Effect of secondary electrons emission in extreme-UV diamond detectors

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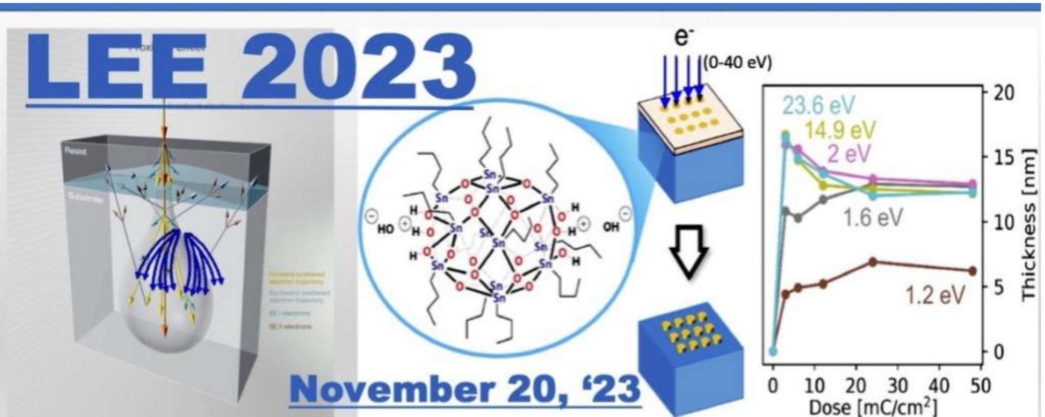
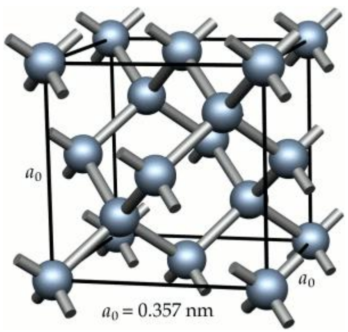


Diamond properties



- *Energy Gap 5.5 eV* → *225nm Cutoff Wavelength*; *Few thermal charge carrier*; *High breakdown electric field*
- *Physical Properties* → *Strong chemical bond*; *High thermal conductivity*
- *Electric Properties* → *Low dielectric constant*; *High electric charge mobility*

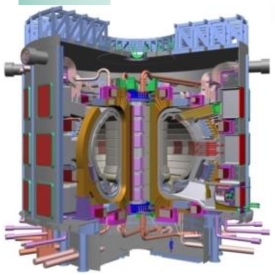
→ *Solar Blindness*; *High XUV sensitivity*; *High temperature operation*; *Low noise*; *Chemical inertness*; *Radiation Hardness*; *Mechanical Robust*; *High power dissipation*; *Fast response time*; *Low Capacitance*

HARDNESS	**9000 Kg/mm^2**	**(the highest)**
YOUNG'S MODULES	**1012 N/m^2**	**(the strongest)**
FRICTION	**0.05**	**(the lowest)**
THERMAL CONDUCTIVITY	**20 W/cm K**	**(5 times Cu)**
ELECTRICAL RESISTIVITY	**10^{16} Ωcm**	
ELECTRICAL BREAKDOWN	**10^7 V/cm**	**(30 times GaAs)**
ELECTRON, HOLE MOBILITY >2000 cm2/V s		
OPTICAL ABSORPTION	**transparent from IR to IV (5.4 eV)**	
MELTING POINT	**3350 °C**	
RADIATION HARDNESS	**very high**	
CHEMICAL REACTIVITY	**extremely low**	

Diamond based UV detectors applications:

- ✓ Plasma diagnostic in fusion reactors
- ✓ Sun observation from satellite
- ✓ Synchrotron radiation detectors
- ✓ EUV spectroscopy

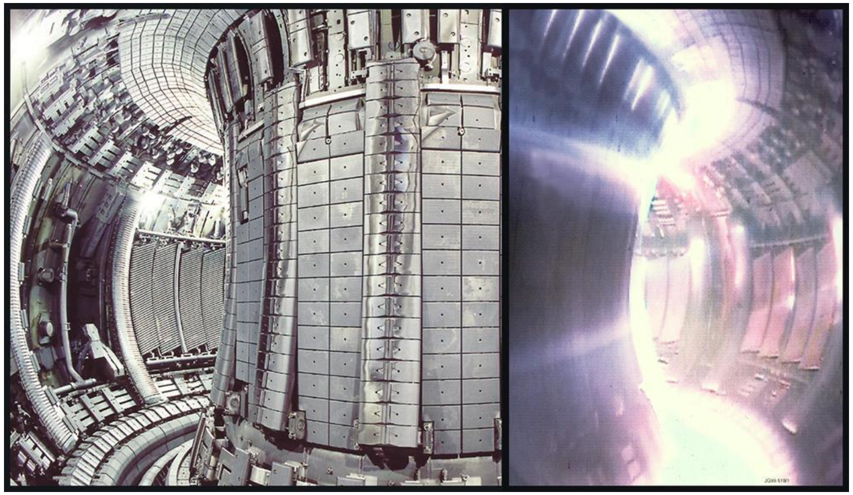
Plasma V-UV and soft X-ray diagnostic



ITER fusion reactor

SPARC fusion reactor

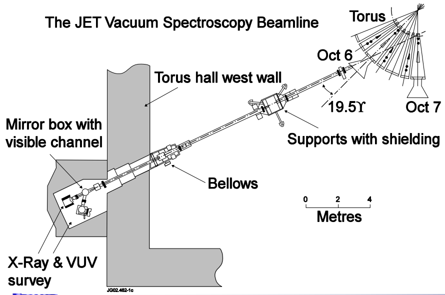
- ✓ Plasma temperature: (T) 100-200 million Kelvin
- ✓ Plasma density: (n) 1-2 x 10^{20} particles m^{-3}
- ✓ Most relevant emission for plasma diagnostics in extreme-UV / soft-X ray spectral range

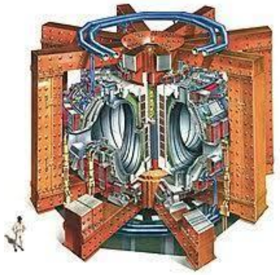


Plasma diagnostic in Fusion reactors

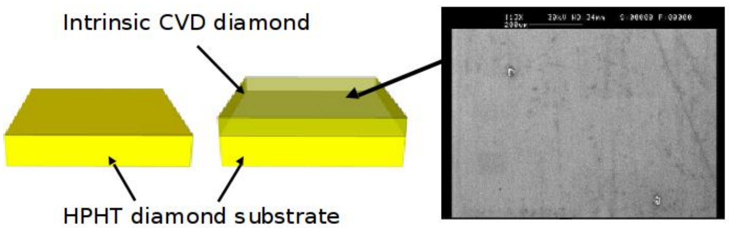
- ➢ temperature
- ➢ density
- ➢ particle and energy confinement timescale
- ➢ impurity dynamics
- ➢ atomic collision rates
- ➢ plasma-wall interaction
- ➢ plasma dynamics
- ➢ characterization of the electron fluid
- ➢ atomic structure of highly ionized atoms

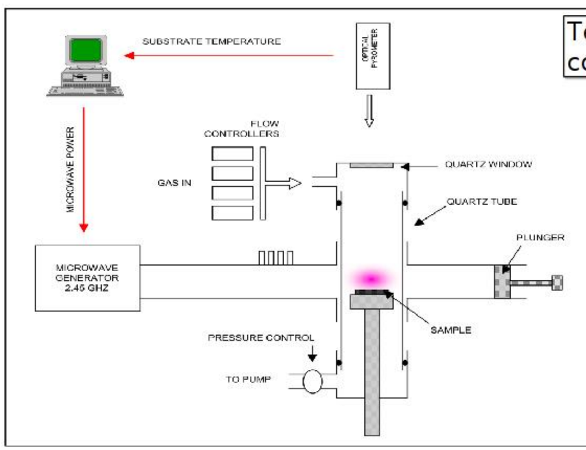
CVD diamond detectors fabricated at Rome "Tor Vergata" University were permanently installed at Joint European Torus (JET), and currently used by plasma physics groups at JET to study impurity dynamics, to monitor the ELMs (Edge Localized Modes) and for MHD (MagnetoHydroDynamics) analysis.

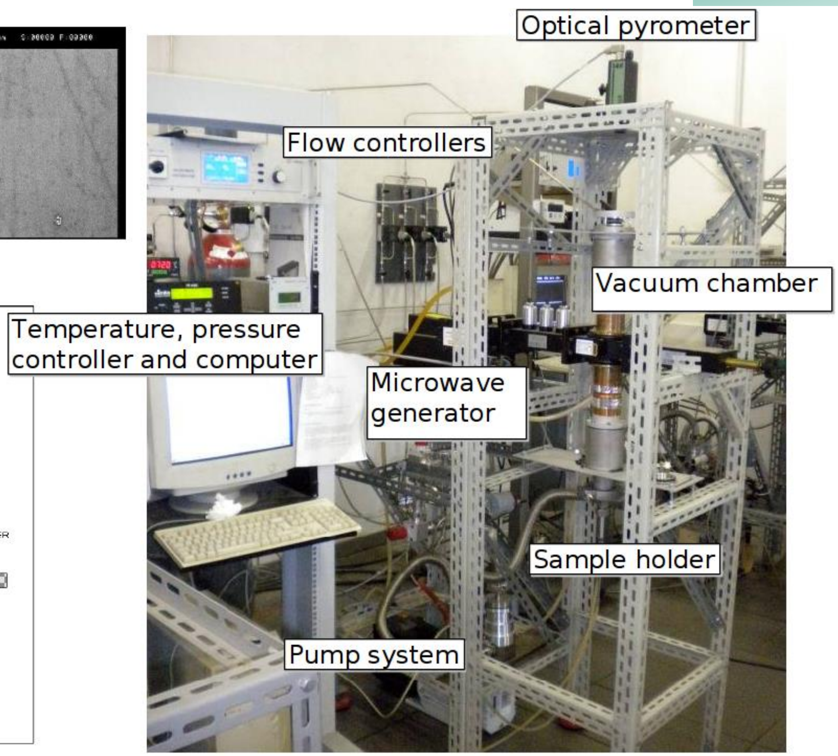




Single Crystal Diamond film synthesis







Doping

✓ B_2H_6 10-30 sccm

Substrates

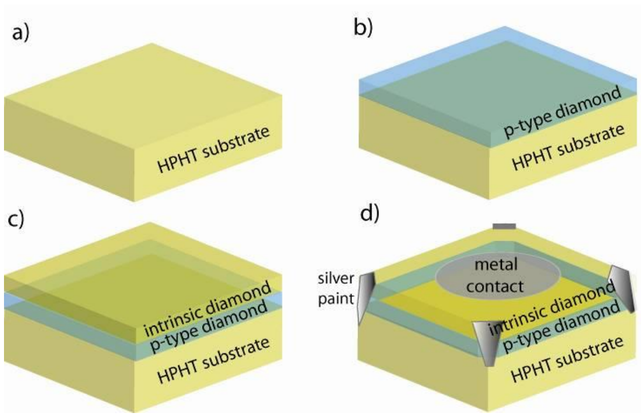
✓ (100) HPHT type Ib 4×4 mm^2

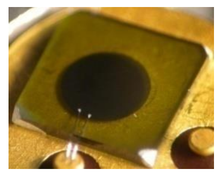
Typical growth parameters

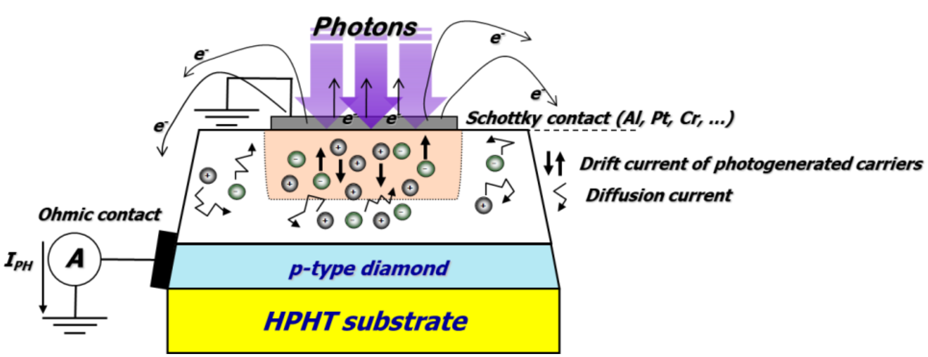
Plasma composition	99% H_2- 1% CH_4
Temperature	650 – 800 °C
Microwave power	500 - 600 W
Pressure	100 - 150 mbar
Gas flow rate	100 sccm

Diamond based detectors

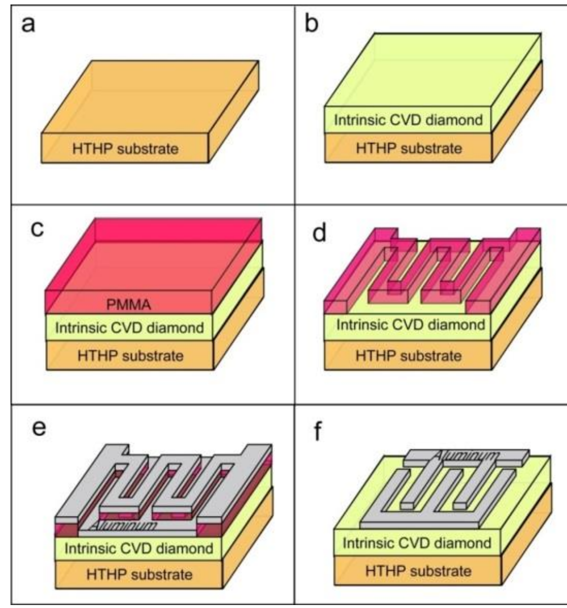
Fabrication process of diamond detector operating in transverse configuration



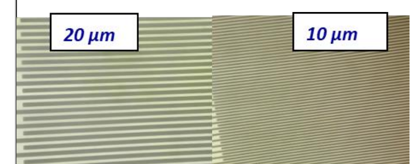


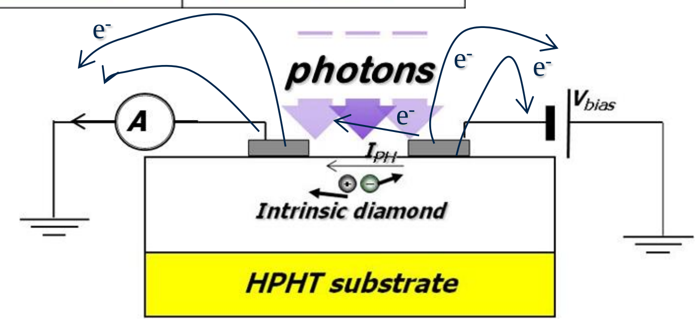


Fabrication process of diamond detector operating in planar configuration



- ✓ ***Small dimensions***
- ✓ ***Low voltage operation***





Secondary electron emission current

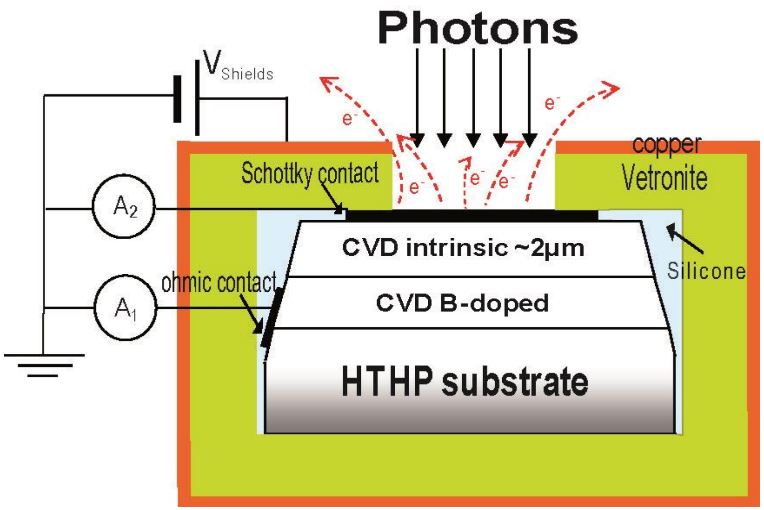
Study of secondary emission current from the illuminated surfaces to the device response

The secondary electron emission can depend on

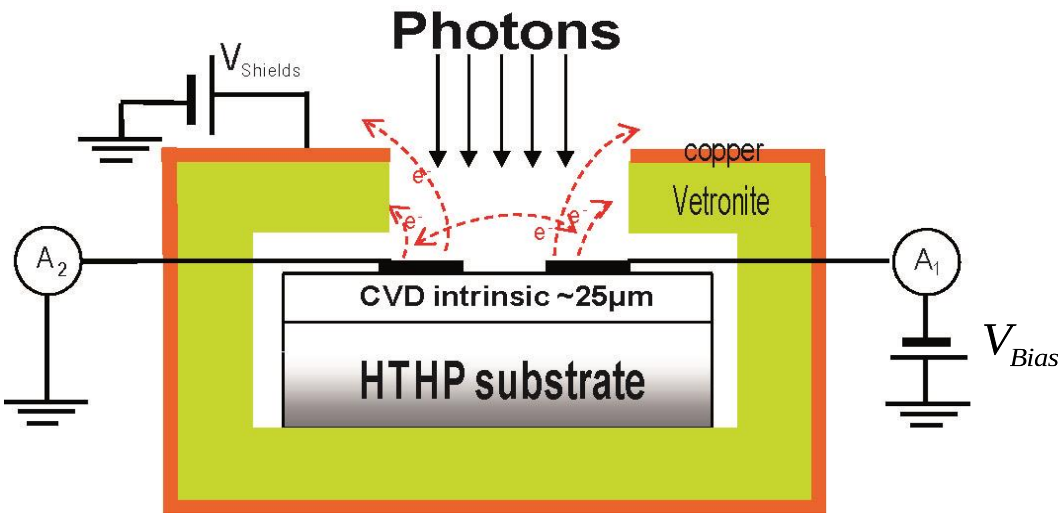
- ✓Environment conditions
  - ✓ External electric fields
  - ✓ Charging effects of insulating materials
  - ✓ Pressure, humidity
- ✓Operating condition (applied voltage)
- ✓Device geometry (transverse, planar)
- ✓Wavelength

Such contribution must be taken into account in order to obtain a precise and reliable absolute calibration of the UV-based device.

Experimental setup



P-type/intrinsic diamond/metal Schottky photodiodes



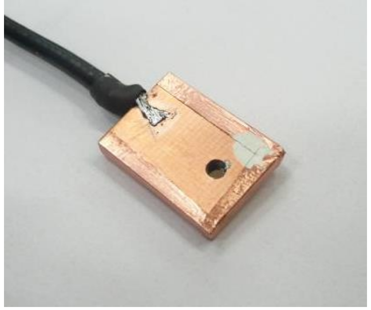
Photoconductive detector in planar configuration with interdigitated electrodes

Current simultaneously is measured by two electrometers (A_1 and A_2)

A_1

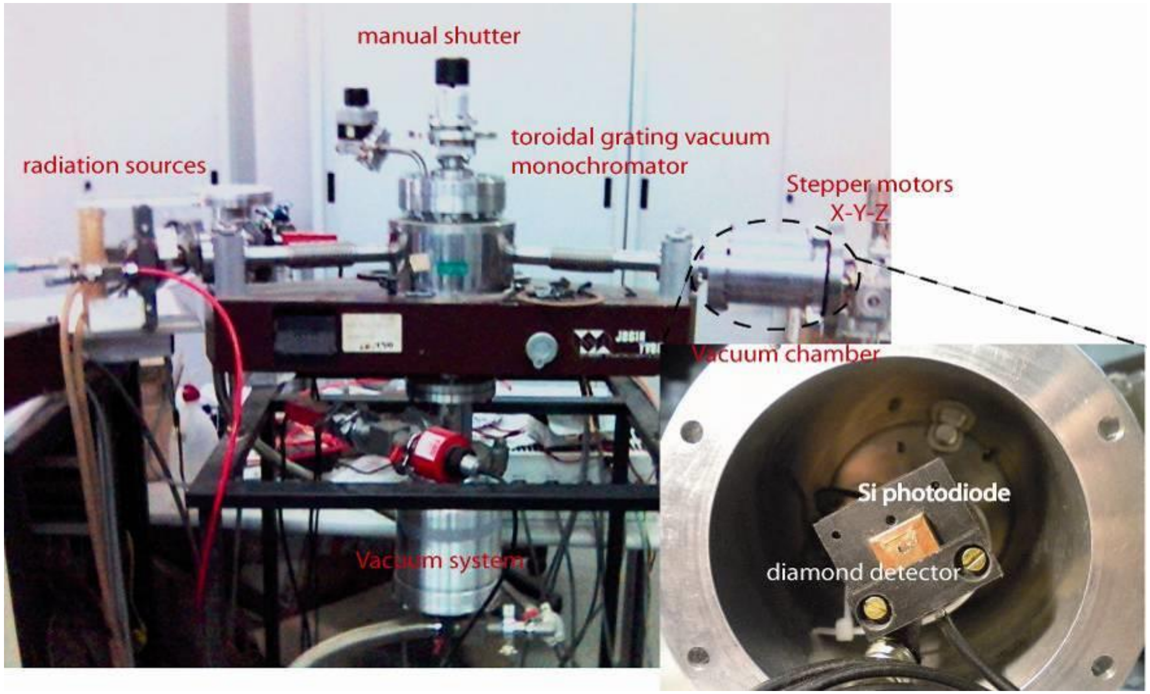
A_2

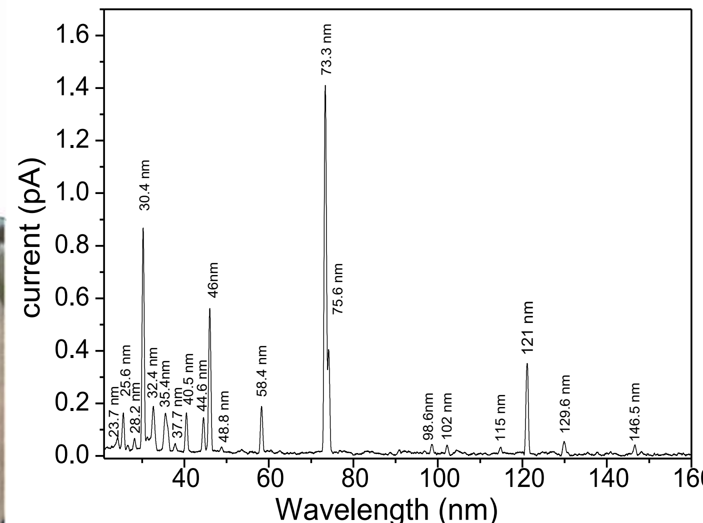
V_{shield}



Keithley 6517b picoammetters (the internal voltage source was used as bias voltage for both devices.

Experimental setup

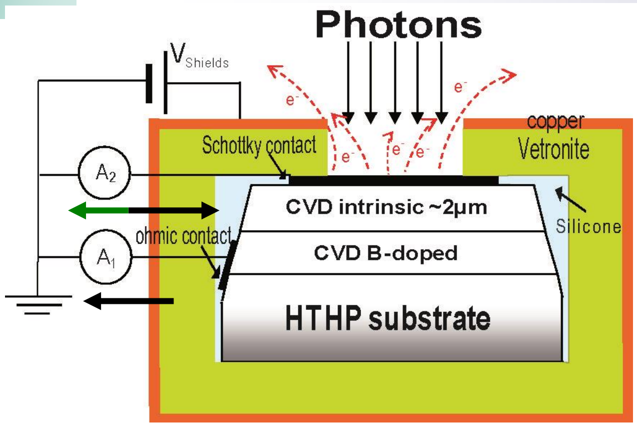




- **EUV toroidal grating vacuum monochromator (5 Å wavelength resolution)**
- **DC He/Ne gas discharge radiation sources, spot size: 0.25×6.00 mm^2, spectral range : 20 nm - 150 nm.**
- **Calibrated NIST AXUV Silicon photodiode for comparison.**

The emission spectrum of a DC discharge He and He-Ne lamp measured in unbiased mode by the SCD detectors.

Transverse configuration: Photocurrent



$V_{shield} \gg 0$

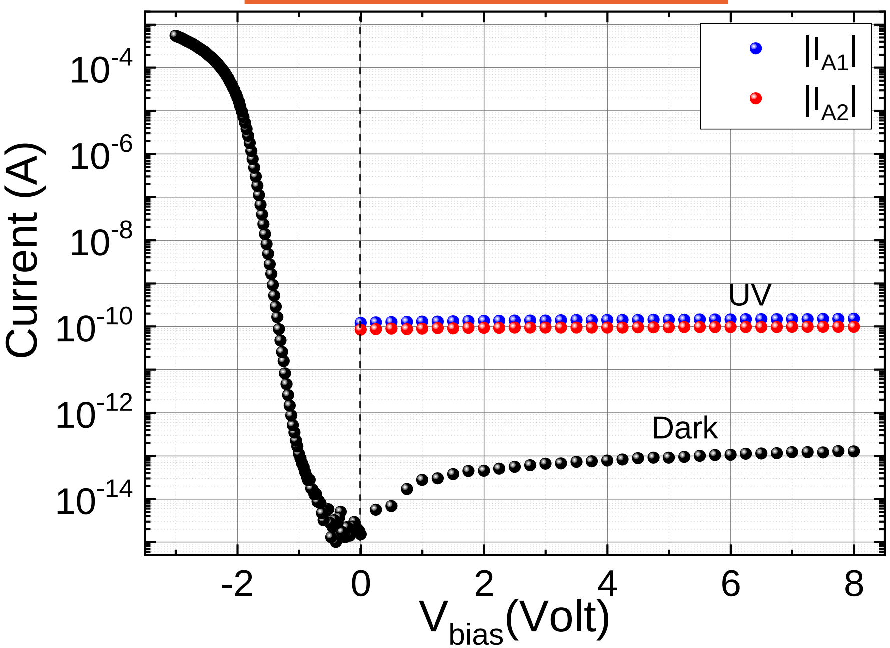
$I_{A_1} = |I_{ph}|$

$I_{A_2} = |I_e - I_{ph}|$

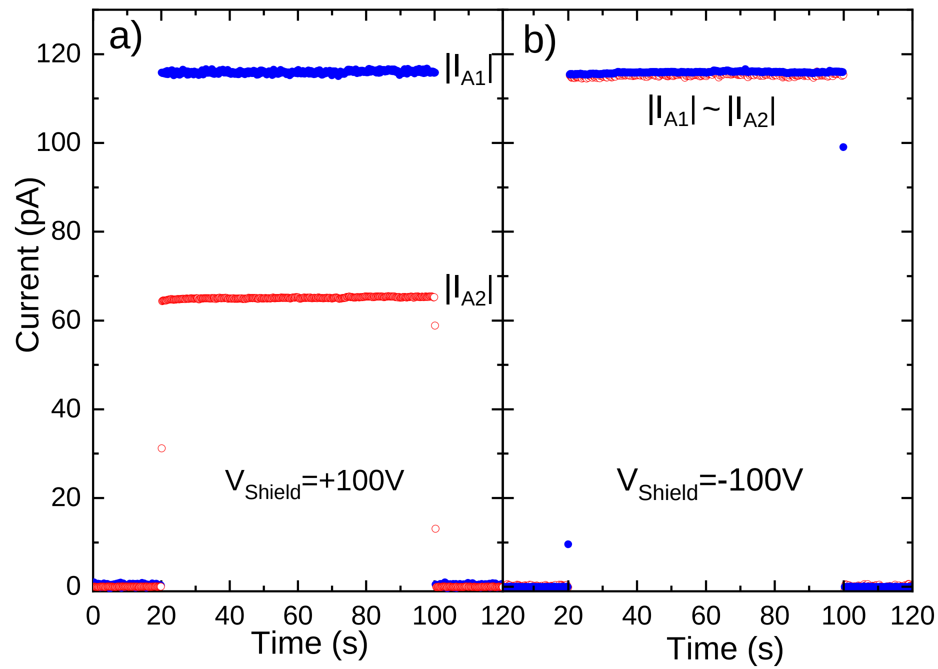
$V_{shield} \ll 0$

$I_{A_1} = |I_{ph}|$

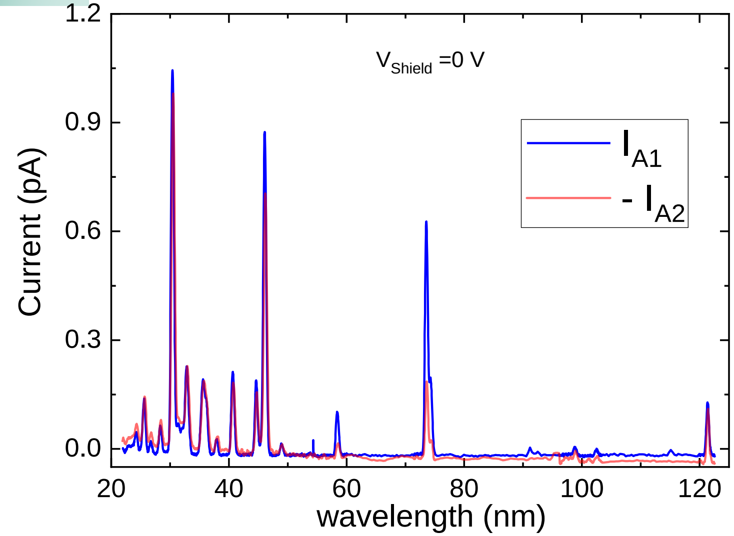
$I_{A_2} = |I_{ph}|$

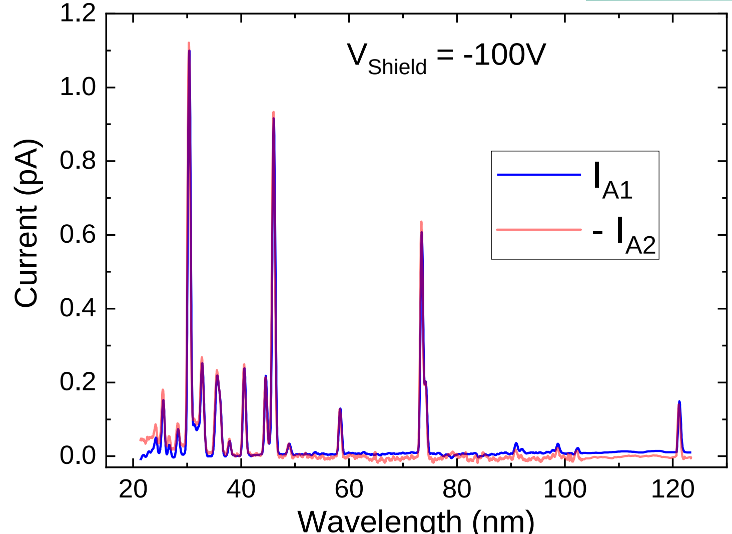


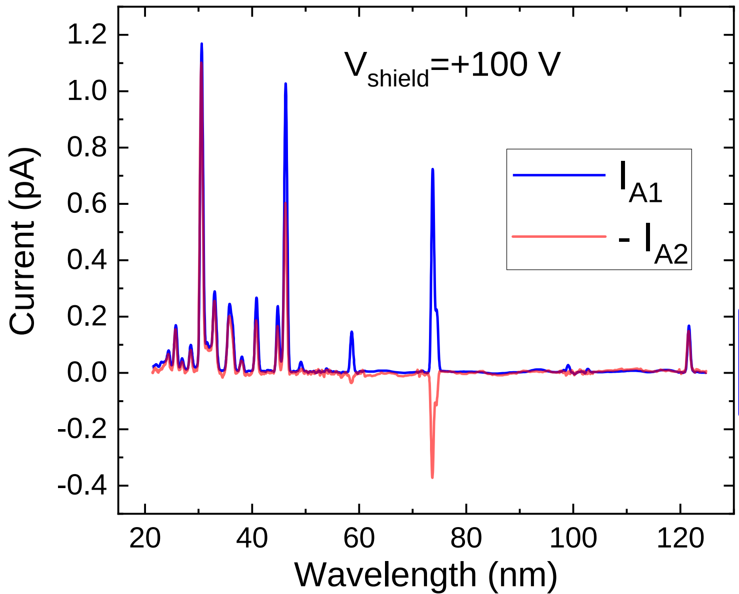
I-V characteristics in dark and under broadband UV irradiation



Transverse configuration: He-Ne spectra







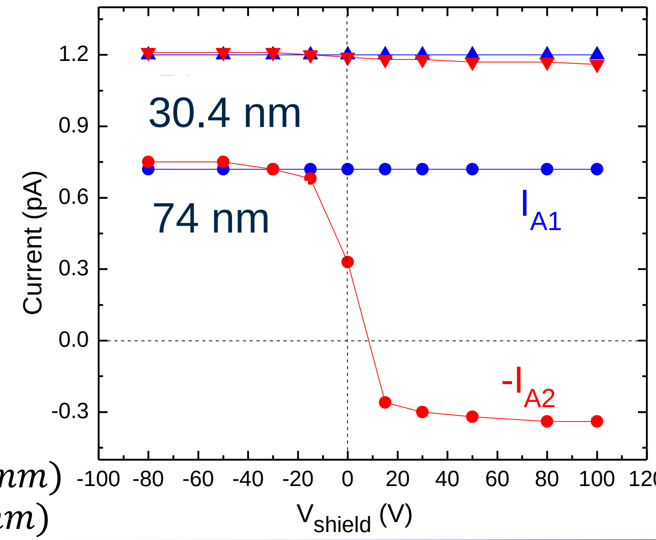
$$I_{A_1} = I_{ph}$$

$$I_{A_2} = I_e - I_{ph}$$

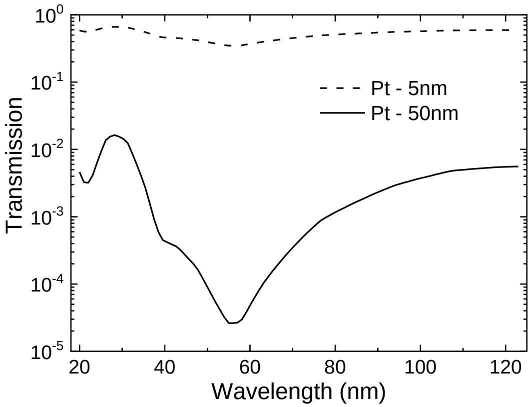
$$I_e = I_{A_1} + I_{A_2}$$

$I_e \sim$ **143 %** I_{ph} $(@\lambda = 74\ nm)$

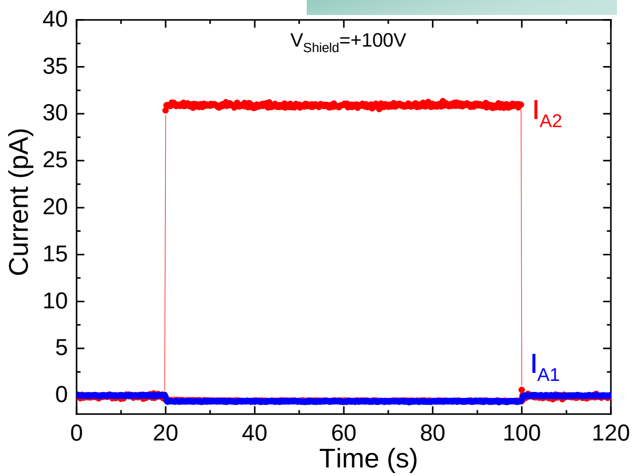
$I_e \sim$ **8 %** I_{ph} $(@\lambda = 30.4\ nm)$

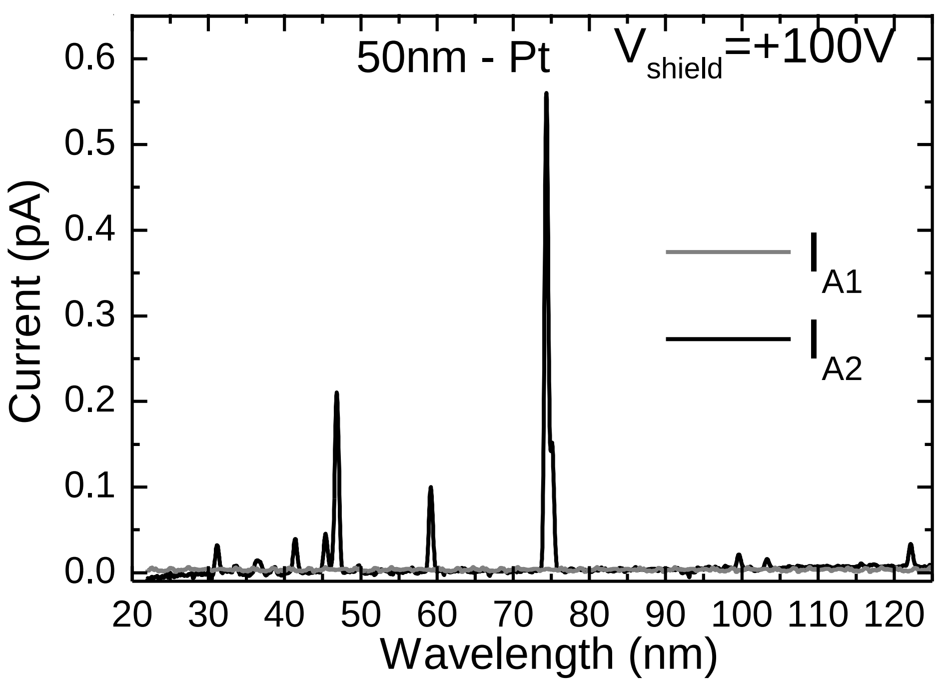


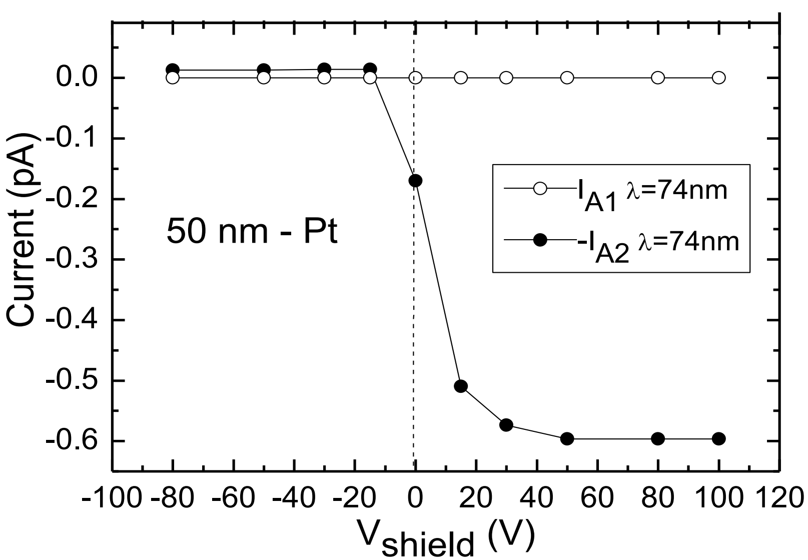
Transverse configuration



$$now\ I_{ph} = 0 \quad \begin{cases} I_{A_1} = 0 \\ I_{A_2} = I_e \end{cases}$$

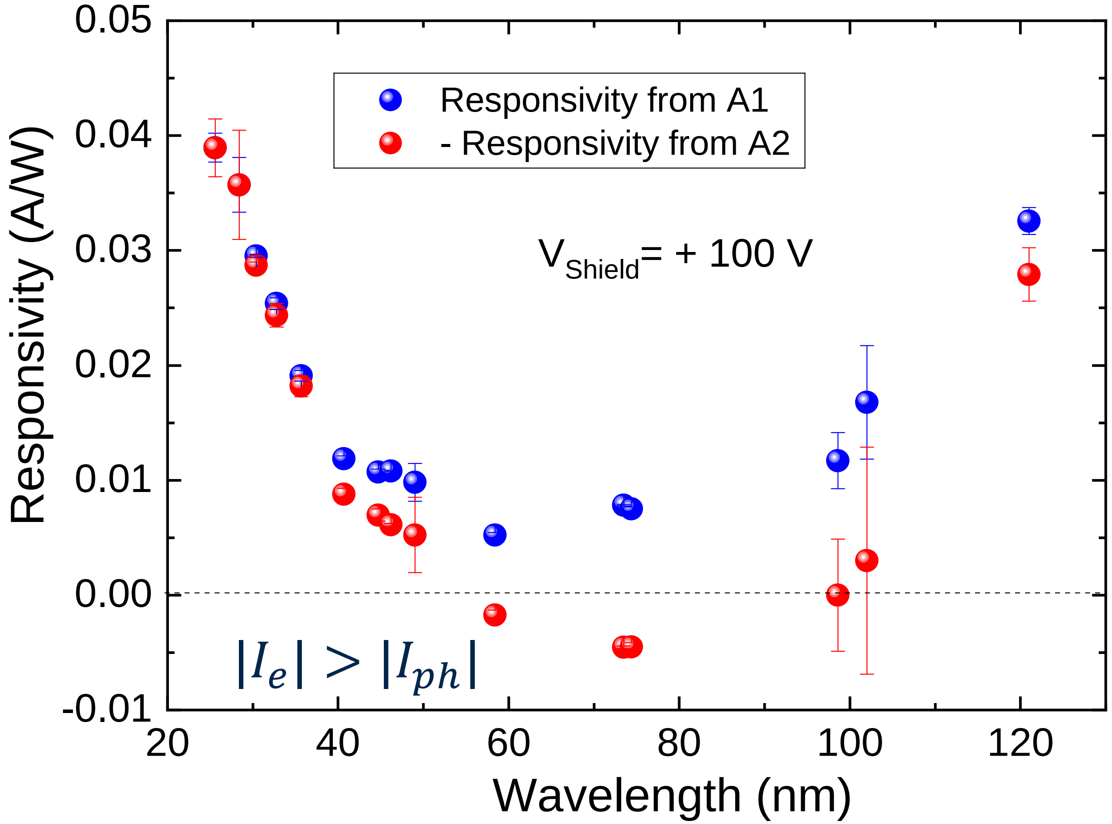






Transverse configuration: Responsivity

The spectral responsivity ***R*** is the current per unit of incident UV light power (A/W)



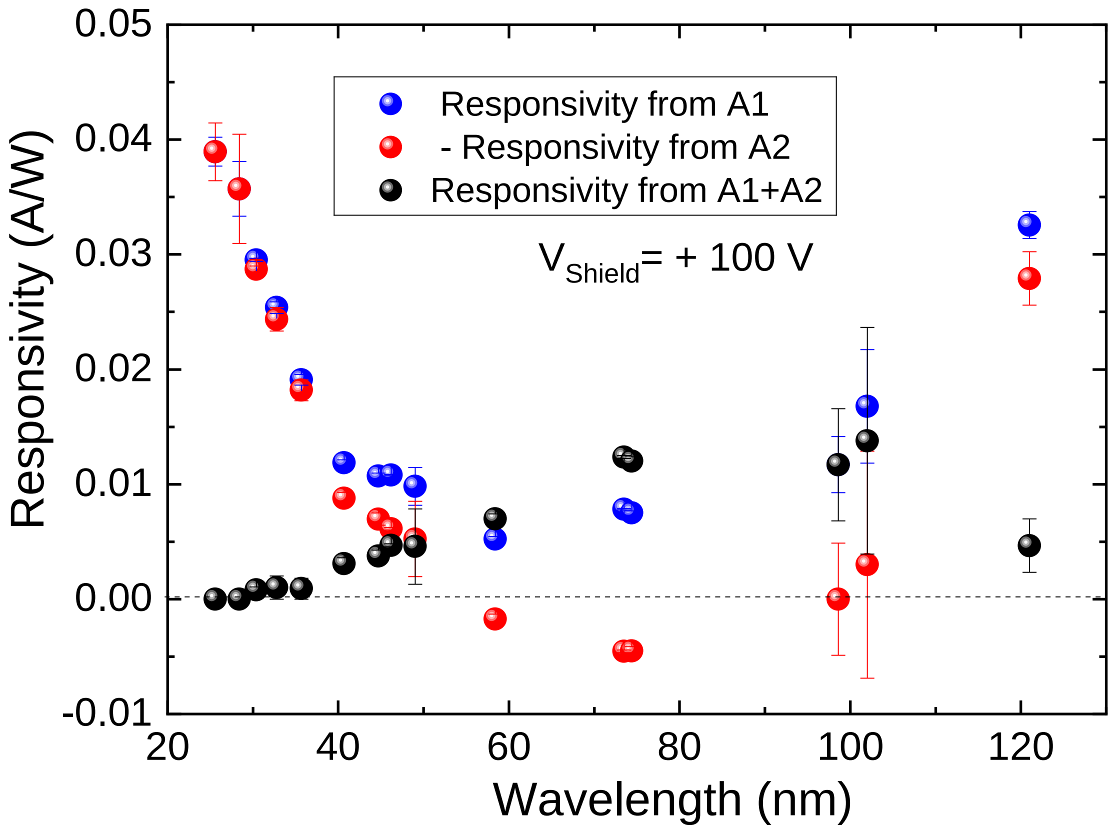
$$V_{shield} = +100\ V$$

$$R_{A_1} = \frac{I_{A_1}}{W} = \frac{I_{ph}}{W} = R_{ph}$$

$$R_{A_2} = \frac{I_{A_2}}{W} = \frac{I_e - I_{ph}}{W}$$

Transverse configuration: Responsivity

The spectral responsivity ***R*** is the current per unit of incident UV light power (A/W)



$$V_{shield} = +100\ V$$

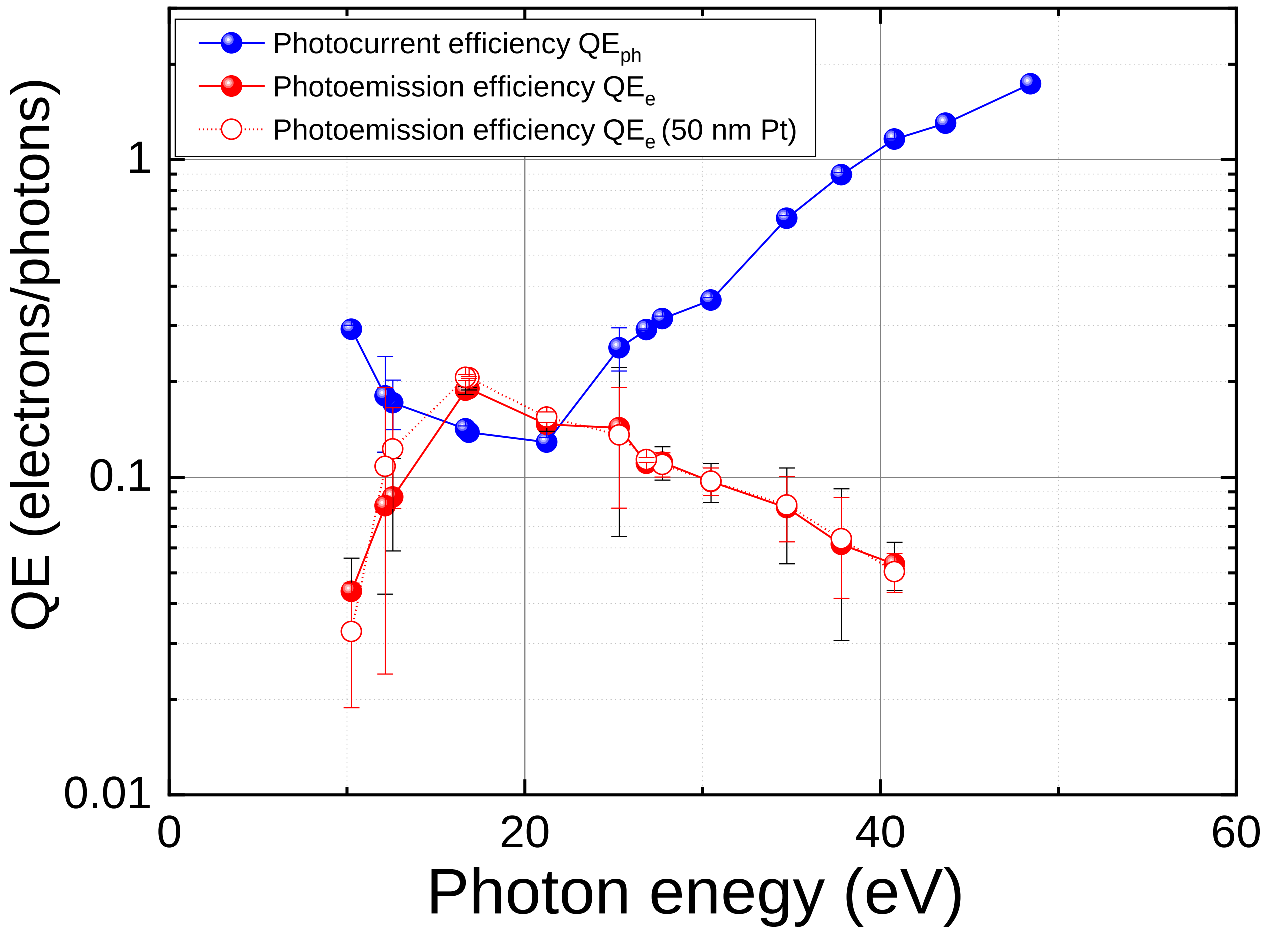
$$R_{A_1} = \frac{I_{A_1}}{W} = \frac{I_{ph}}{W} = R_{ph}$$

$$R_{A_2} = \frac{I_{A_2}}{W} = \frac{I_e - I_{ph}}{W}$$

$$R_e = \frac{I_{A_1} + I_{A_2}}{W} = \frac{I_e}{W}$$

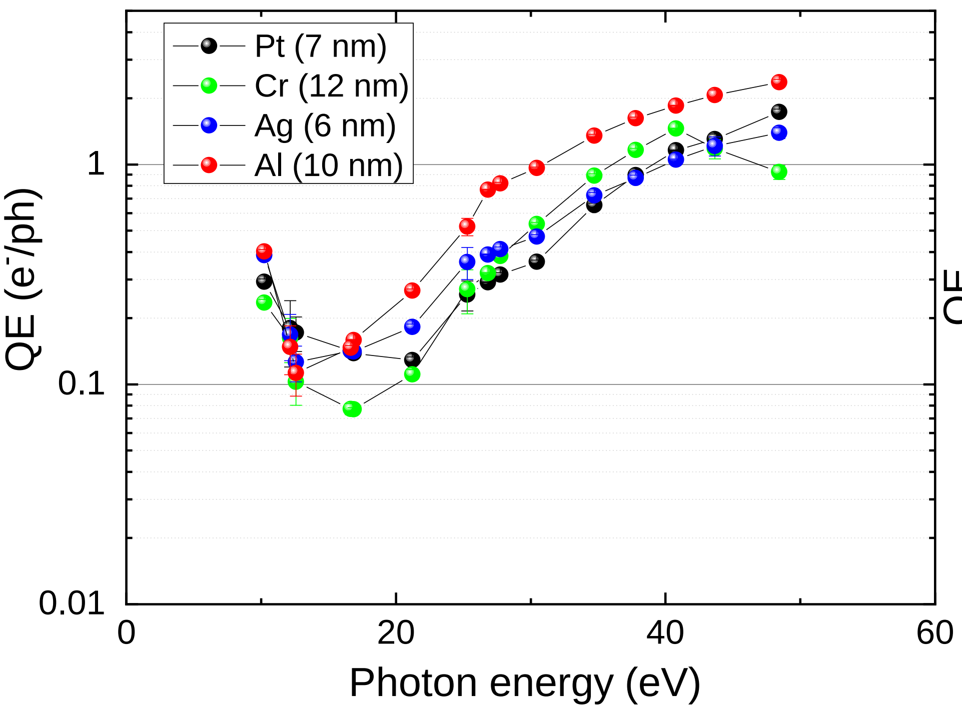
Transverse configuration: Quantum efficiency

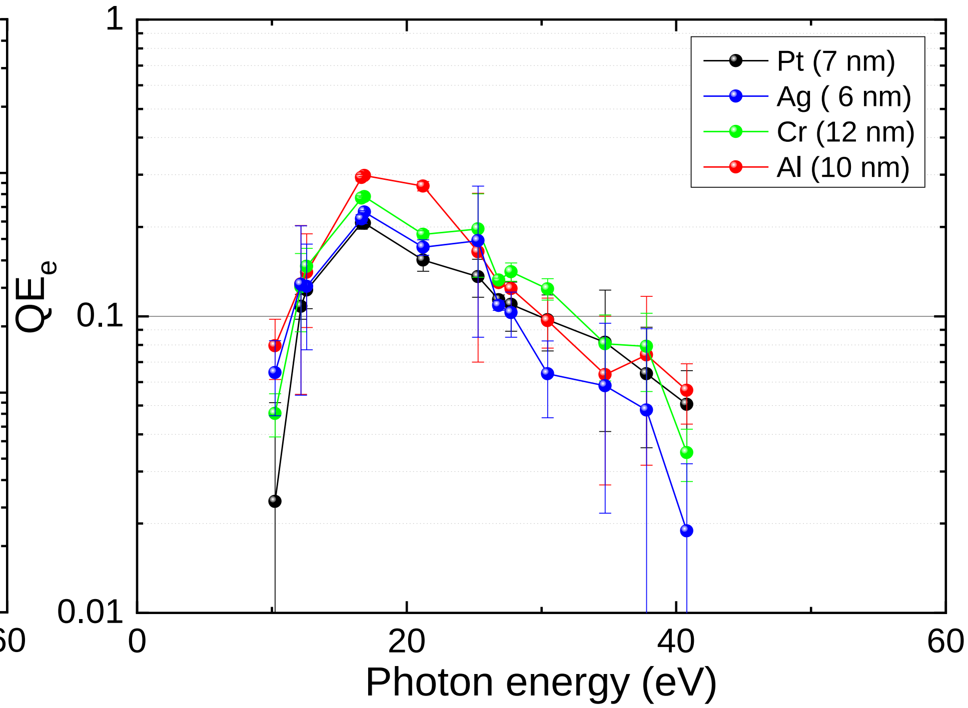
The quantum efficiency, defined by the number of photoelectrons per incident photons is given by $QE = \frac{R}{\lambda} \times (1240\ W \cdot \frac{nm}{A})$



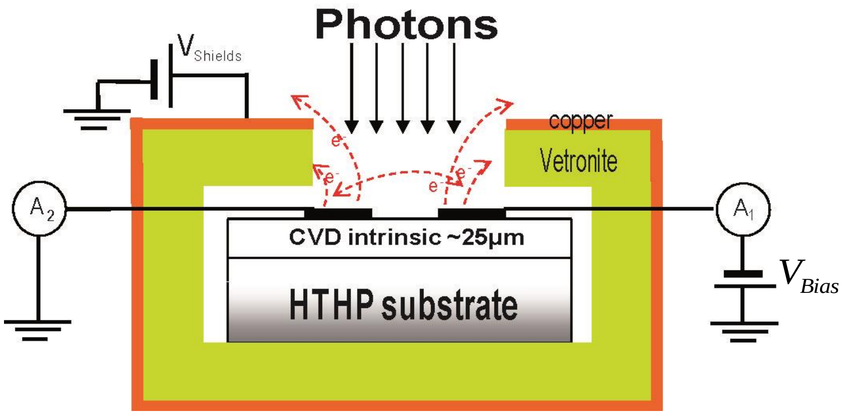
Influence of the metallic contact

- ✓ Influence of the metallic contact on the performances of extreme UV diamond detector

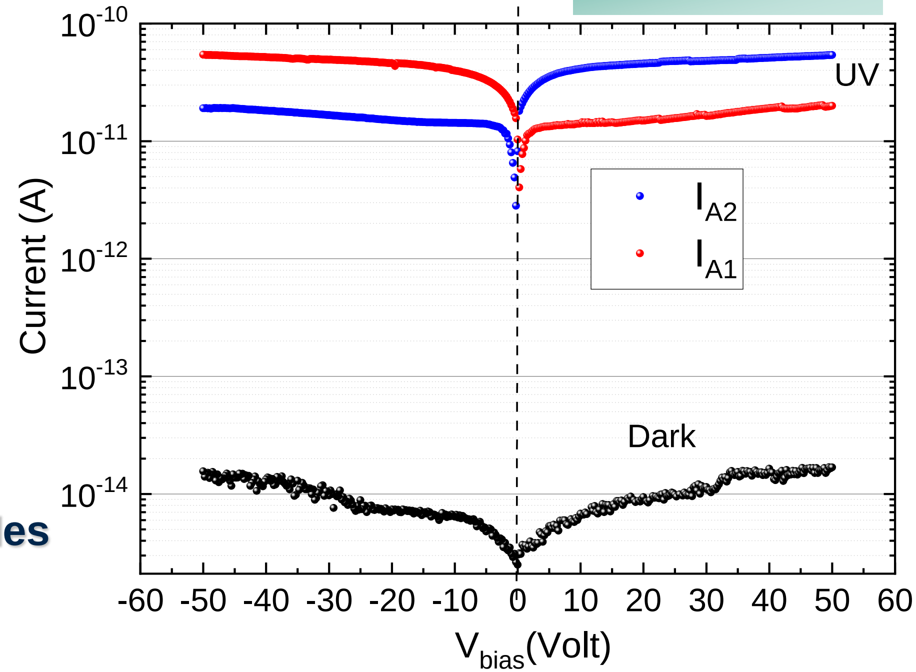




Planar configuration (interdigitated)



Photoconductive detector in planar configuration with interdigitated electrodes



$$(I_{e_{1,2}}, I_{e_{2,1}} \ll I_{e_1}, I_{e_2})$$

$$|V_{shield}| \gg |V_{bias}| > 0, \qquad V_{bias} > 0$$

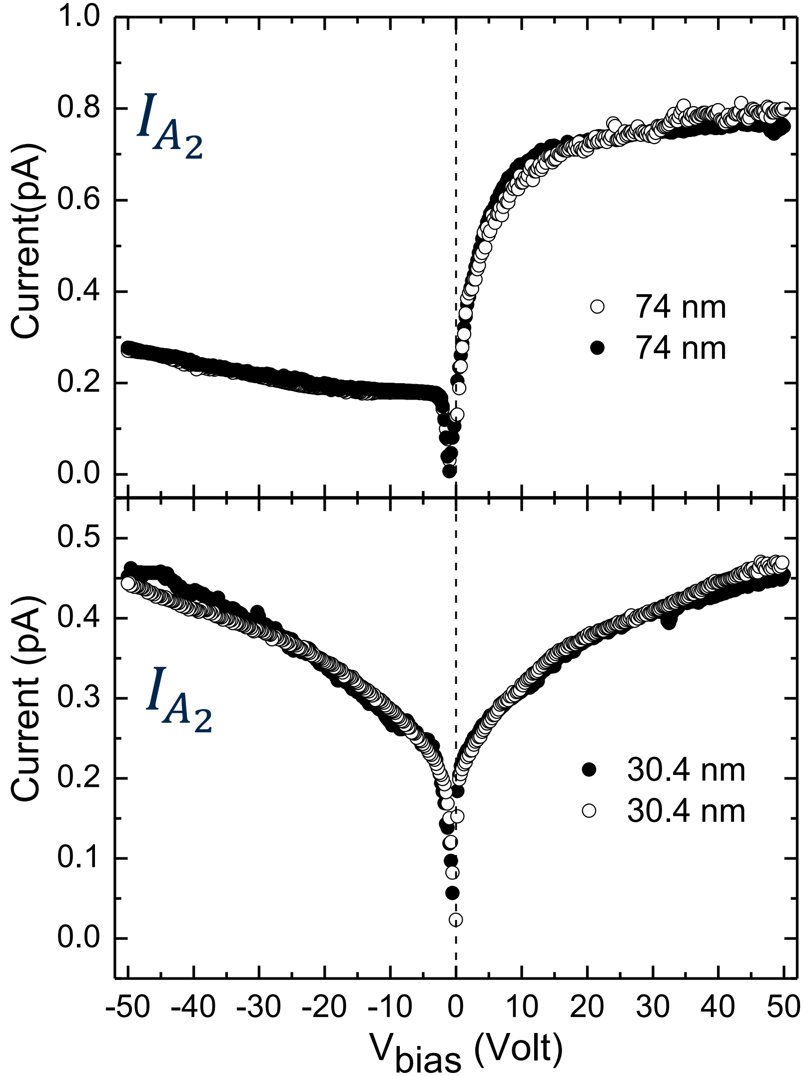
$$\begin{cases} I_{A_1} = -I_{ph} + I_{e_1} \\ I_{A_2} = I_{ph} + I_{e_2} \end{cases}$$

$$|V_{shield}| \gg |V_{bias}| > 0, \qquad V_{bias} < 0$$

$$\begin{cases} I_{A_1} = I_{ph} + I_{e_1} \\ I_{A_2} = -I_{ph} + I_{e_2} \end{cases}$$

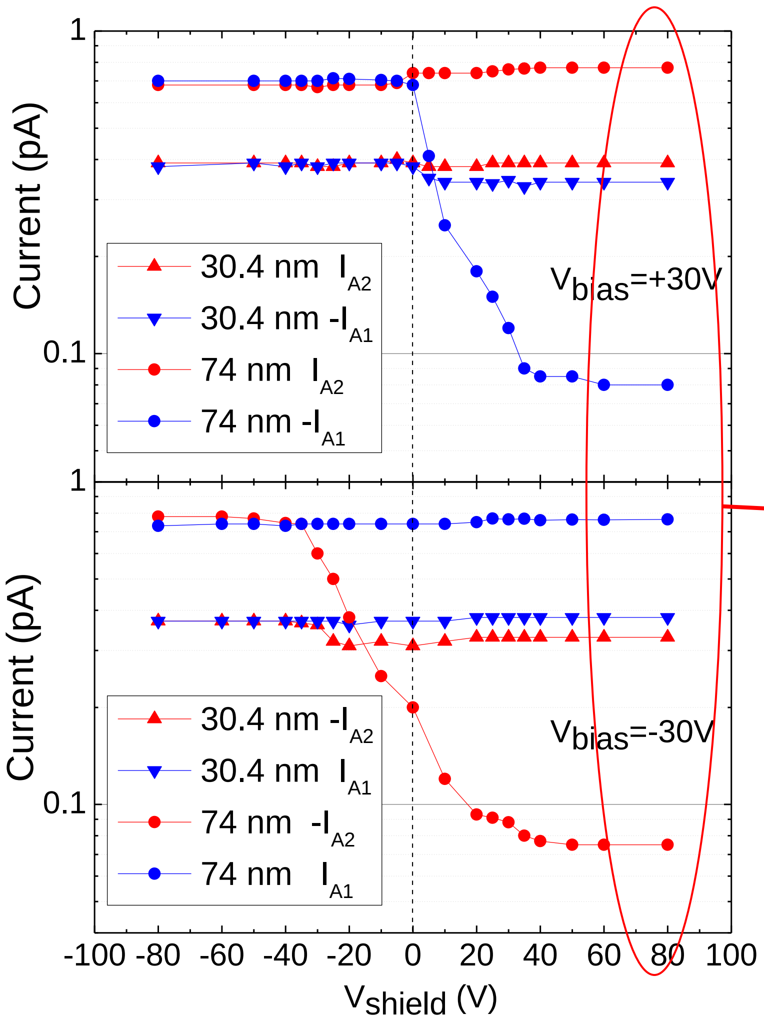
- **I-V characteristics in dark and under broadband UV irradiation**
- **Due to the symmetric geometry of the device, a symmetric I-V curve would be expected.**
- **The photoresponse depends on detector bias applied (positive or negative).**
- **The asymmetry is due to photoelectrons emission.**

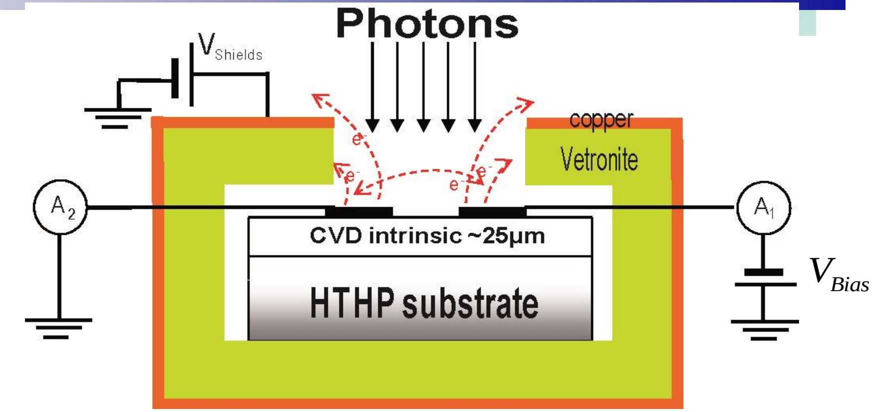
Planar configuration: I-V characteristic



- **Asymmetry depends on UV wavelengths**
- **Asymmetry more pronounced at 74 nm**

Planar configuration (interdigitated)





Photoconductive detector in planar configuration with interdigitated electrodes

$$I_{e1} \sim I_{e2} \sim I_e$$

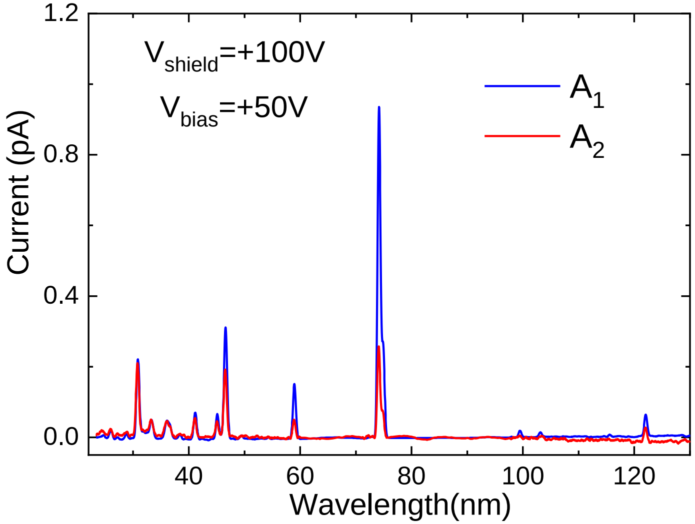
$$|V_{shield}| \gg |V_{bias}| > 0,$$

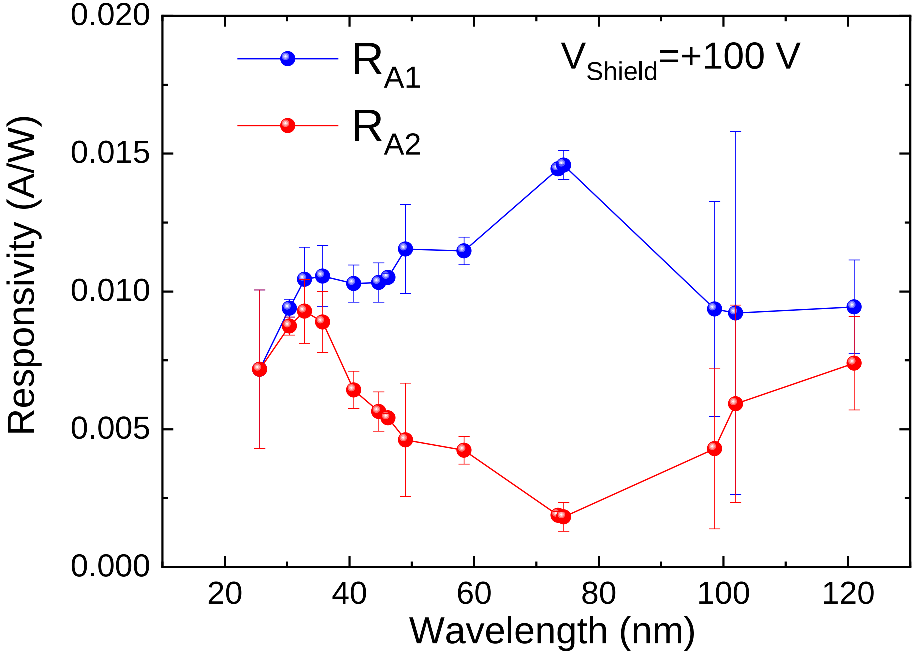
$$I_{ph} = \frac{I_{A_2} - I_{A_1}}{2}$$

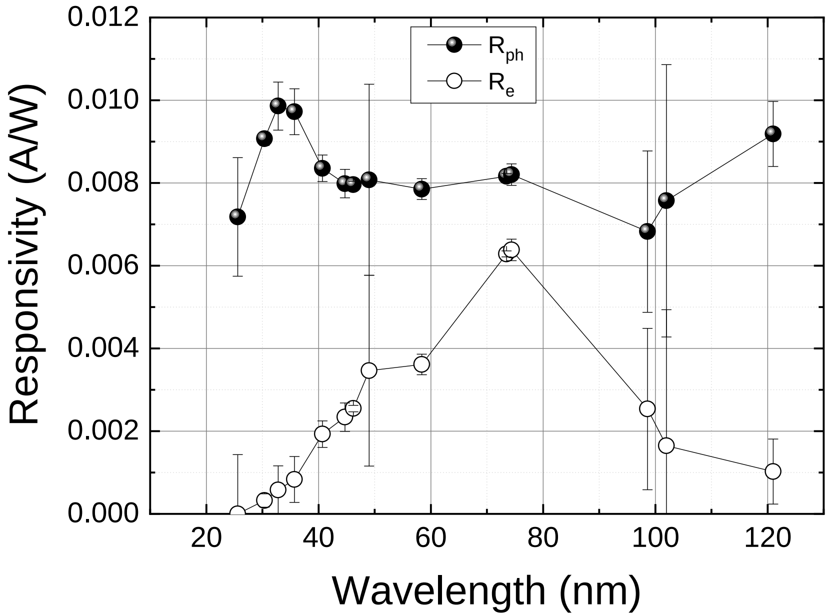
$$I_e = \frac{I_{A_2} + I_{A_1}}{2}$$

I_e~**125%** I_e $(@\lambda = 74\ nm)$

Planar configuration: Responsivity





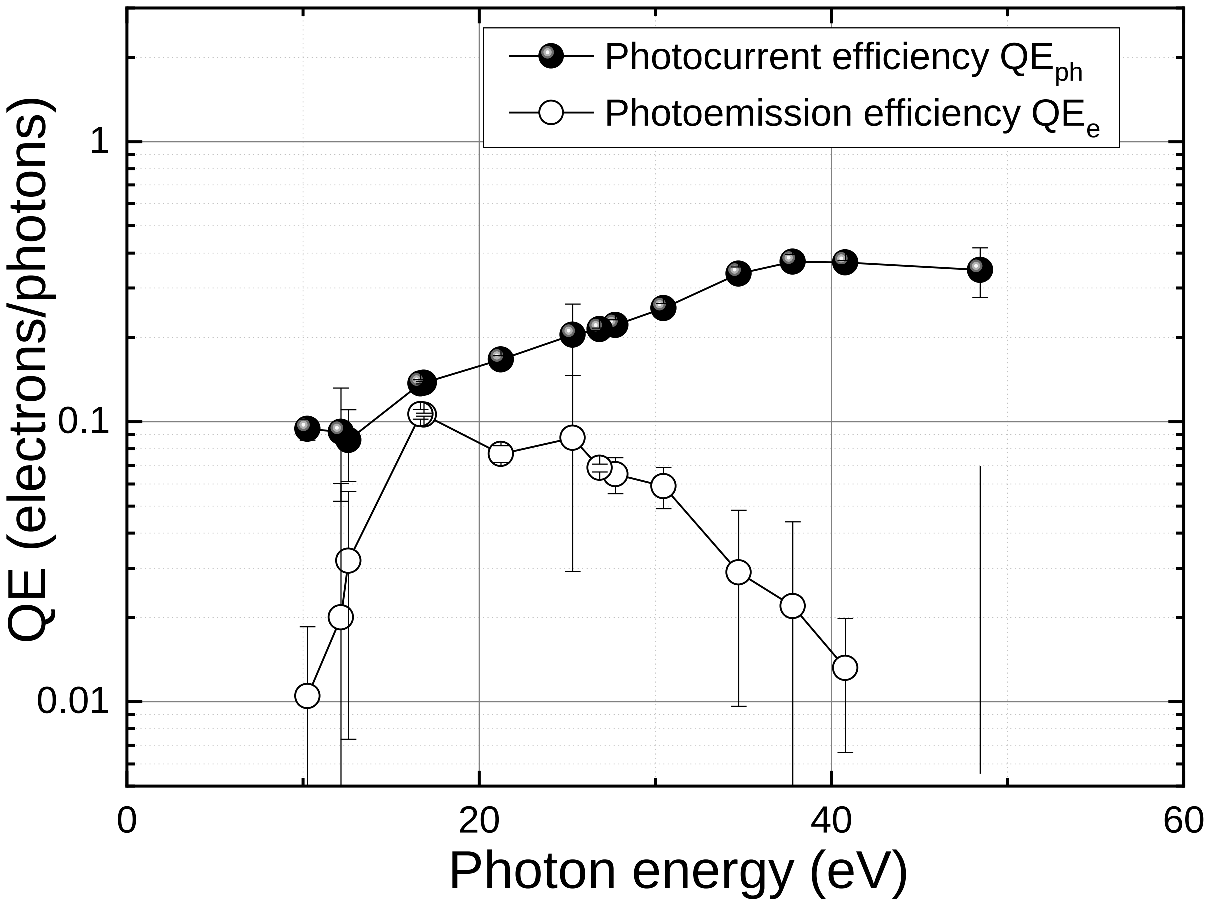


$$R_e = \frac{R_{A_2} + R_{A_1}}{2}$$

$$R_{ph} = \frac{R_{A_2} - R_{A_1}}{2}$$

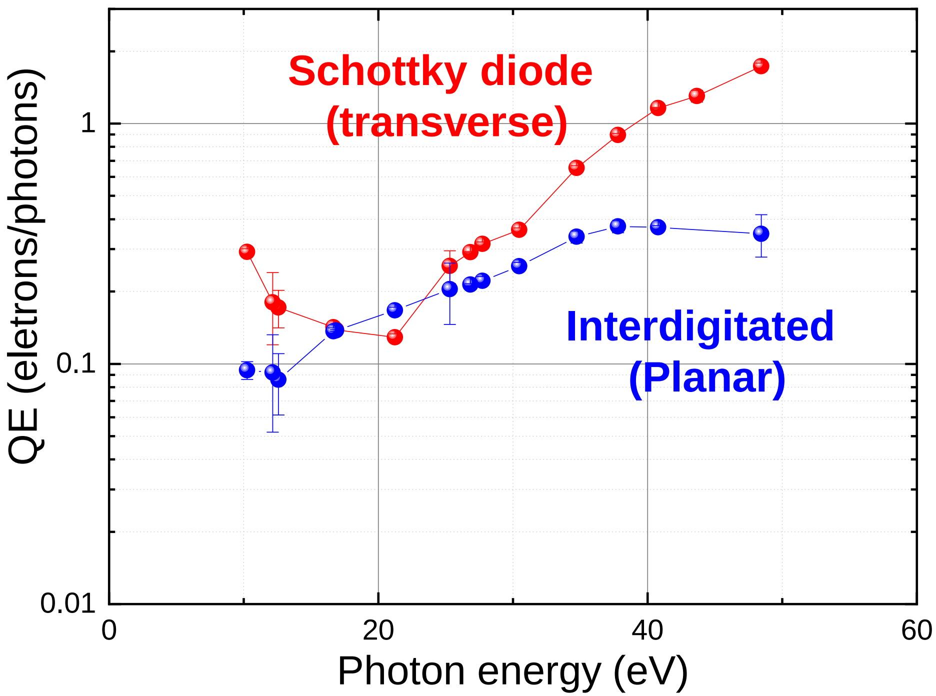
Planar configuration: Quantum efficiency

The quantum efficiency, defined by the number of photoelectrons per incident photons is given by $QE = \frac{R}{\lambda} \times (1240\ W \cdot \frac{nm}{A})$



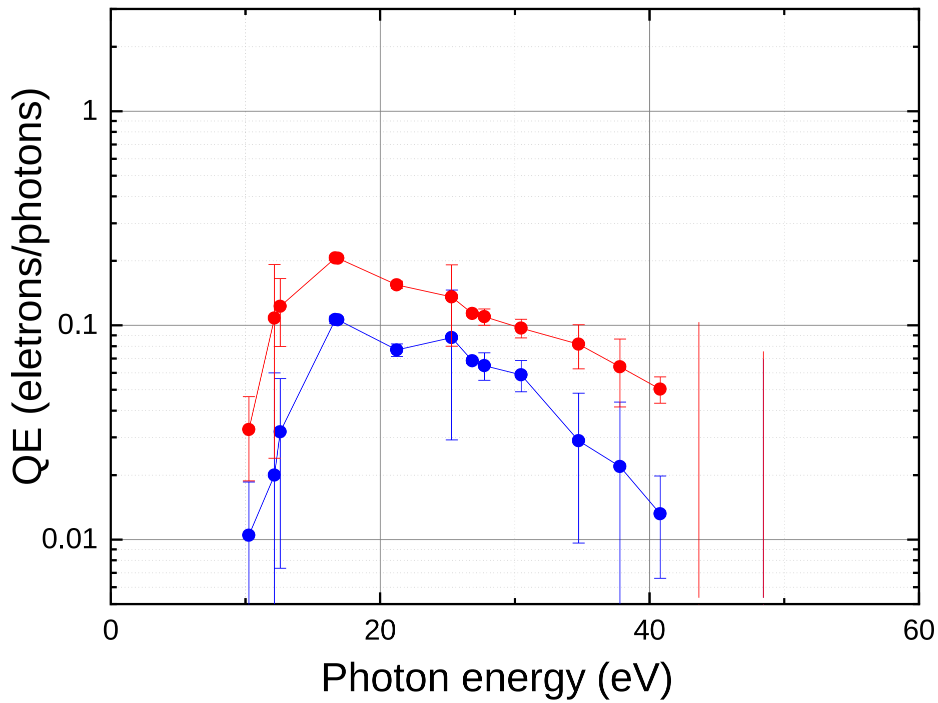
Planar/transverse comparison

QE of diamond detectors



✓Higher efficiency of the Schottky diode device with respect to the one of the interdigitated contact sample was observed at the extremes of the investigated rage (a factor 5 at 50 eV and a factor 3 at 10 eV). Similar efficiency was measured at intermediate photon energies.

QE of secondary electron emission



✓The quantum efficiency of photoelectric emission is high in the range 15-30 eV for both device and rapidly decreases towards the edge of the investigated region.

Conclusions

- ✓ An experimental set-up was arranged to separate the internal photocurrent and secondary electrons current over the 20 – 120 nm spectral range

- ✓ Photoelectric current contribution to the total output current is not negligible being dominant at especially at intermediate wavelength (50-100 nm)

- ✓ The quantum efficiency of the photoelectric current depends on the set-up conditions (*i.e.* external electric field).

- ✓ In the transverse geometry detector, the contribution of secondary electrons can be easily excluded by using proper device housing and measuring the current from the boron doped diamond backing contact (absolute calibration), while in the planar geometry detector the response is inevitably affected to the contribution of photoemission current (the calibration is non reliability).

Thank you
for your attention