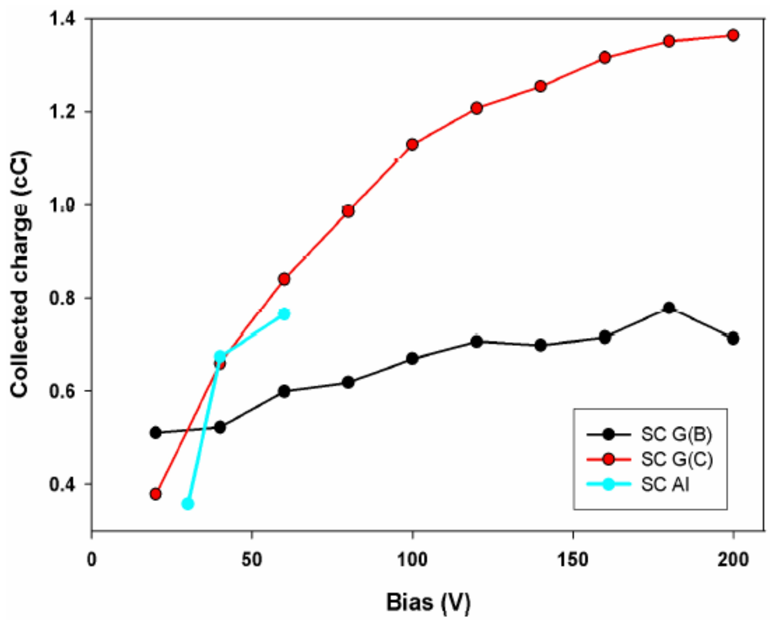

- For V < 100, the collected charge is the same in the two PC samples.
- For V > 100, the PC Al sample became more responsive than the PC G sample (it is due trapping of charge carriers in deep trap levels in grains and grain boundaries.
- For V > 10, the SC G(B) sample responsivity is only about 50 % of SC G(C). Thermal detrapping from shallow level seems to have signicant effect on the signal shape in this sample.
- The SC Al sample has responsivity comparable to the SC G(C) but become unstable at bias higher than 60 V.

X-ray Dosimetric Characterization

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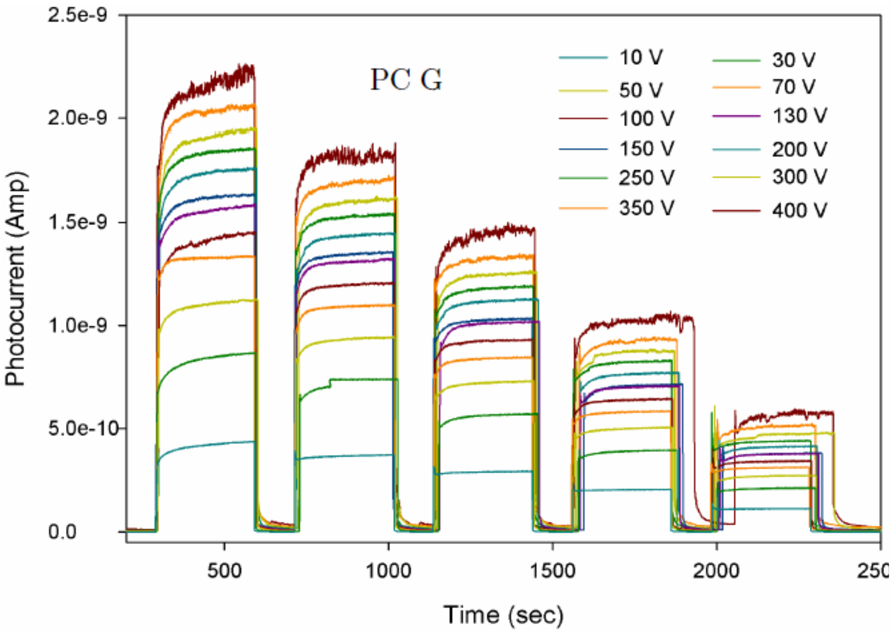
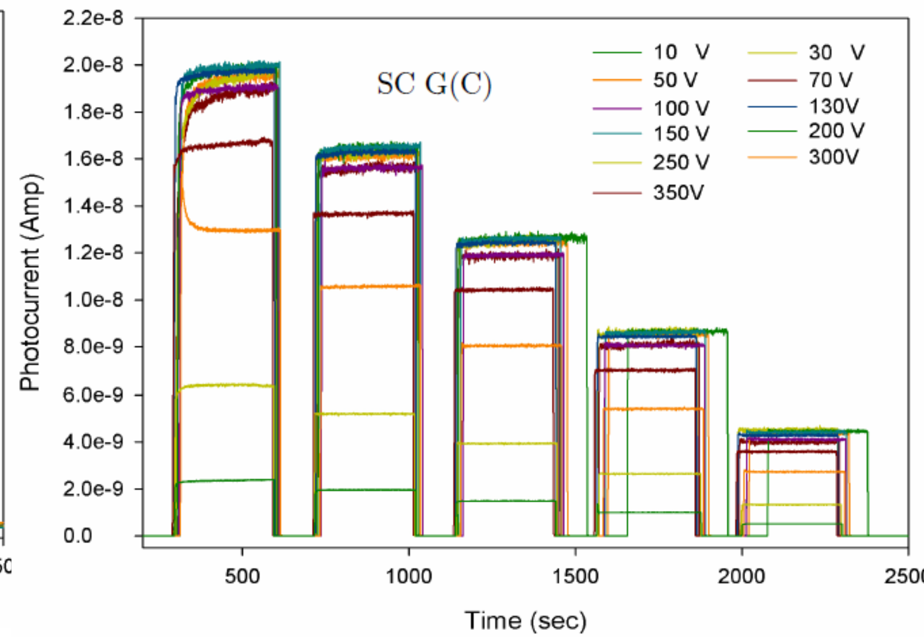
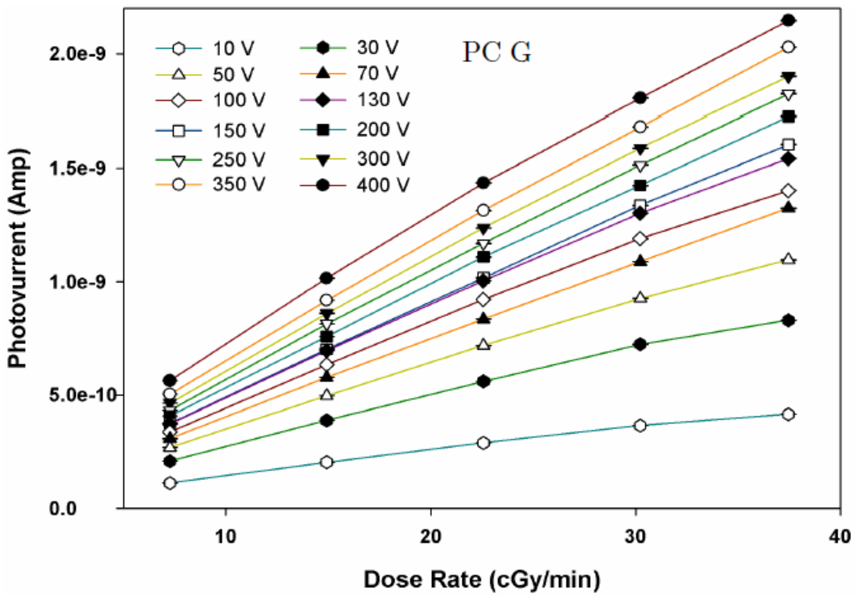
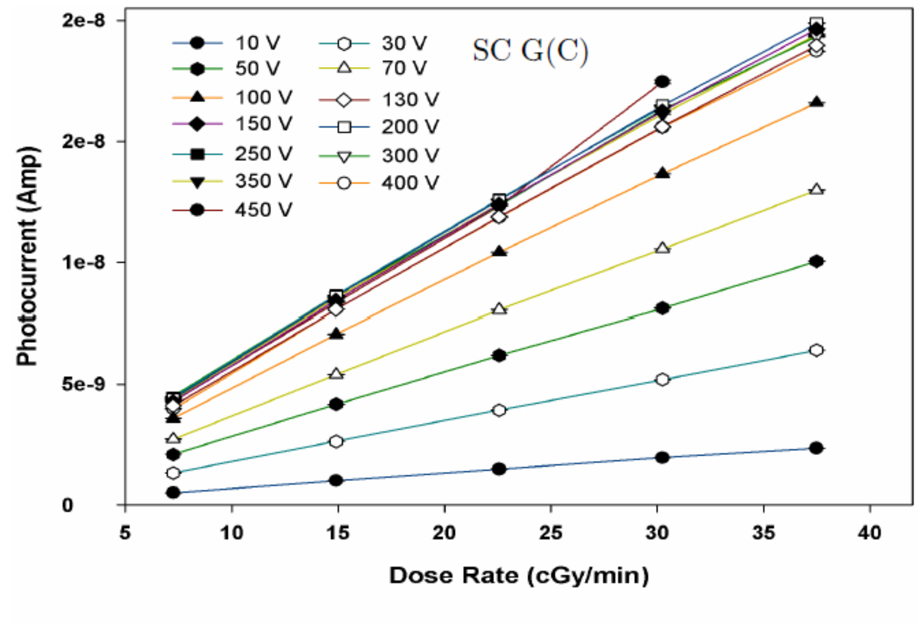




- Dose rate was controlled by changing the X-ray tube current (from 1000 to 200 µA in step of 200 µA).
- The photocurrent is stable for all samples at low bias but at higher voltages only samples with graphite were stable.
- Slower rise time for graphite contacts (B, C) of ~ 40s.

X-ray Dosimetric Characterization

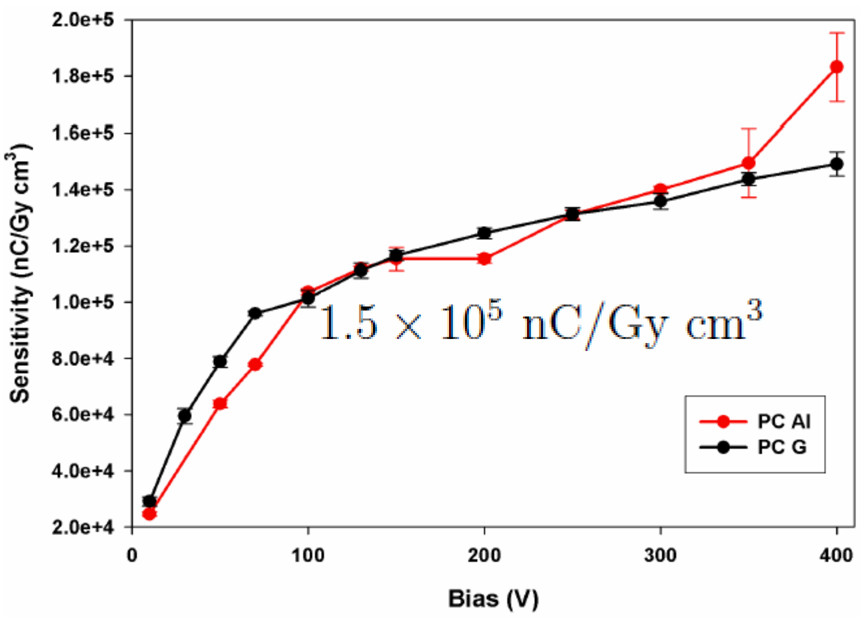


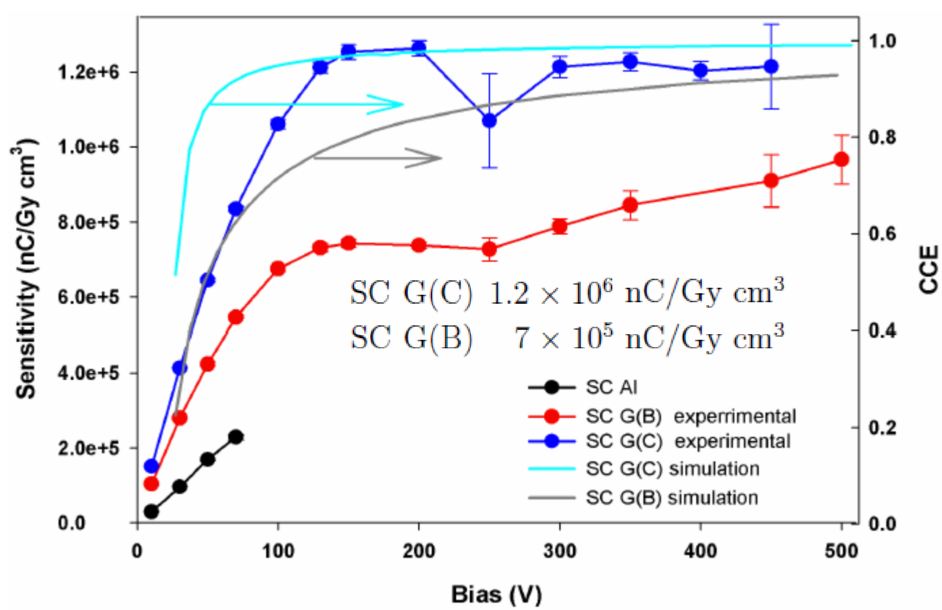


$$I = I_0 + cD^{\Delta}$$

- Δ between 0.92 and 0.95 for *SC G*; Δ between 0.8 and 0.9 for *PC G*.
- Samples with *Al* contacts have Δ between 0.55 and 0.65.

X-ray Dosimetric Characterization



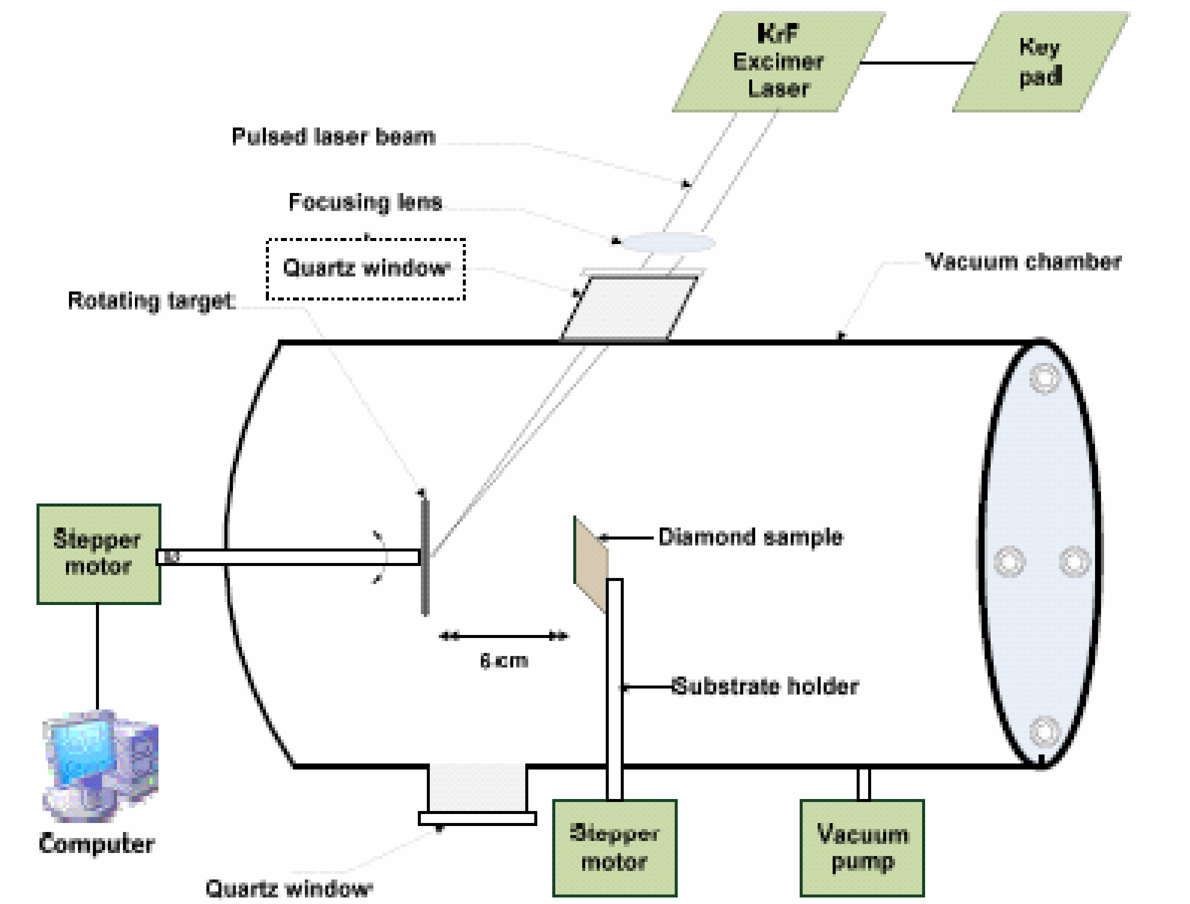


- The sensitivity of the PC samples is not affected by the contact type.
- The sensitivity of the SC samples does depend on the contact type.
- Respect SC Al contact, graphite contacts have the advantage of stability at high voltage operation.

Alternative: amorphous carbon deposited by Pulsed Laser Deposition (PLD)

Optimise deposition parameters (pulse energy, atmosphere) with respect to

- adhesion
- electrical performance
- mechanical performance



In collaboration with the Carbon Electronics Centre (NEC) in the Advanced Technology Institute (ATI)

X-ray imaging with 19/20 keV microbeam (synchrotron)

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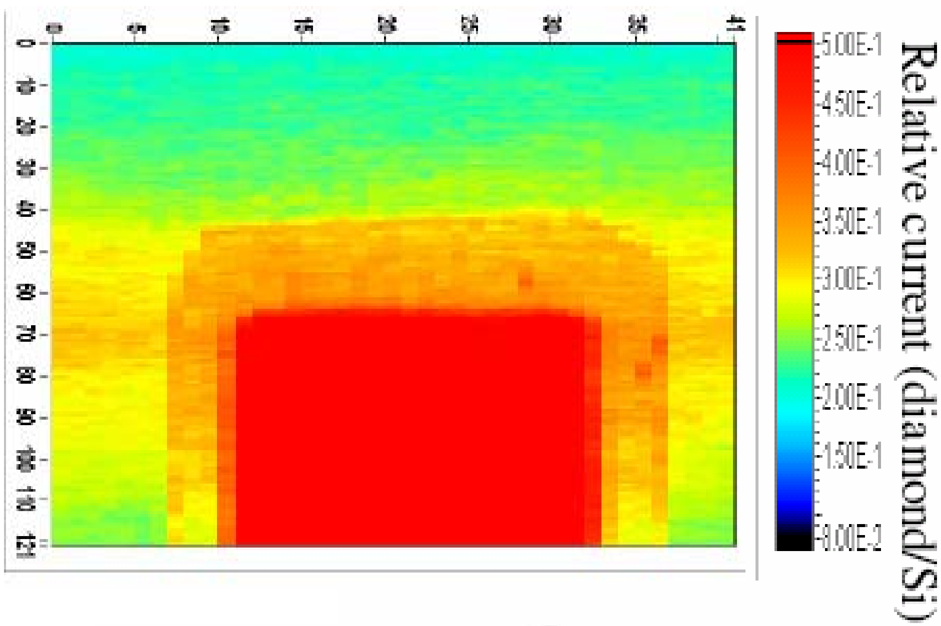

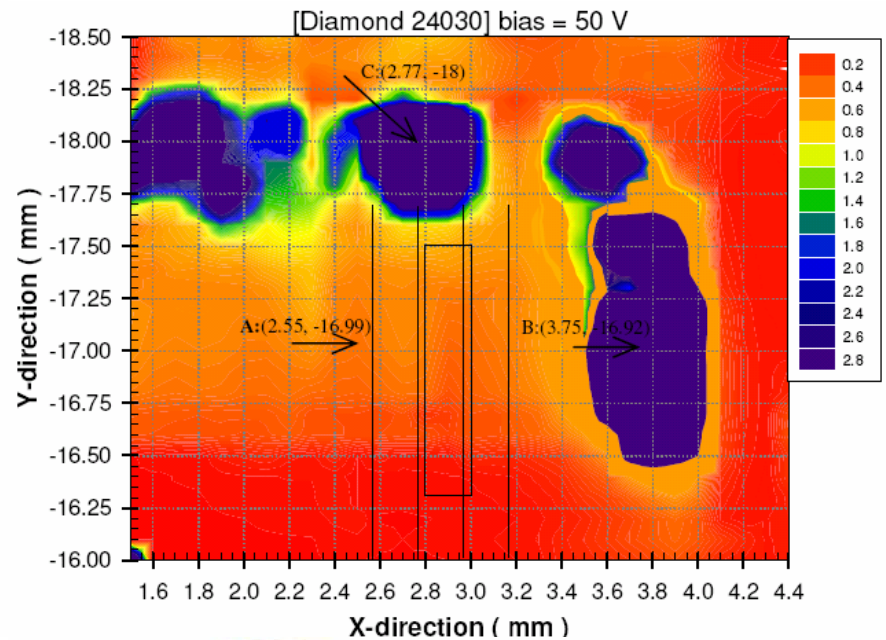

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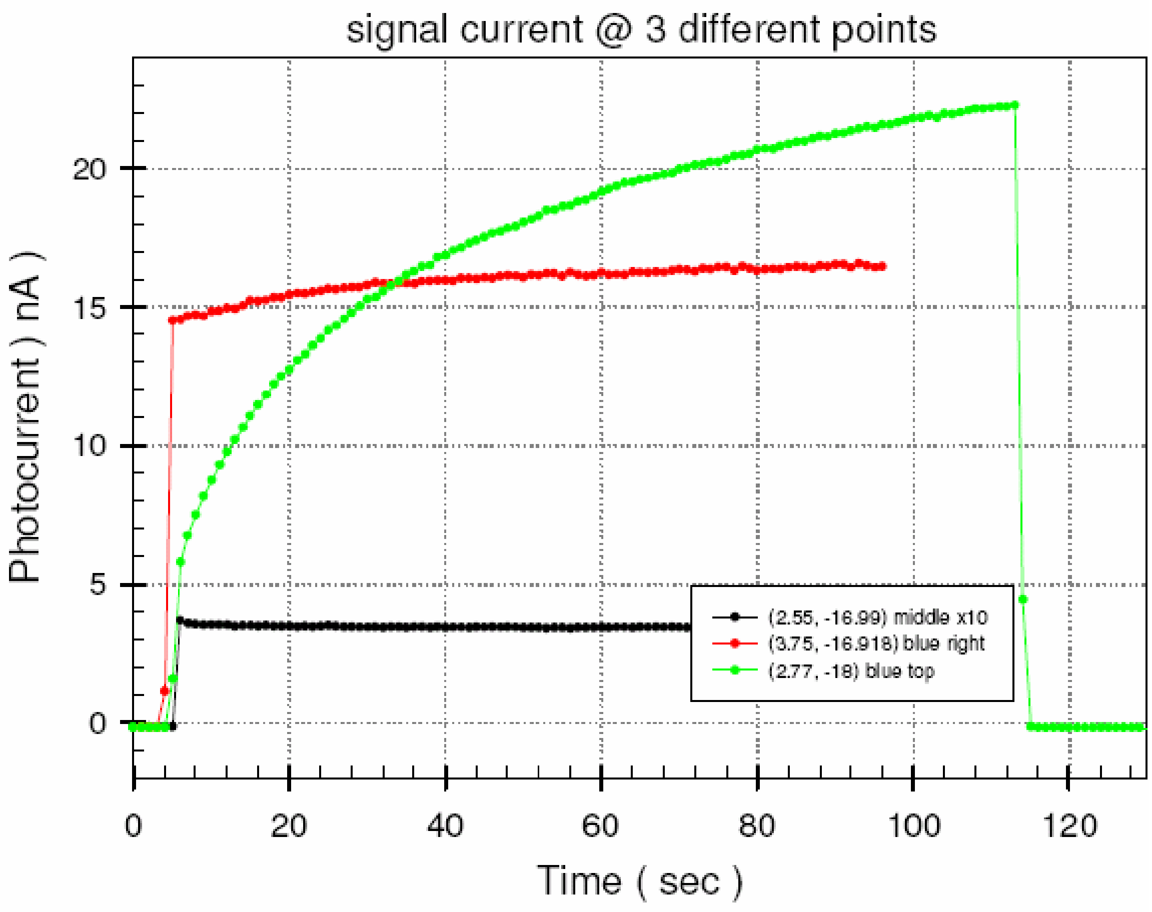
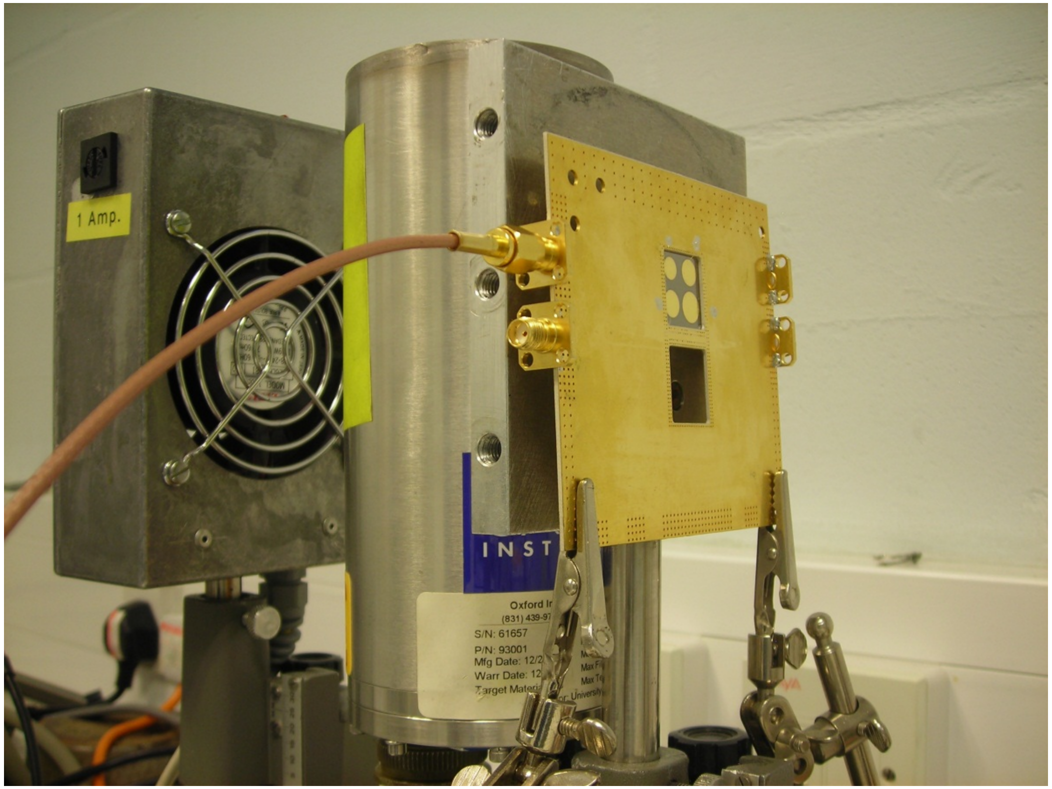
diamond

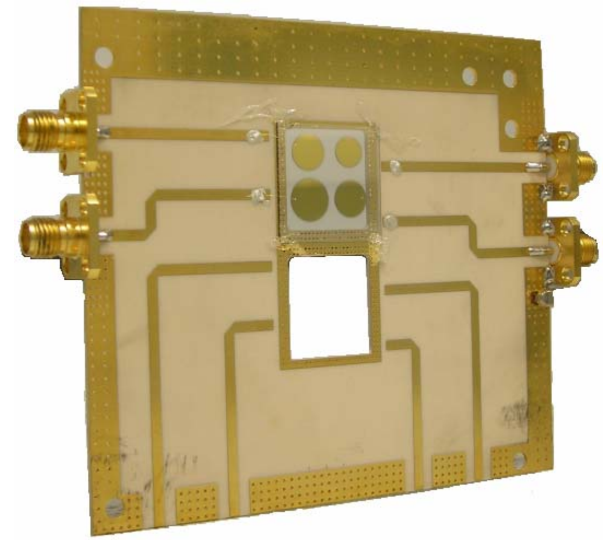
Diamond Light Source

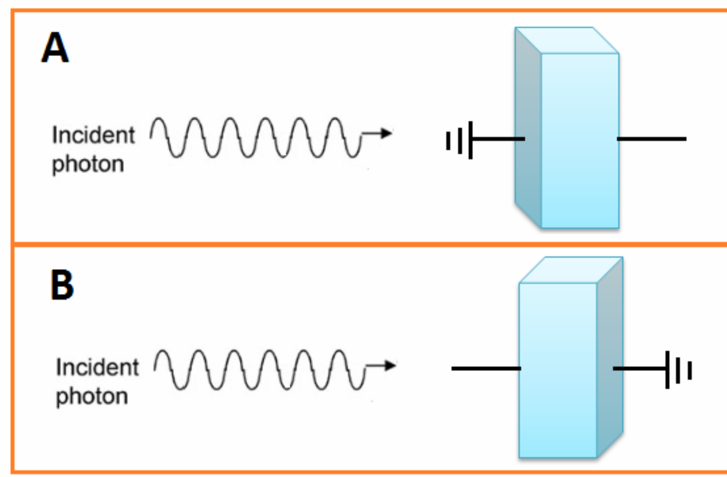
Influence of mounting on response time response/instability ?



New measurements…



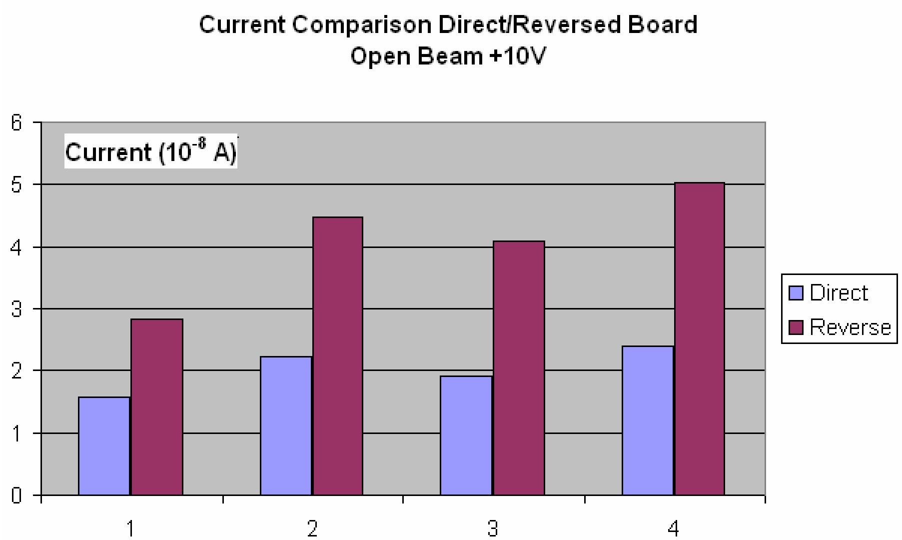


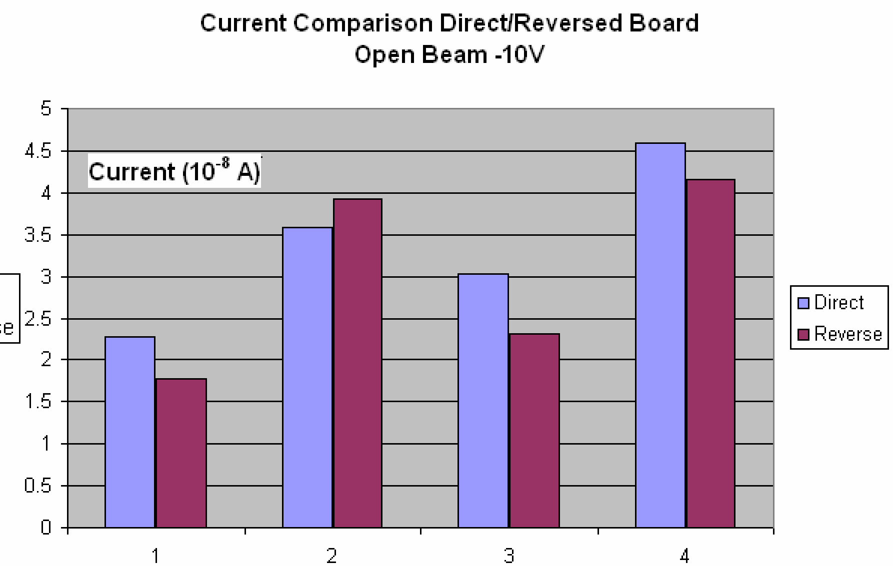


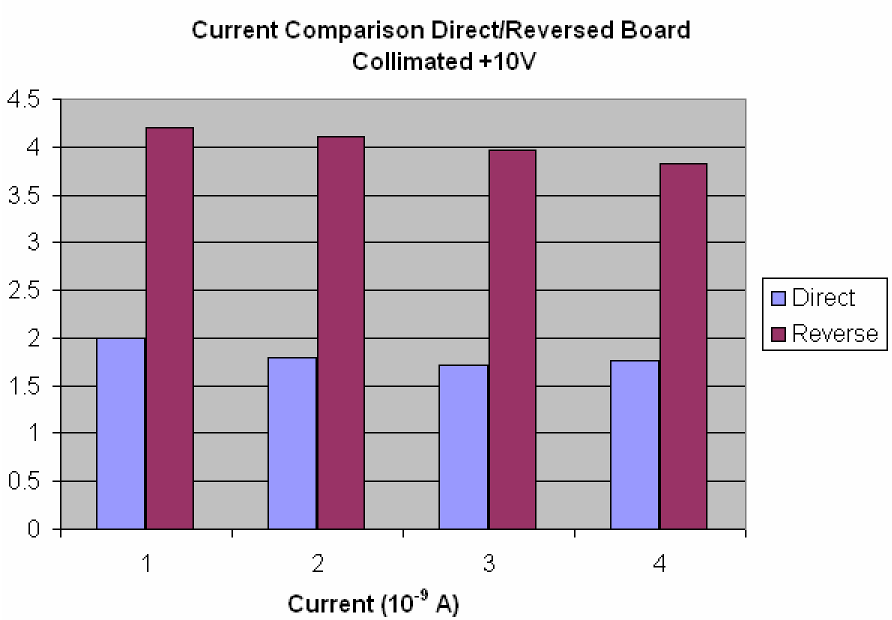
<u>What we want to investigate:</u>

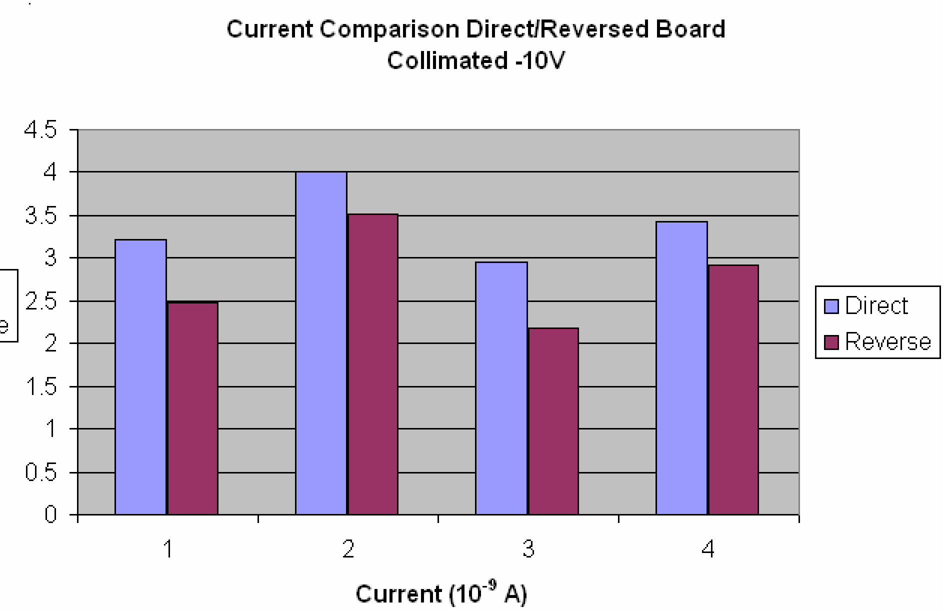
- Does the current scale with the contact area?
- Does the glue affect the current?

First results…









Conclusions

We compared the dosimetric performances of sc/pc CVD diamonds prepared with graphite or Al contacts.

- Samples with graphite contacts showed stable signal even for high voltage.
- Under X-ray pulses, PC samples have faster response and shorter fall-time than the SC samples (multiple trapping).
- Measurements obtained from SC samples depend on the contact as opposite to the PC samples.
- Rise time of implanted (B, C) contacts is very slow ~ 40 s!

PLD method is the technique now used to produce amorphous carbon contacts. With this technique it will be possible to study the dosimetric performances of diamond detectors as a functions of the sp2/sp3 content in the contact layer.

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Thank you!

First results on thermal grade pc CVD

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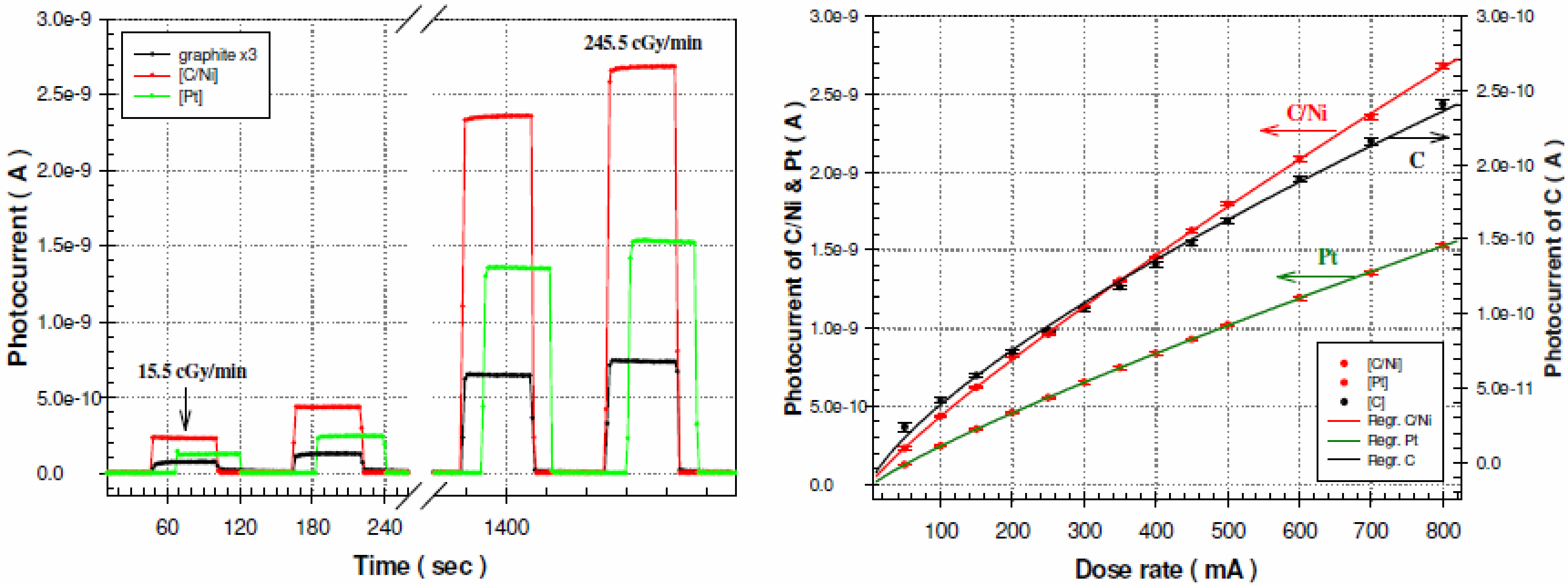

• The photo current signal current for "pure" carbon is low,
⇒ Poor SNR (< 100).

Conductivity might need to increase (possible for example by N addition, or reduction in laser power per pulse, which gives higher sp^2 content).

The Hecht equation: (μτ) product

	SC G(B)	SCG(C)	SC Al
$\mu\tau_e(cm^2/V)$	$(1.0 \pm 0.1) \times 10^{-4}$	$(1.2 \pm 0.1) \times 10^{-4}$	$(3.1 \pm 0.3) \times 10^{-4}$
$\mu\tau_h(cm^2/V)$	$(4.4 \pm 0.1) \times 10^{-4}$	$(1.9 \pm 0.1) \times 10^{-4}$	n
$s/\mu_e(V/cm)$	485.3 ± 2.5	4.2 ± 0.5	11.3
$s/\mu_h(V/cm)$	20.6 ± 0.1	6.93 ± 0.2	n
$P_e(V)$	10.1 ± 0.7	18.2 ± 2.7	47.8 ± 2.2
$P_h(V)$	$(1.9 \pm 0.5) \times 10^{-13}$	$(2.7 \pm 0.3) \times 10^{-14}$	n

- The SC Al diamond shows the highest electron μτ $1.3 \cdot 10^{-4}$ cm^2/V

- The SC G(C) sample has higher extracted μτ than the SC G(B)

- The hole μτ in the the SC G(B) and SC G(C) samples is higher than the electron μτ

- Electron surface recombination velocity to mobility s/μ_e in the SC G(B) sample is very high compared with the other samples.