Thin single crystal diamond detectors for alpha particle detection

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Outline

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Material/Methods

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Theory

The electronic properties of a diamond sample can be studied by the Time of Flight (ToF) technique which measures the duration of the current pulse induced on a read-out electrode by the drift of free charge carriers under the influence of an externally field applied.

In first approximation, by knowing the drift time t_{dr} and the thickness d of the diamond sample, the drift velocity of the carrier v_{dr} can be easily calculated as $v_{dr} = d/t_{dr}$.
Extraction of field mobility μ_0 and saturation velocity (maximum drift velocity) of the carrier v_{sat} can be performed analysing $v_{dr}(E)$:

$$v_{dr} = \frac{\mu_0 E}{1 + \frac{\mu_0 E}{v_{sat}}}$$

Assuming that the effective charge carrier lifetime is longer than the drift time, the current pulse width equals the time the charge carriers need to traverse the detector t_{dr}.

Motivation

Electronic properties of thick (usually 300÷500 µm) single crystal CVD (scCVD) diamonds have been studied and discussed by many authors using the ToF technique.

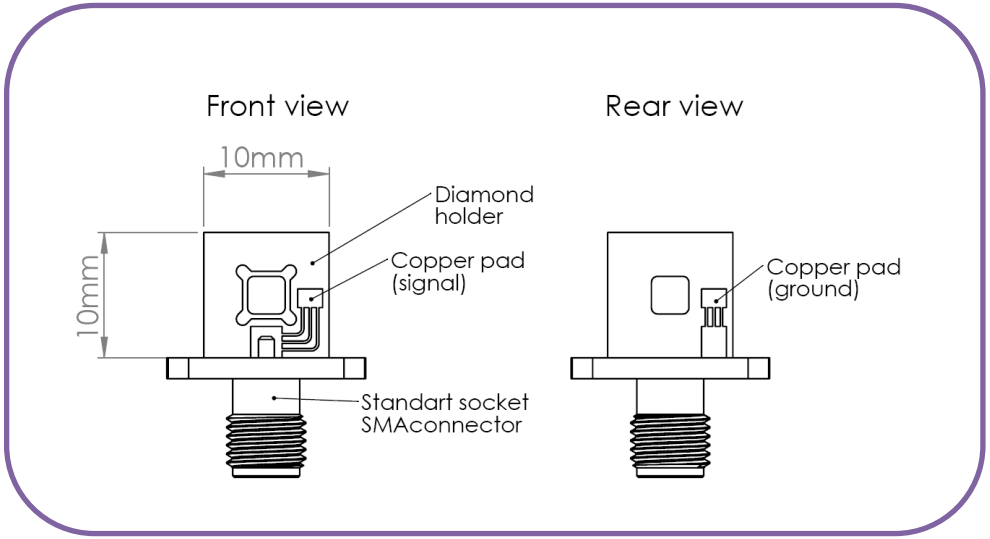
However...

•Little can be found in literature about thin samples with thickness below 100 µm.
•There is a lack of comparative measurements between the electronic properties of the diamond device and the different type of electrode metallization adopted.

We report on the electronic properties (mobility, transit time, saturation velocity) and spectroscopic resolution of charge particle detectors based on 90 µm thin scCVD diamond samples provided of gold (Au) and Aluminium (Al) electrodes. The results, derived from measurements taken at room temperature by the ToF technique, are also compared with those obtained from commercially available scCVD diamond detectors.

Material

Label	Type	Sizes (mm)	Thickness (µm)	Contacts	Area (mm^2)	Thickness (nm)
Dmd#1	scCVD	3.0x3.0	90	Au -> Al/Au	4	100 -> 100/30
Dmd#2	scCVD	3.0x3.0	90	Au	4	100
B10044	scCVD	4.6x4.6	500	Al	21	300
B10045	scCVD	4.6x4.6	500	Al	21	300



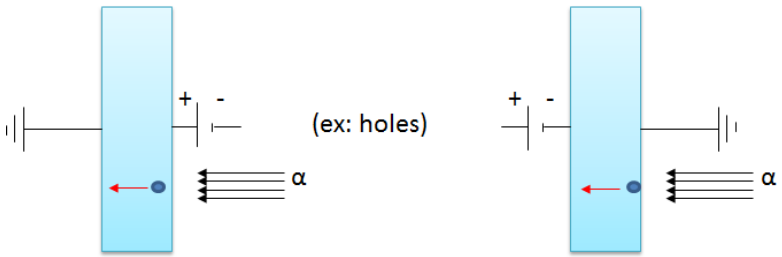
The noise generated by the PCB itself was reduced by decreasing its capacitance and increasing as much as possible the resistance of the housing.

Methods

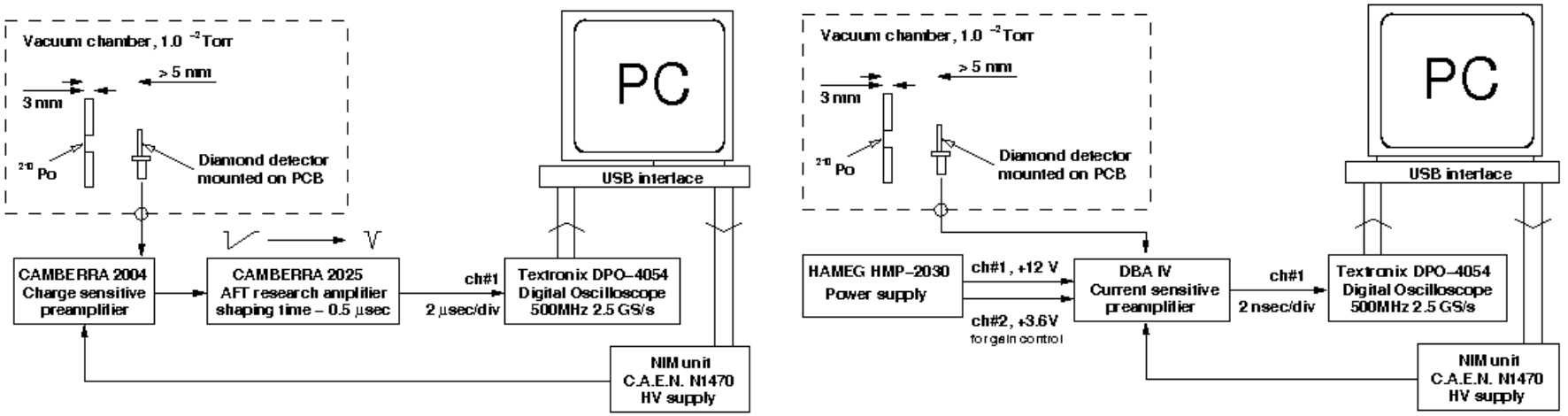
- Investigate the spectroscopic and charge transport properties of the diamond detectors Dmd#1 and Dmd#2 fabricated with Au electrodes
- Compare the properties of spectroscopic resolution of Dmd#1 and Dmd#2 with those obtained from the diamond detectors B10044 and B10045
- Compare the charge transport properties of the diamond sensor Dmd#1 fabricated first with Au and then with Al/Au electrodes

Device	Source	Mode	Bias range (V)	Max El. F. (kV/cm)
Dmd#1	^{210}Po	Fw / Bw	8 - 160	17.8
Dmd#2	^{210}Po	Fw / Bw	8 - 160	17.8
B10044	^{210}Po	Fw / Bw	8 - 300	6
B10045	^{210}Po	Fw / Bw	8 - 300	6

Fw = Forward, Bw = Backward



Experimental Setup



- Measurements were performed at ~ 10^{-2} Torr in a new developed vacuum chamber (see details in the next talk).
- Charge sensitive preamplifier (CANBERRA 2004) for spectroscopic characterization or current sensitive (DBA IV) preamplifier for a ToF characterization.
- Cable lengths are as short as possible to minimize the loss of signal.

Data acquisition performed by an oscilloscope (Tektronix DPO4054) with a sampling time of 400 ps.

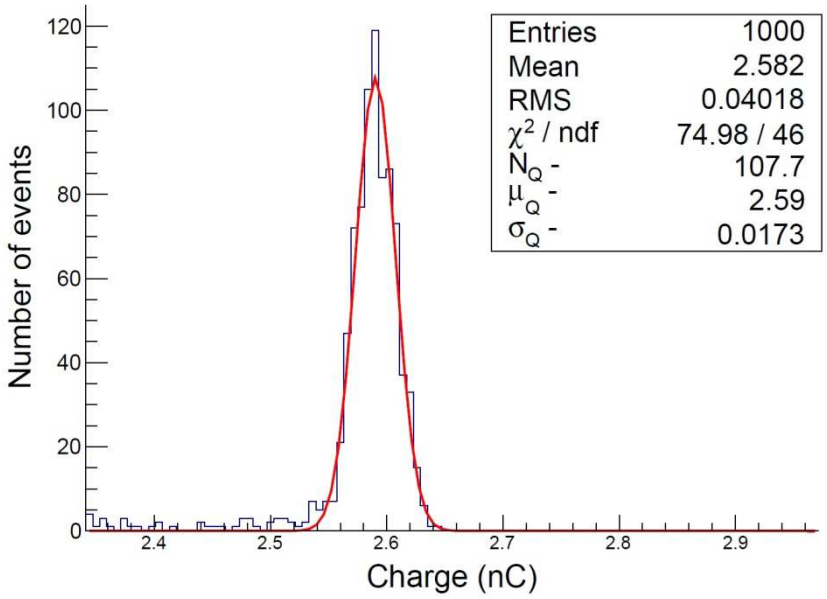
Data processing

A set of N = 1000 events was recorded from the oscilloscope and then stored in a file.

The recorded pulses were fitted by a combination of Gaussian and polynomial functions.

$$y = y_0 + A\exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right)$$

The integral or the FWHM of each fitted pulse P_i where used to create the charge and drift time distribution respectively whose Gaussian fit returned the diamond detector resolution and the carrier drift time at the bias V.



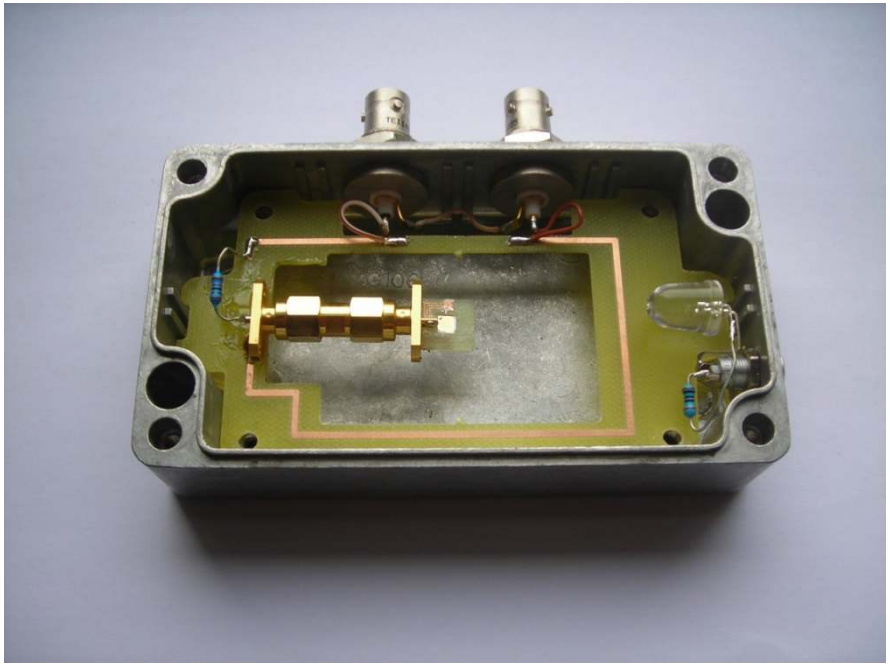
Charge distribution of the diamond detector Dmd#2 referred to a voltage applied of +50 V. For this case a spectroscopic resolution of 1.9 % was achieved.

Results

Leakage Current

Measurements were performed both in darkness and under illumination conditions by using an in house developed metallic box.

Conditions of illumination were achieved by a white LED mounted inside the box and connected to a voltage supply of 5V via current limiting resistor.

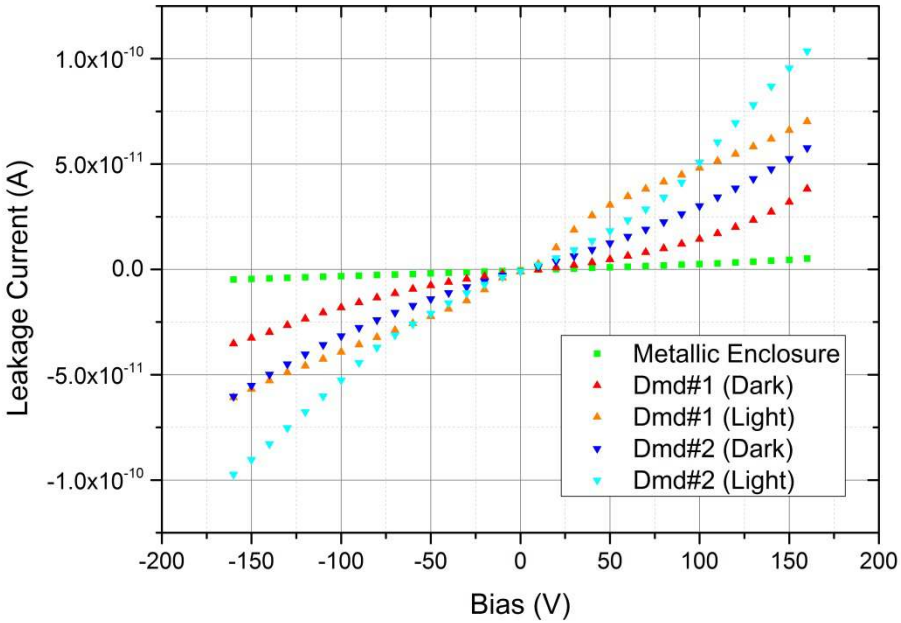


Results

Leakage Current

- It is similar for both detectors.
- Its magnitude does not change significantly under conditions of illumination.
- The metallic box itself (with the detectors disconnected) does not influence the detector performance.
- @ 17.8 kV/cm, $I < 1.04 \cdot 10^{-10}$ A.
- Resistivity $\rho \sim 10^{13}$ Ω·cm.

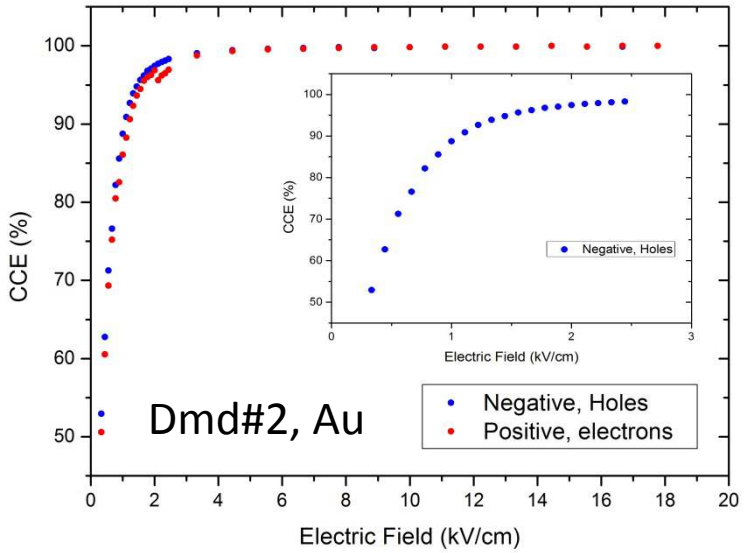
B10044 and B10045
6 kV/cm, $I < 10^{-11}$ A

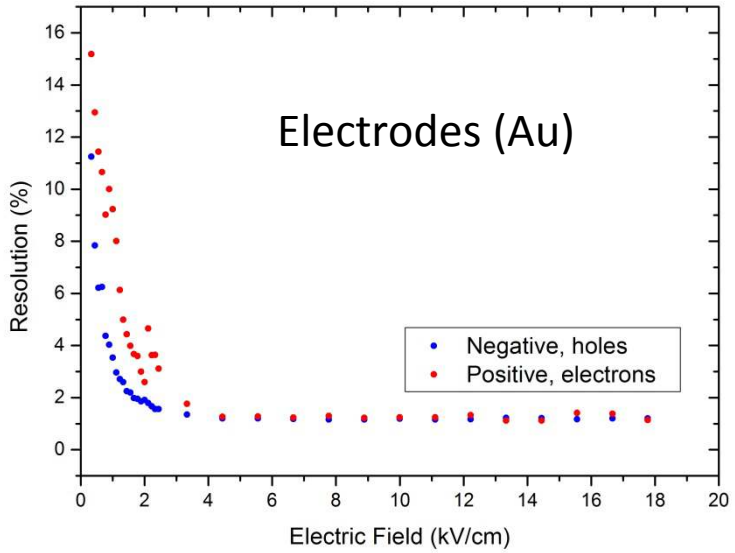


Leakage current measurements of the diamond detectors with Au (orange and red data points) and Al (blue and cyan data points) electrodes. The green points represent the leakage current measured from the metallic box.

Results

CCE and spectroscopic resolution (vacuum)



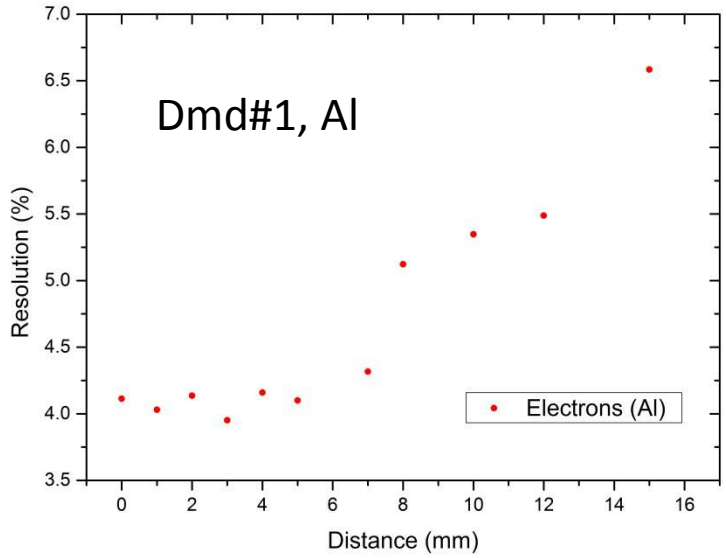


- "forward" irradiation
- 100% CCE for bias > 50 V
- Resolution 1.2% for bias > 50 V

Keeping the bias at 160 V but irradiating the device at an incidence angle of ±45º, the resolution worsened to 2.0%.

Results

CCE and spectroscopic resolution (air)



- Bias = 160 V, backward
- For x = 0, d = 5mm
- Conditions of illuminations
- Resolution of 4% up to 1 cm away from the alpha source and then decreased.

Opposite to devices like those based on silicon, diamond detectors offer the possibility to perform measurements in air and under condition of illumination while keeping a reasonable good value of spectroscopic resolution.

Results

CCE and spectroscopic resolution (vacuum)

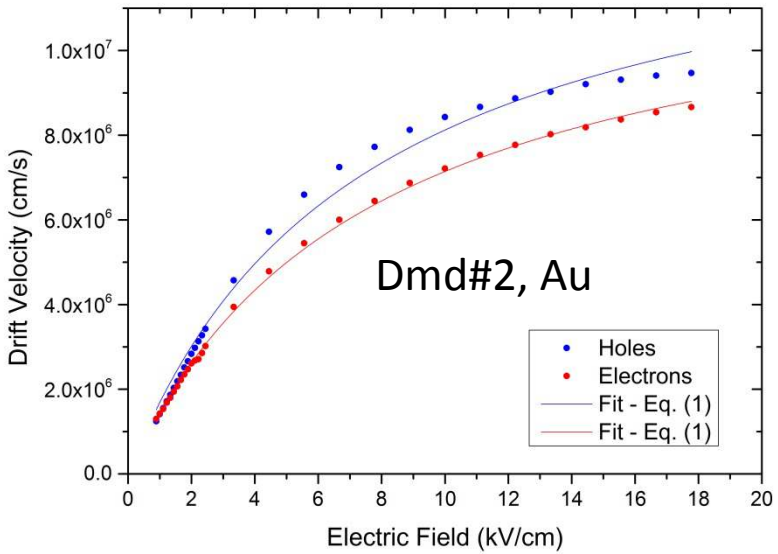
Device	Electr.	Thickn. (nm)	CCE (%)	Res. (%)
Dmd#1	Au	100	100	1.2
	Al/Au	100/30	100	1.8
Dmd#2	Au	100	100	1.2
B10044	Al	300	100	1.9
B10045	Al	300	100	3.8

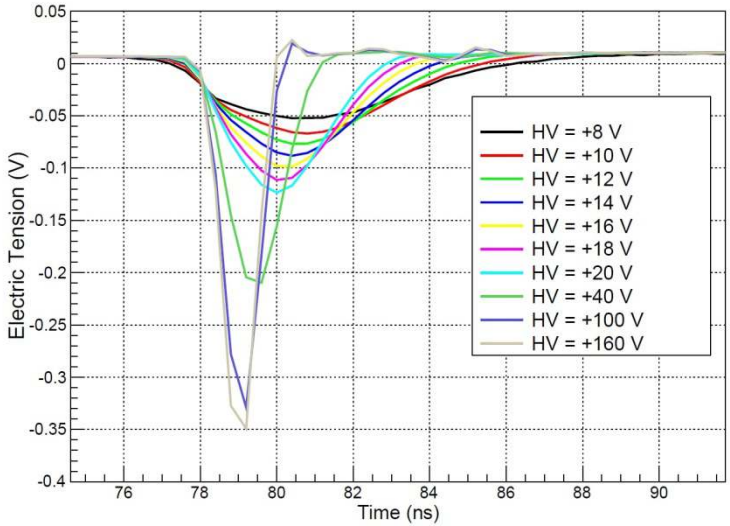
- Comparison performed for electric field of $-6.0 \cdot 10^3$ V/cm where the commercial sensors show 100% of CCE too.
- The best spectroscopic resolution is achieved by the detectors made of thinner samples.

With thicker material it increases the probability of carrier trapping which in turns could reflect on a bigger variation of the charge collected at the electrodes. These results may suggest the preference in using thinner samples for alpha spectroscopy purposes, provided that the thickness is large enough to detect the alpha particle.

Results

Charge transport properties





- Mode “forward”.
- Increasing E, pulses become narrower and v_{dr} becomes higher (charge is collected at the electrodes in faster time). $v_{dr} = d/ t_d$ (from the current pulse width).
- For an electric field of $+6.0 \cdot 10^3$ V/cm, the drift time of electrons and holes calculated for the device Dmd#2 was ~1.5 ns while ~7 ns that estimated for the commercial devices made up of thicker diamond samples.

Results

Charge transport properties (parameters obtained by fitting)

Device	Electr.	Irrad. Mode	Carrier	Sat. Vel. (10^7 cm/s)	Mobility ($cm^2/V \cdot cm$)	Res. (%)
Dmd#1	Au	fw	e	1.2	1463	4.1
		fw	h	1.3	1424	3.6
	Al	fw	e	1.1	1808	3.3
		fw	h	2.1	1036	3.2
Dmd#2	Au	fw	e	1.2	1628	4.1
		fw	h	1.5	1539	3.9
	Au	bw	e	1.2	1658	4.0
		bw	h	1.4	1914	3.5

- Holes mobility (Dmd#2) increases while changing the modality of irradiation (the resolution follows the same trend).
- The same type of charge carrier drifts inside the diamond in opposite directions.

A change in the mobility of the charge carriers could be linked to the different way at which they cross the detector thickness (Bulk properties?).

Results

Charge transport properties (parameters obtained by fitting)

Device	Electr.	Irrad. Mode	Carrier	Sat. Vel. (10^7 cm/s)	Mobility ($cm^2/V \cdot cm$)	Res. (%)
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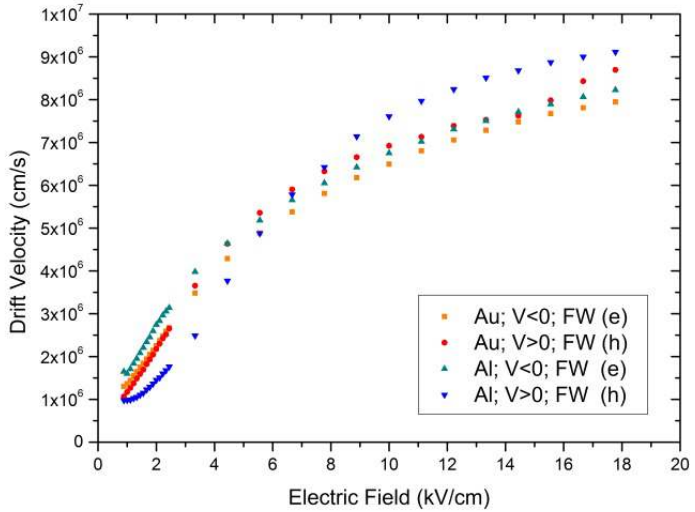

- With Au electrodes (Dmd#1), charge carriers show similar low field mobility.
- With Al electrodes, the mobility decreases for holes while it increases for electrons.
- Schottky barrier effect (interface effect for one type of charge carrier?).
- For higher electric field applied, the highest drift velocity observed is related to the device with Al electrodes which also shows the best spectroscopic resolution.
- Fit does not include the effect of the Schottky barrier (first approximation).

Conclusions

Spectroscopic and electronic properties of charge particle detectors based on 90 µm thick samples and provided of Au or Al electrodes have been presented.

Spectroscopic properties

- Compared to the commercial detectors, the devices based on thinner diamond samples showed better spectroscopic performance up to 1.2% for a CCE of 100%.
- In air and under condition of illumination, the detectors showed a good resolution of 4% up to 1 cm of distance from the alpha source which could make these devices a portable tool for alpha spectroscopy measurements.

Charge transport properties

- According to the modality at which the devices were irradiated, variations in the mobility were observed (Is it related to the bulk properties).
- Increase in the mobility led to an improvement of the spectroscopic resolution of the devices.
- The device Dmd#1 with Au electrodes showed similar values of mobility of the charge carriers. The same sample, provided of Al electrodes, showed a change in the carrier mobility (Schottky barrier effect)?

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