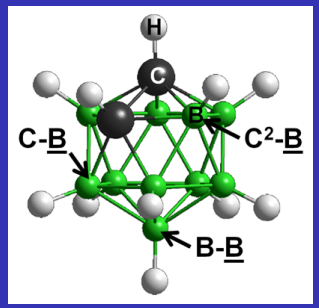
New Icosahedral Boron Carbide Semiconductors



Elena M. Echeverría

University of Nebraska-Lincoln
July 17/2017

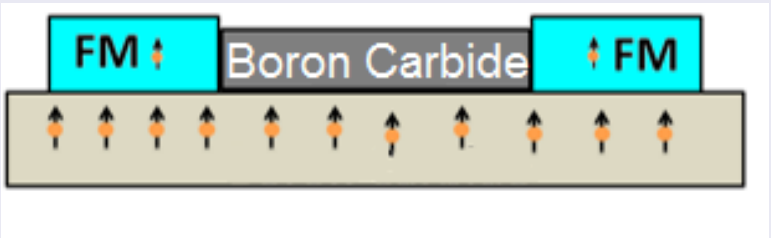
Why Semiconductor Boron Carbides

Neutron Detectors

- Portable, low weight, scalable, inexpensive (from PECVD fabrication)
- Improved charge hole separation $\Rightarrow$ better charge extraction

Devices such that ...

- Huge resistance $> 10^{12}$ Ohm·cm $\Rightarrow$ a potential dielectric gate
- Low κ $\Rightarrow$ better switching speeds



Why Neutron Detectors?

Detecting fissile materials

Studying neutrons emitted by the sun

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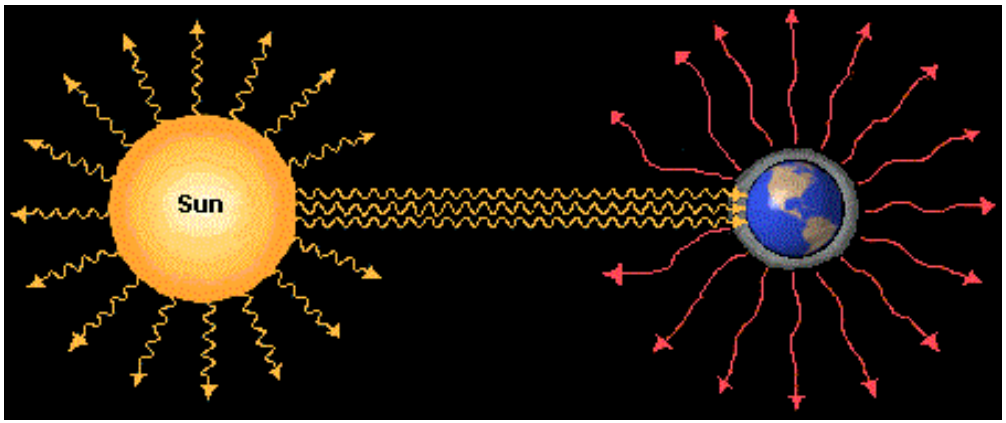
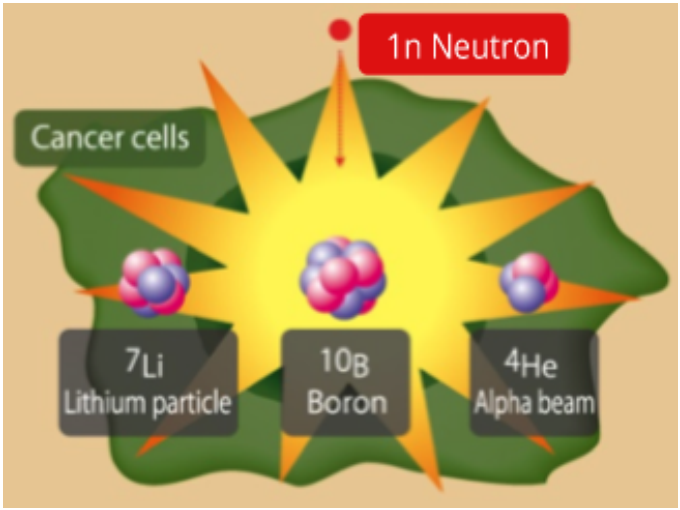


Studying neutrons emitted by the sun

Some Applications

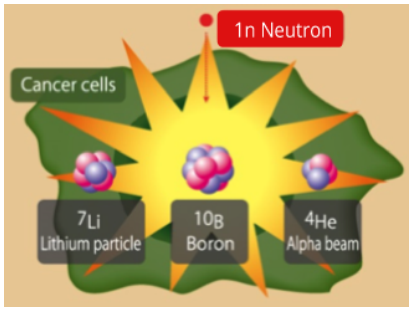


Medicine

Why Neutron Voltaics?

if neutron voltaics are possible $\Longrightarrow$ spaceships with their own power supply

Some Applications



Medicine

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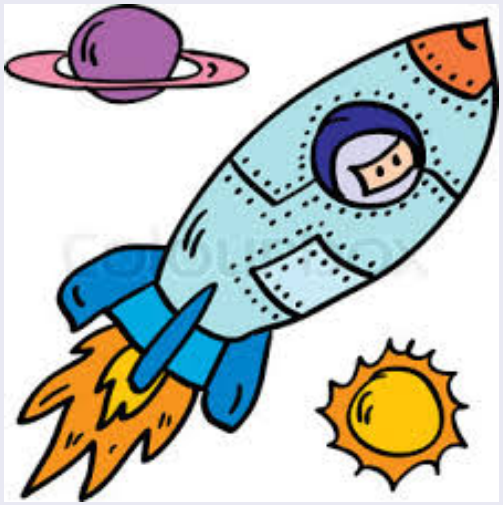
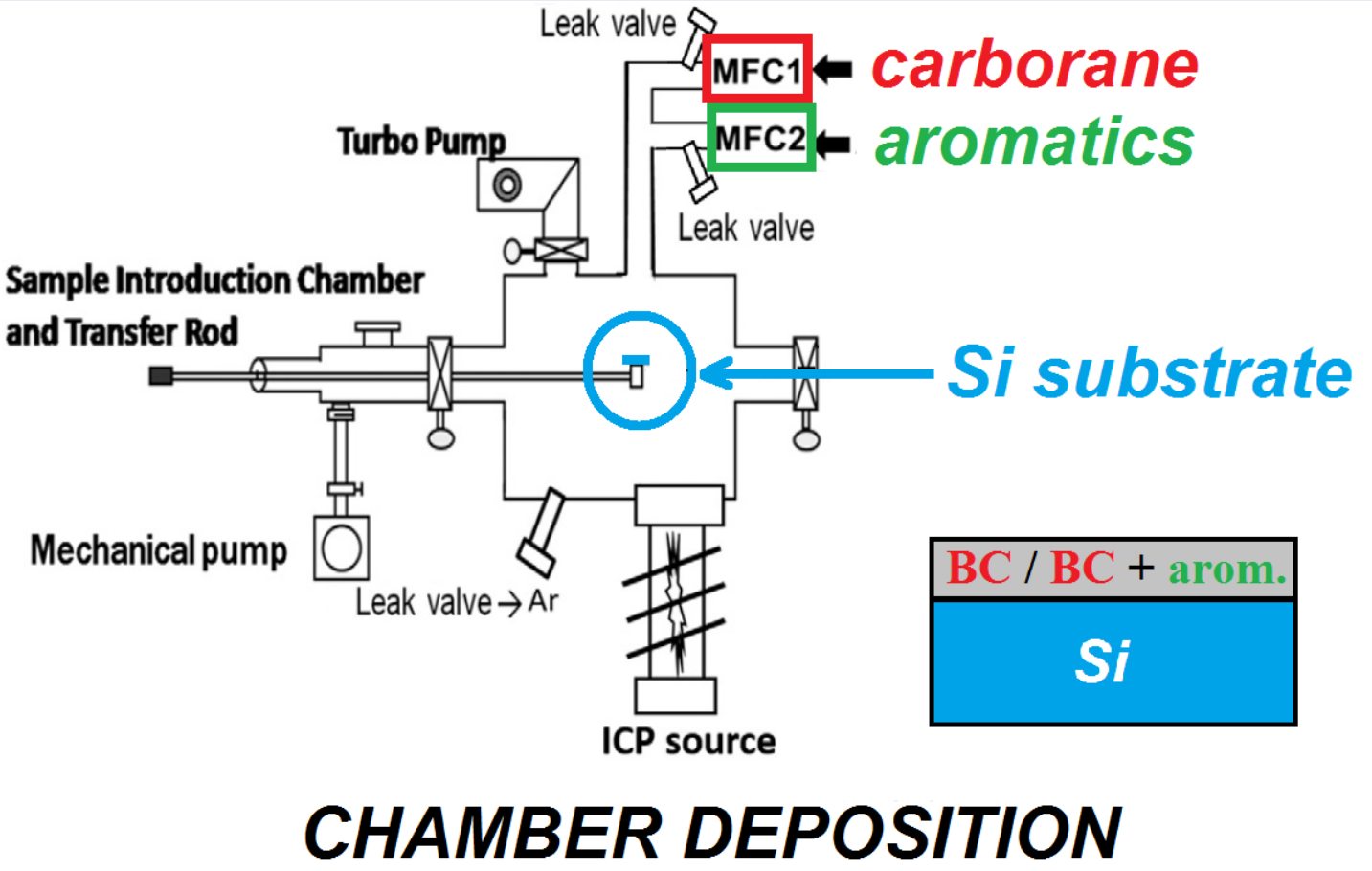


if neutron voltaics are possible $\Longrightarrow$ spaceships with their own power supply

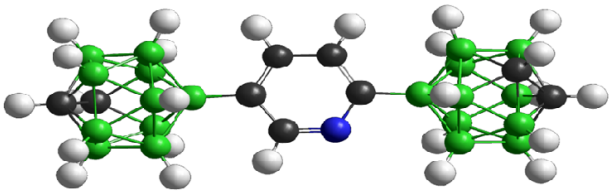
SAMPLE DESCRIPTION

How we make the semiconductor

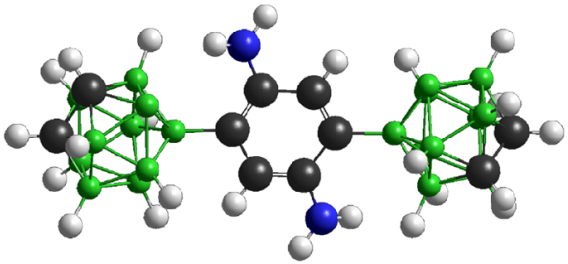
New class of polymers $B_{10}C_2H_X : Y$ formed by plasma-enhanced chemical vapor deposition (PECVD) $\Longrightarrow$ quality samples at low cost



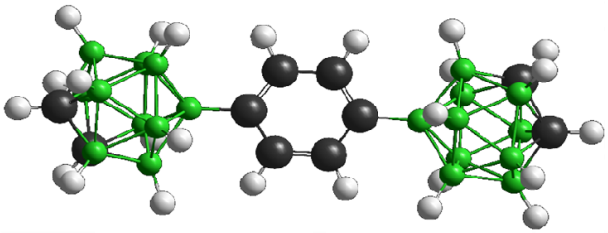
Structural models of Boron Carbide-Based Semiconductors



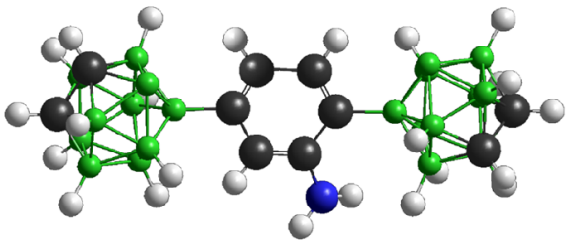
BC + pyridine



BC + diaminobenze

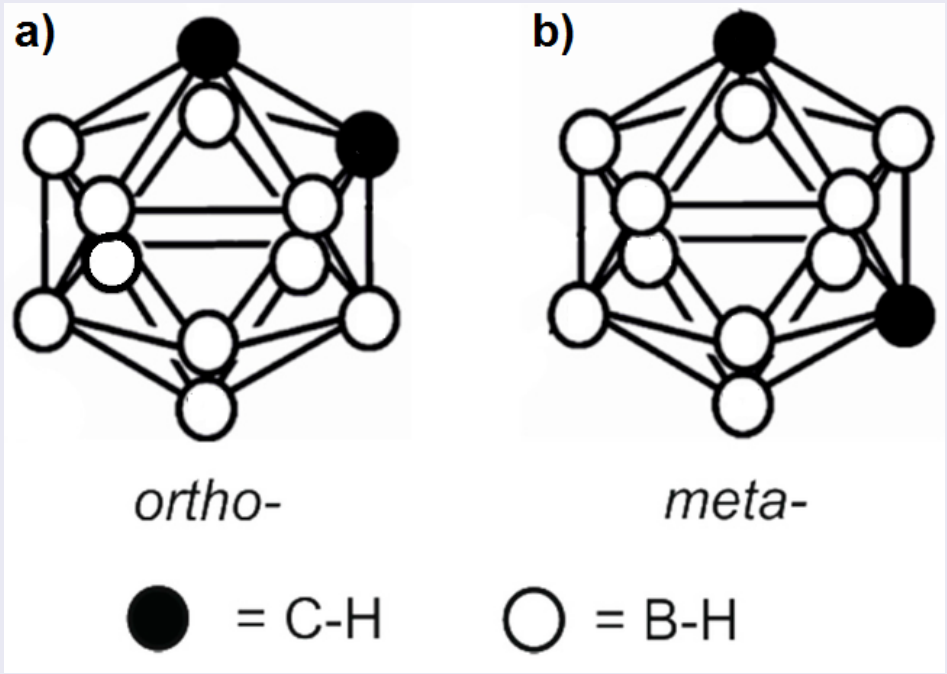


BC + benzene



BC + aniline

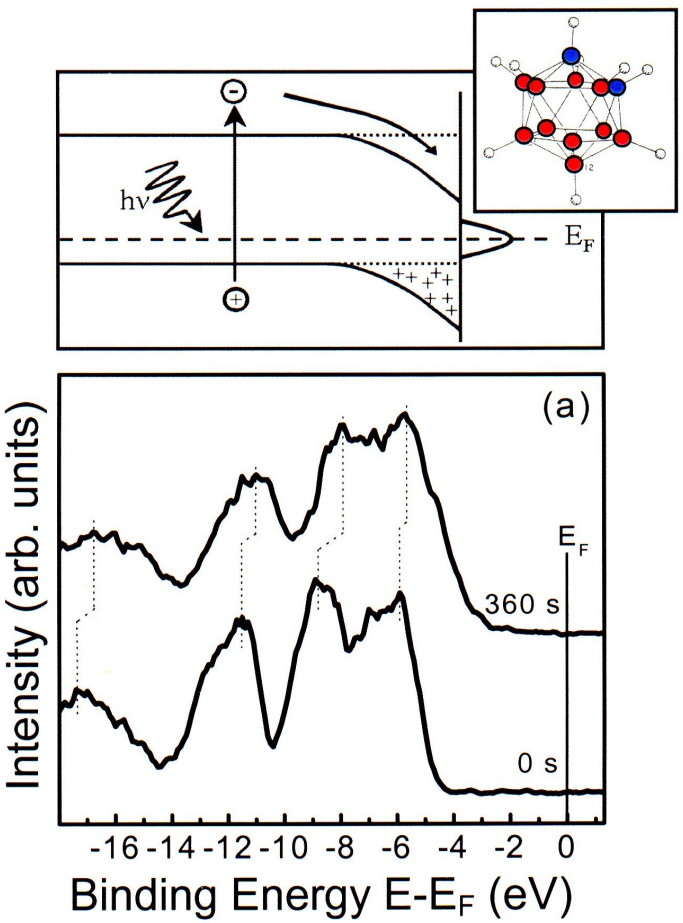
Two types of precursors: *ortho*- and *meta*-carborane



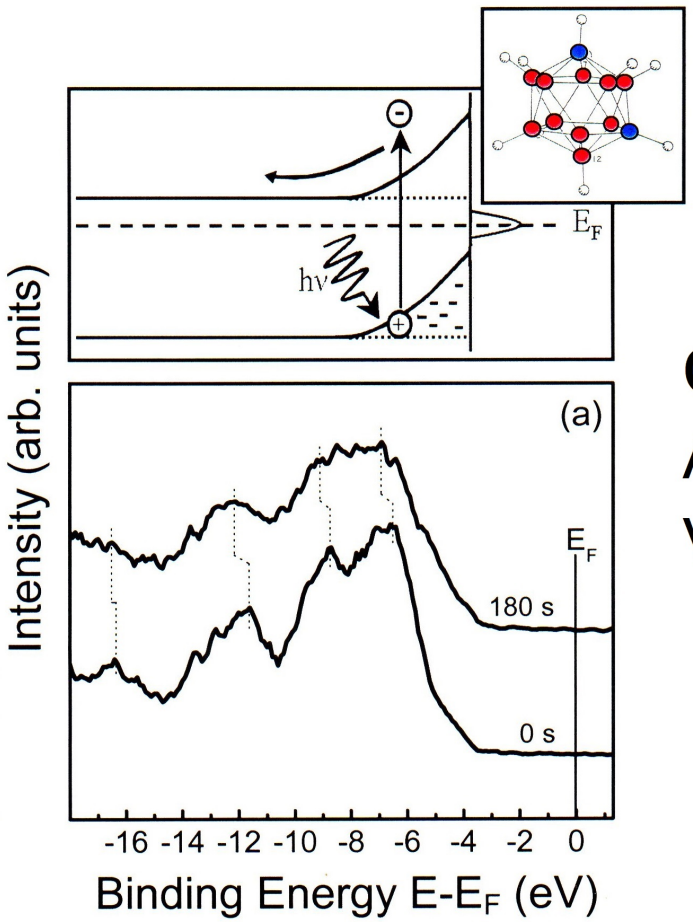
⇒ n- and p-type semiconductors

Photoemission → surface photovoltage effects

ortho-carborane



meta-carborane

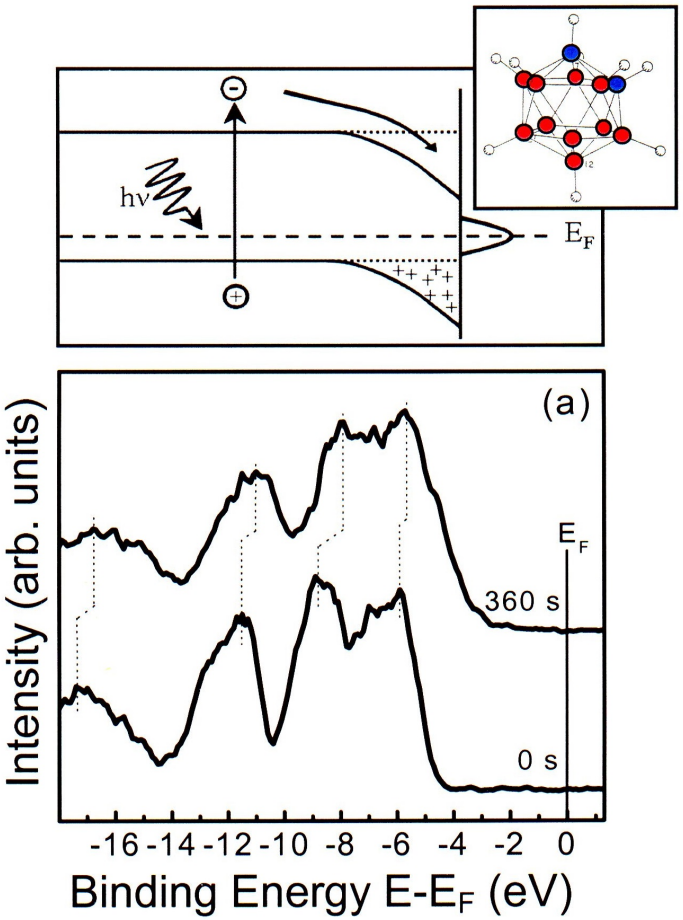


Caruso, A.N, et al., Appl. Phys. Lett., Vol **84** (2004)

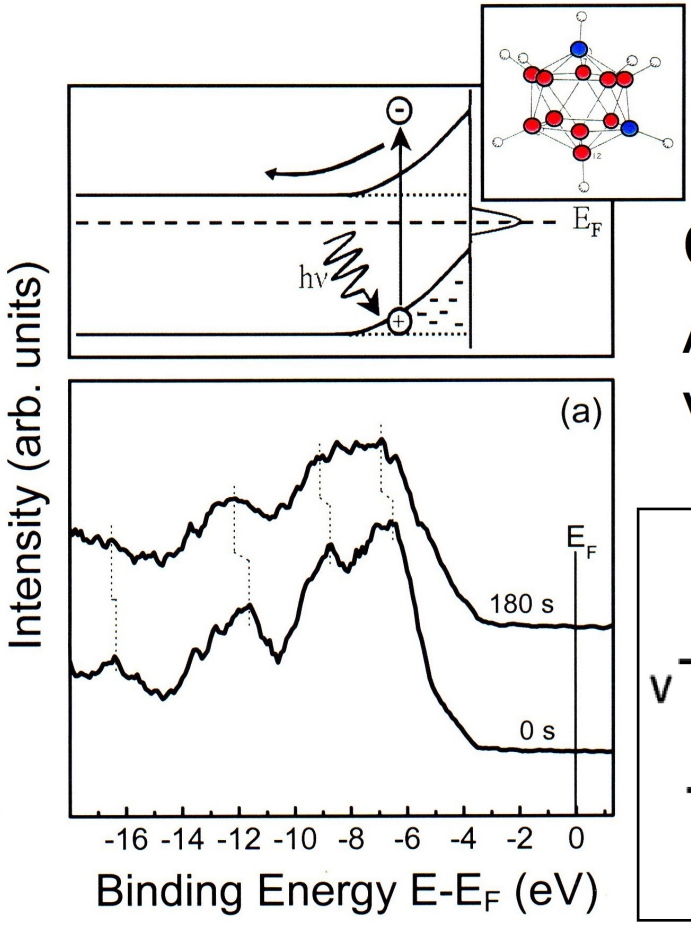
Band Bending ⇒ metal/semiconductor interface studies

Photoemission → surface photovoltage effects

ortho-carborane



meta-carborane



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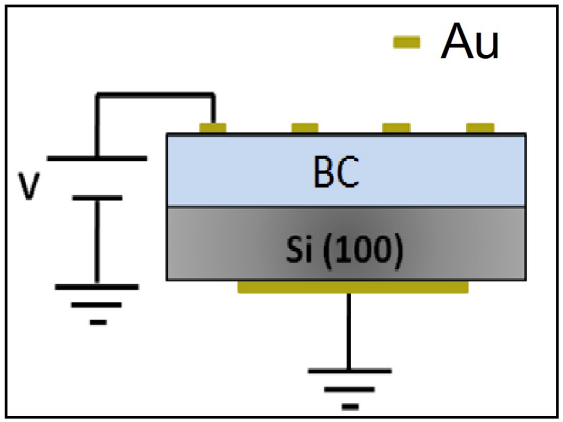
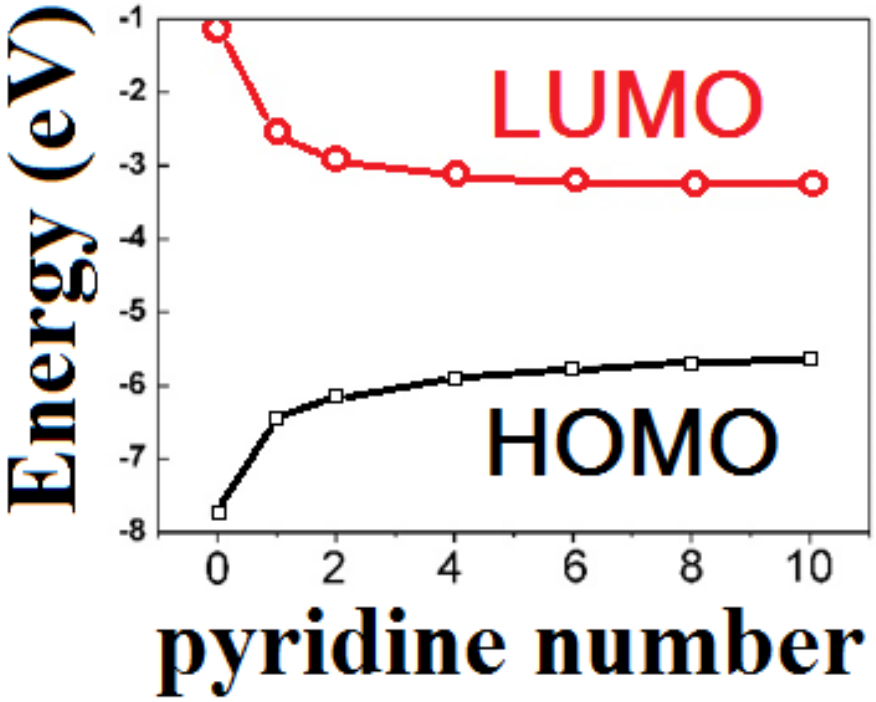


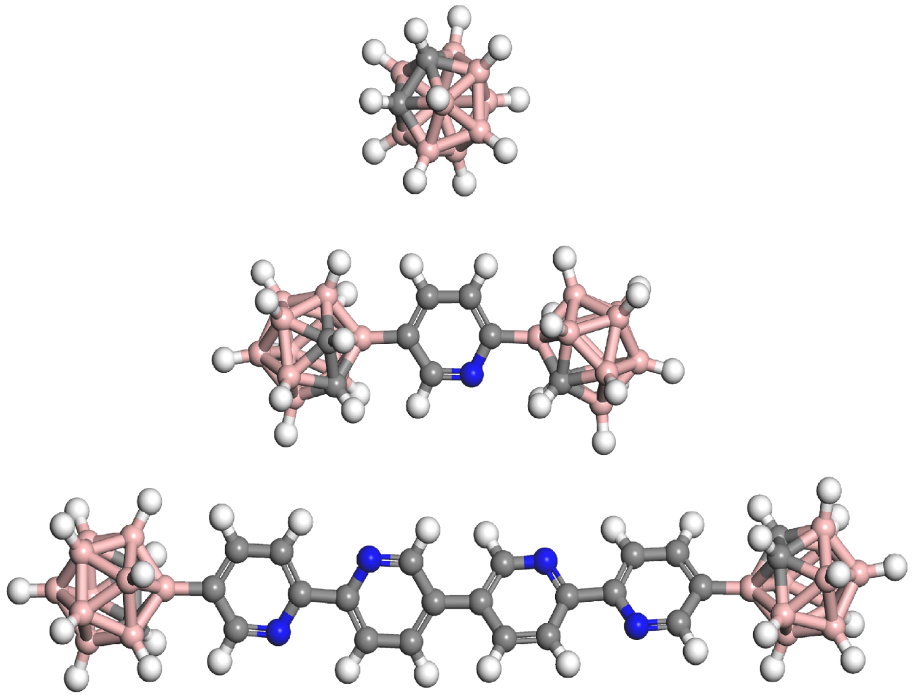
Contacts are important!

EFFECTS OF DOPING WITH AROMATICS COMPOUNDS

Effects of aromatic compound inclusion
Band Gap Decreases

High concentrations ⇒ 2.7 eV





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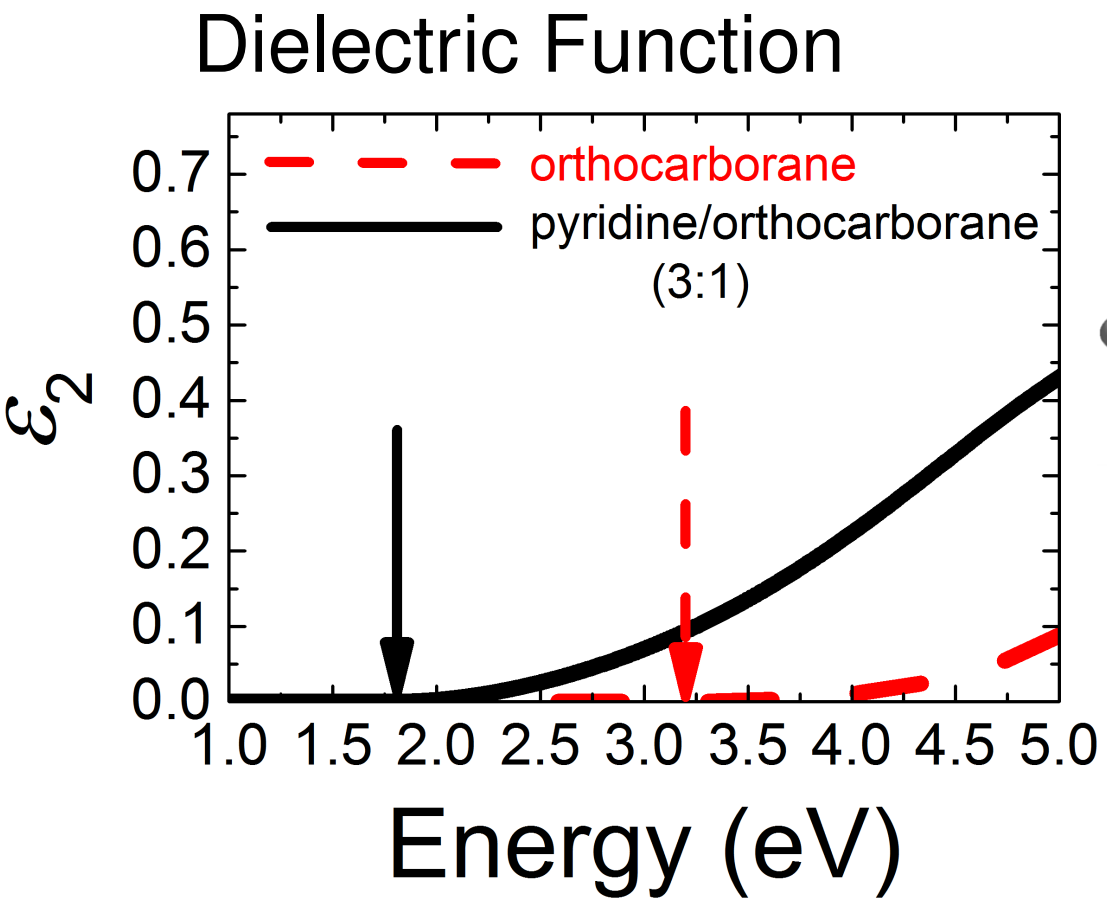
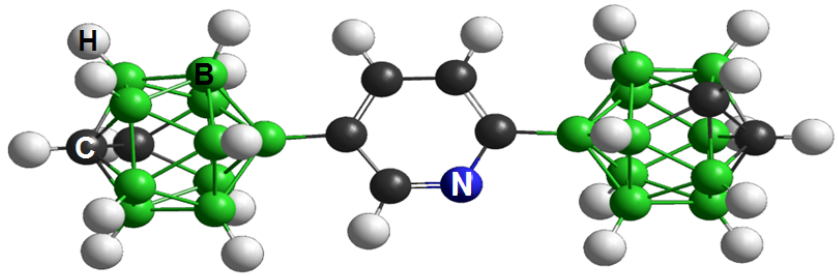
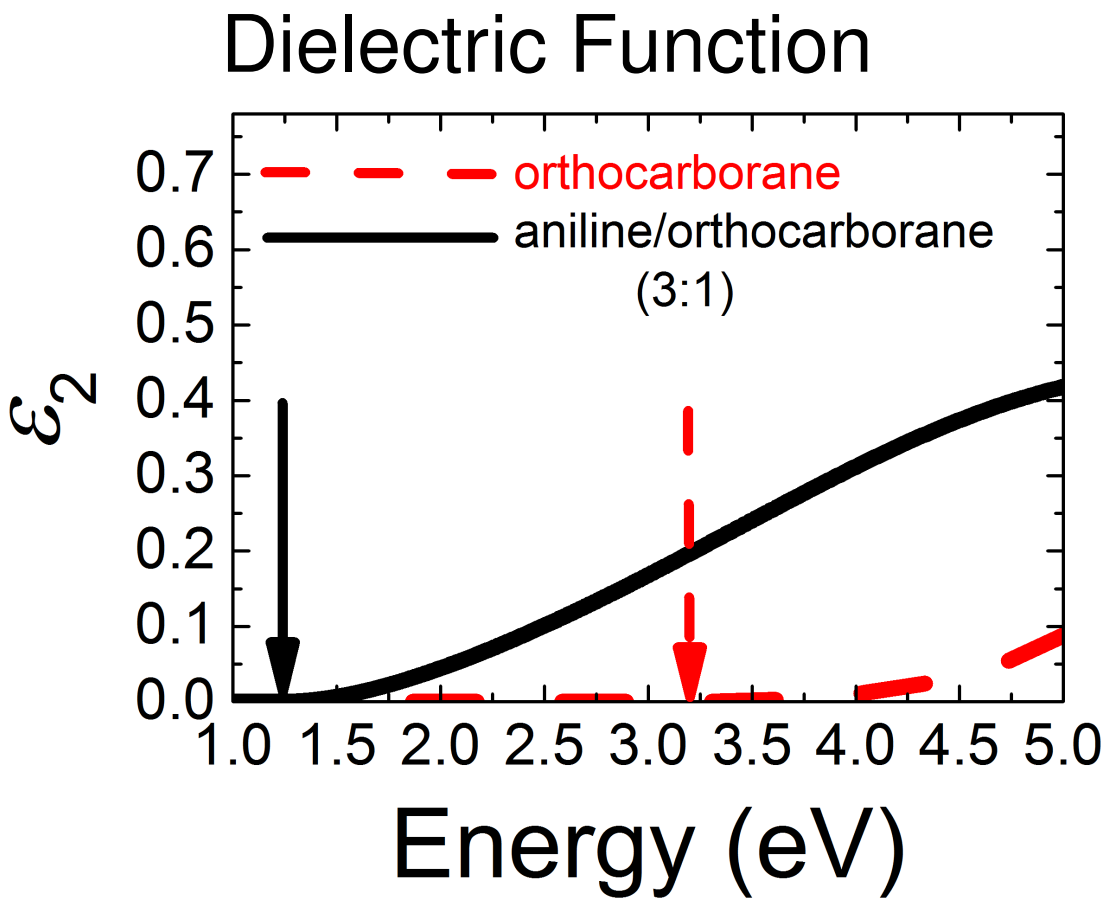


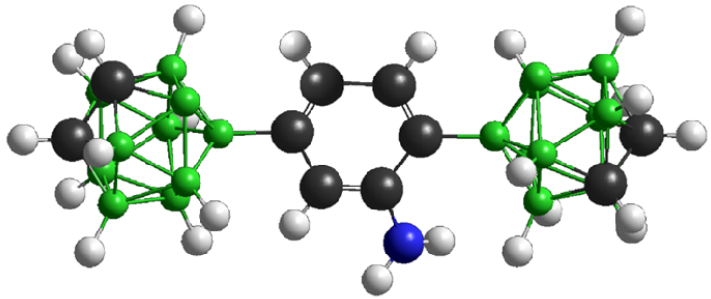


$B_{10}C_2H_X$: Py

from 3.2 eV → 1.8 eV

Effects of aromatic compound inclusion
Band Gap Decreases

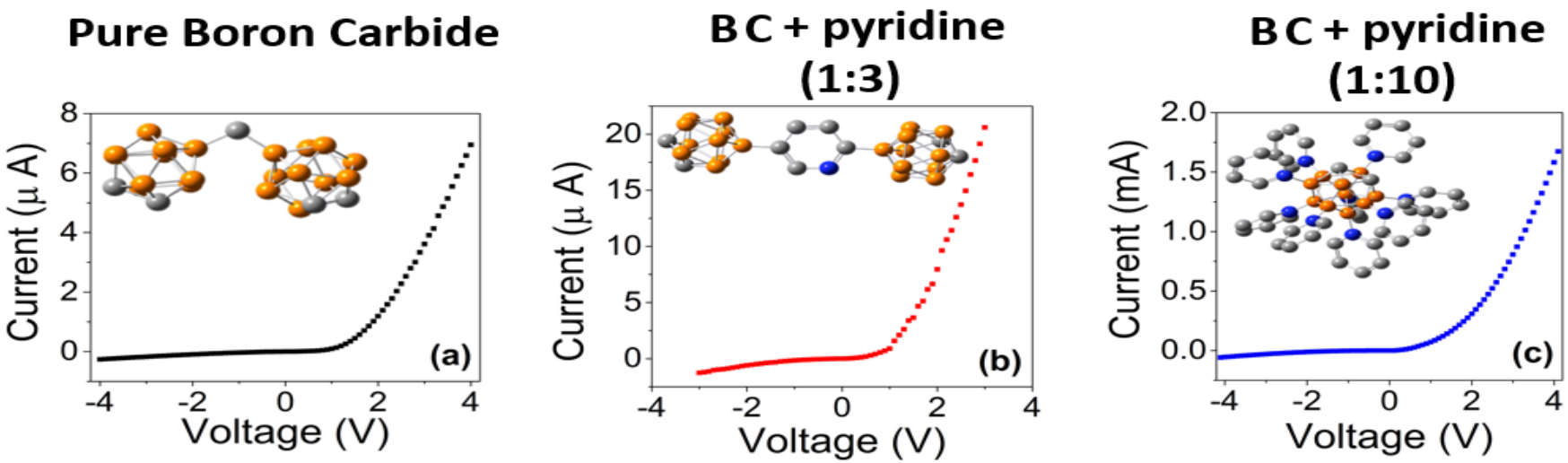




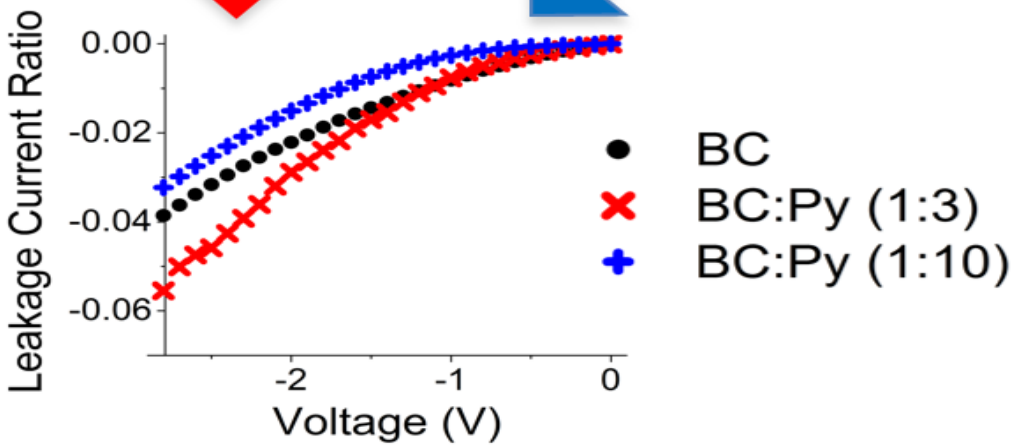
$B_{10}C_2H_X$: Aniline

from 3.2 eV → 1.3 eV

Effects of arom. inclusion → Better rectification



LEAKAGE CURRENT IMPROVED WITH Py ADDITION



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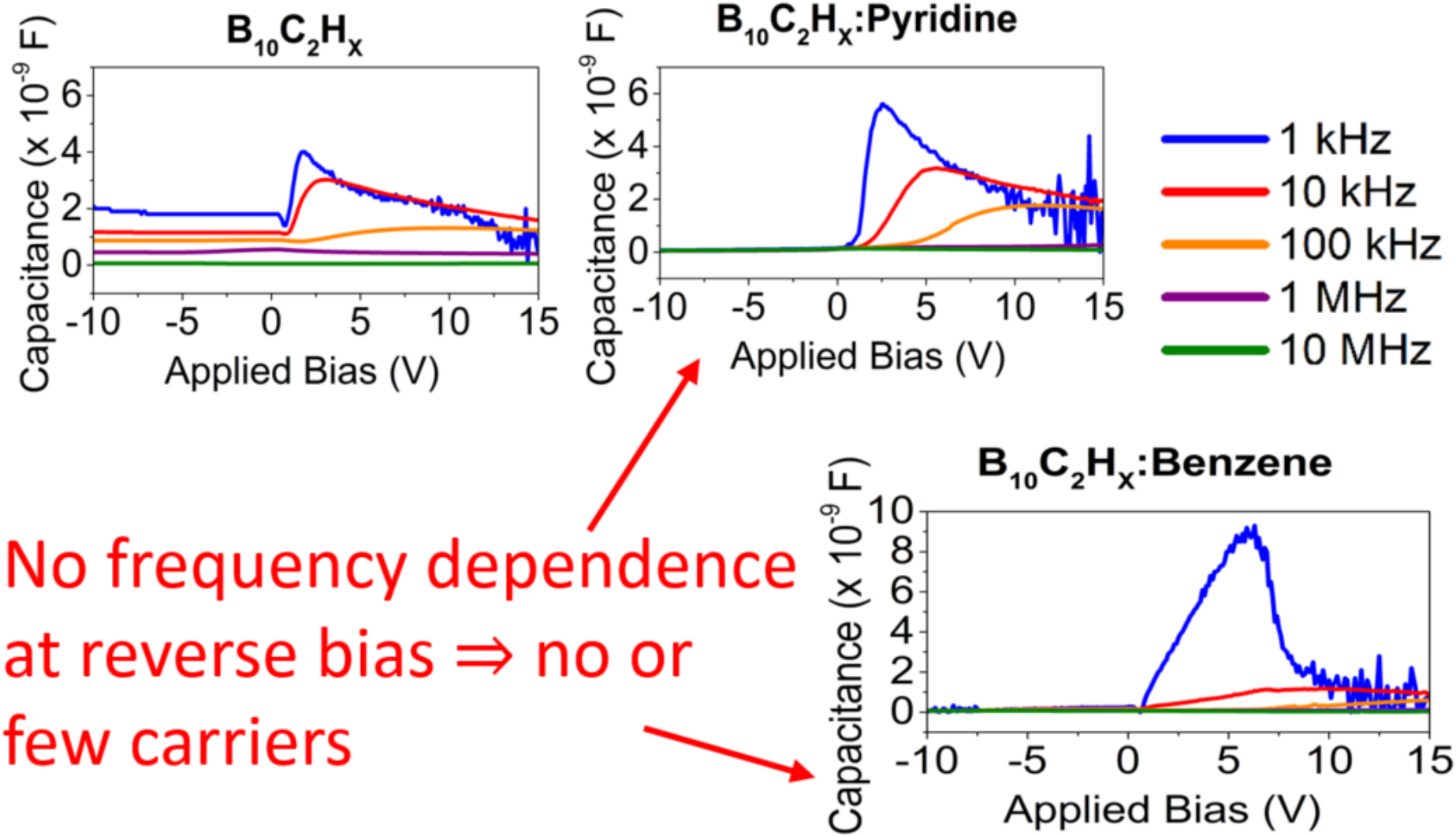
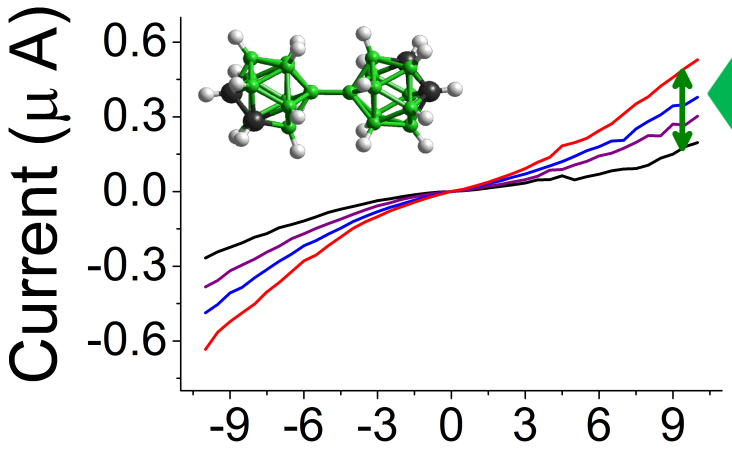


Novel boron carbide-based semiconductors with enhance electron-hole separation

SAMPLE	o-carborane based (s)	m-carborane based (s)
Pure PECVD Boron Carbide	$\leq 35 \times 10^{-6}$	50×10^{-9}
Pyridine doped PECVD	350×10^{-6}	Not measured yet
Benzene doped PECVD	2.5×10^{-3}	300×10^{-9}

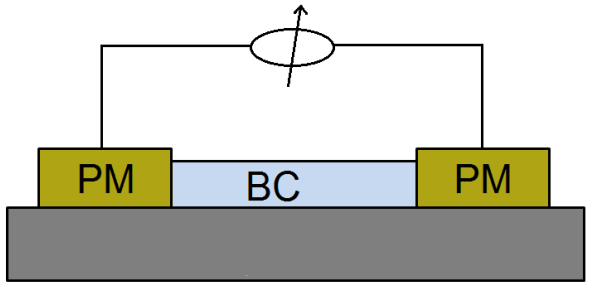
Inclusion of the aromatic compounds leads to increases in hole carrier lifetimes

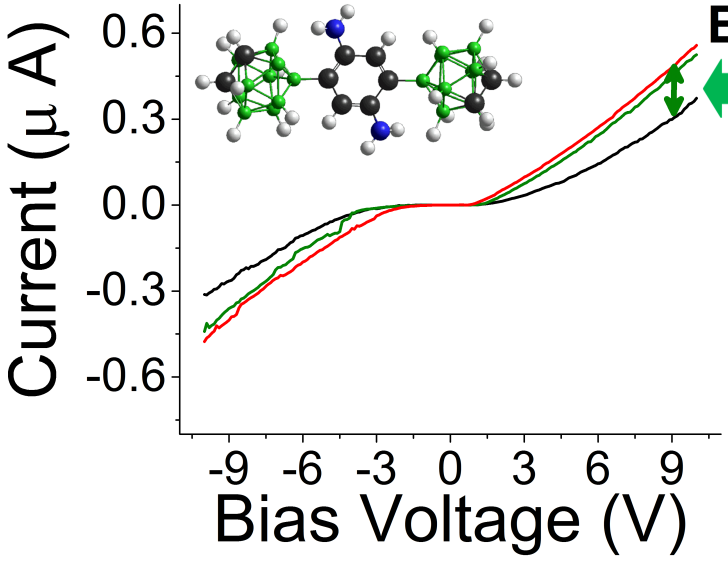
Magneto-resistence measurements



Pure BC
50% to 250% change in magneto-resitance

0 Tesla
1 Tesla





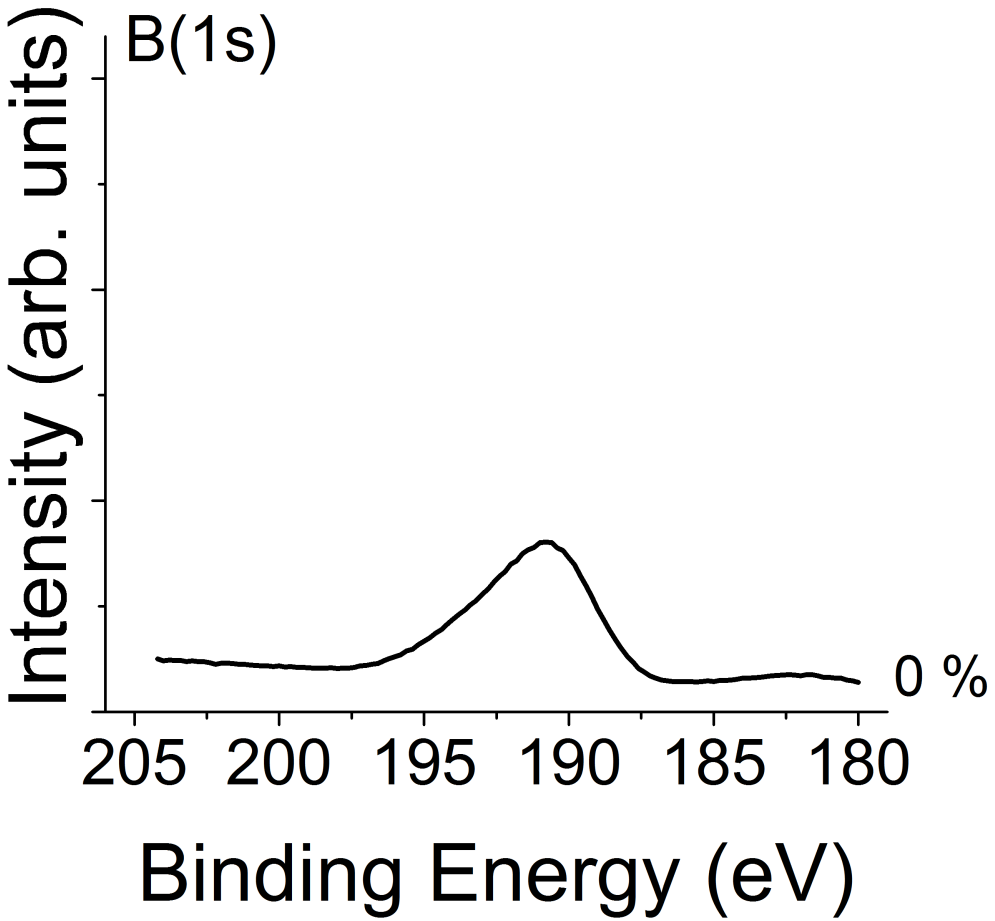
BC:Diaminobenzene
50% to 110% change in magneto-resitance

Smaller magneto-resistance consistent with the longer carrier lifetimes

EFFECTS OF GOLD DEPOSITION

But contacts are also important ... Au/Semiconductor Interface by XPS analysis

Pure p-type semiconductor and $\Phi_M > \Phi_S$



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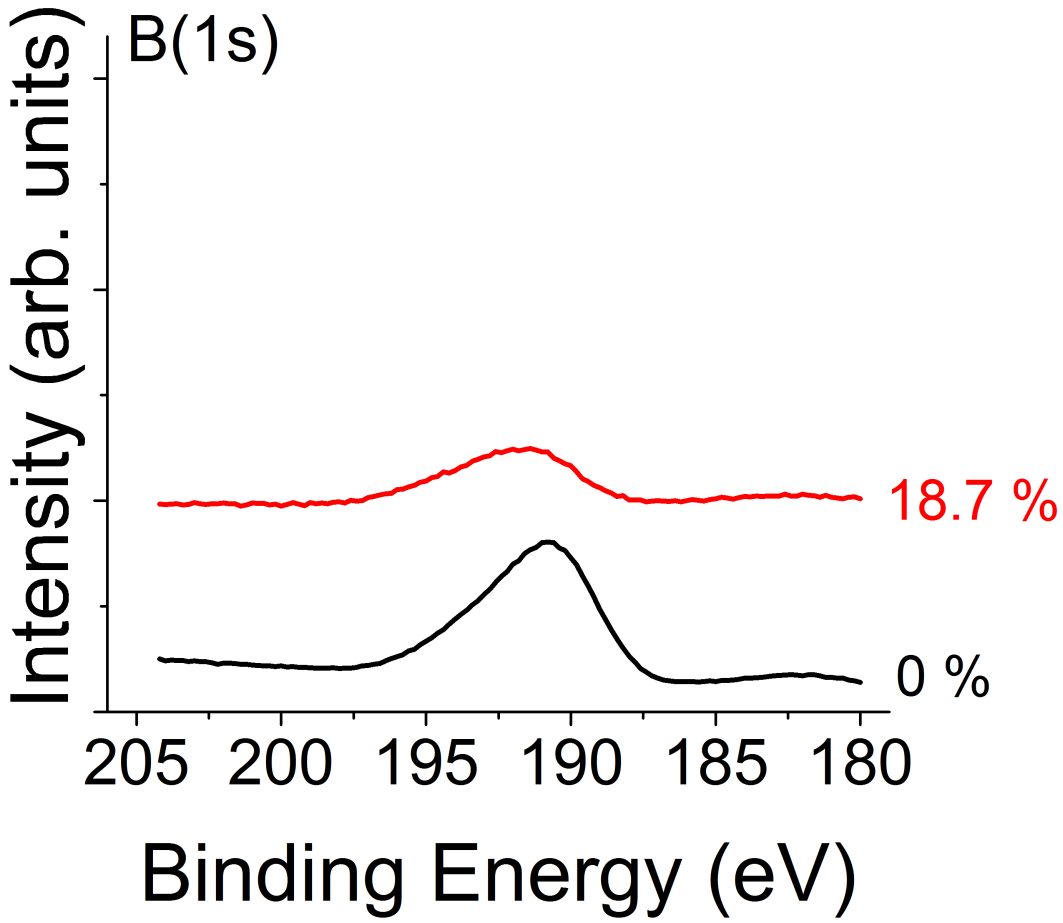

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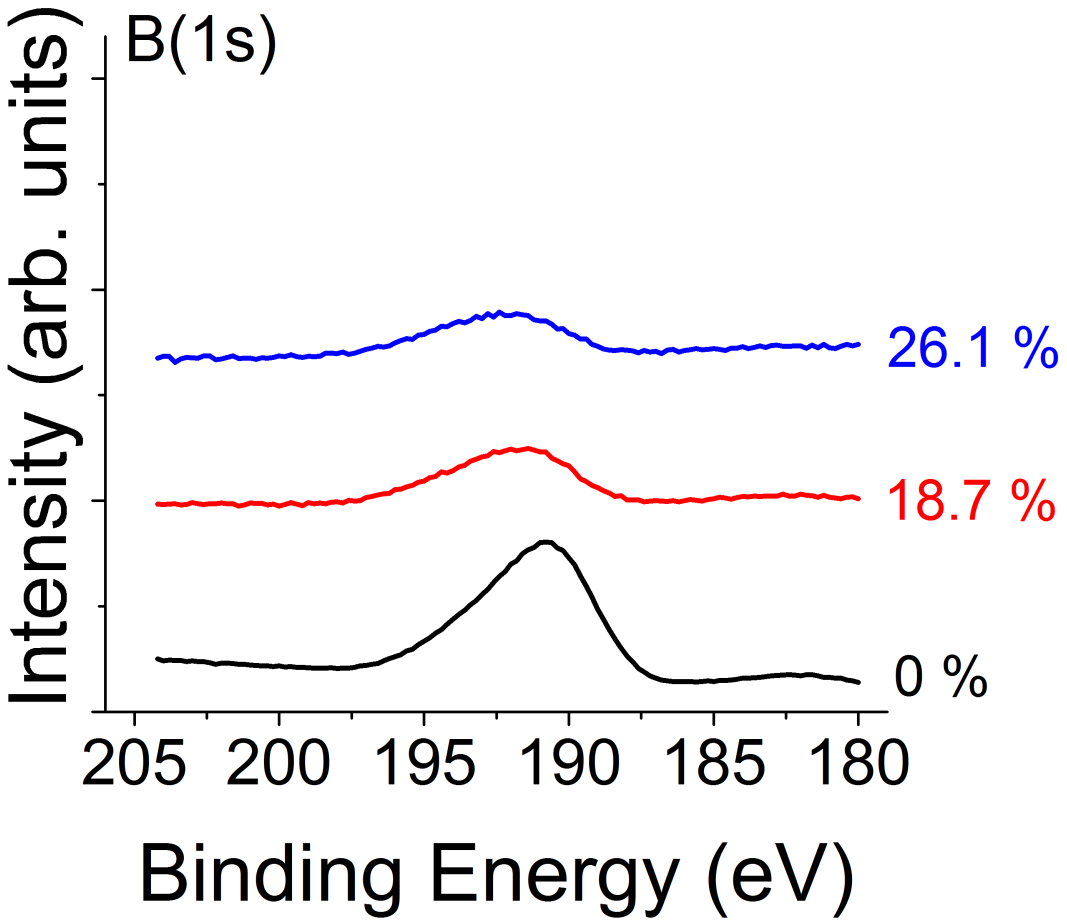

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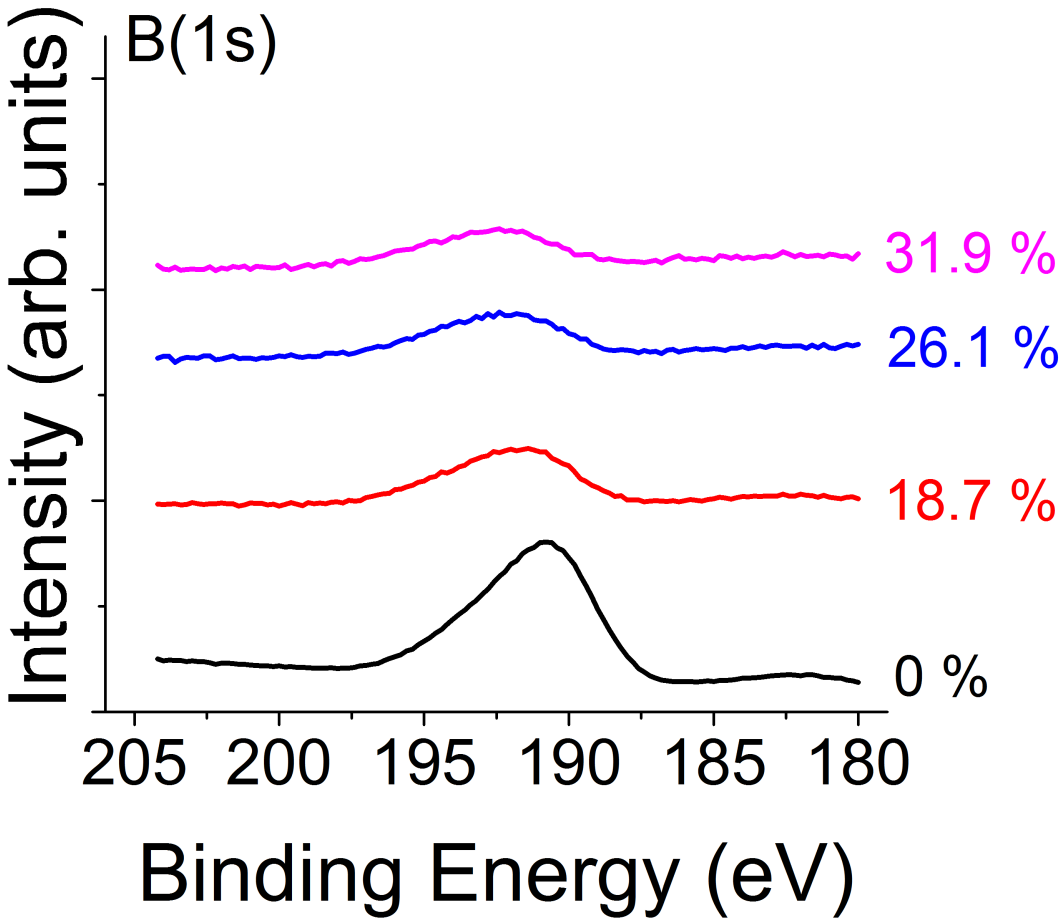

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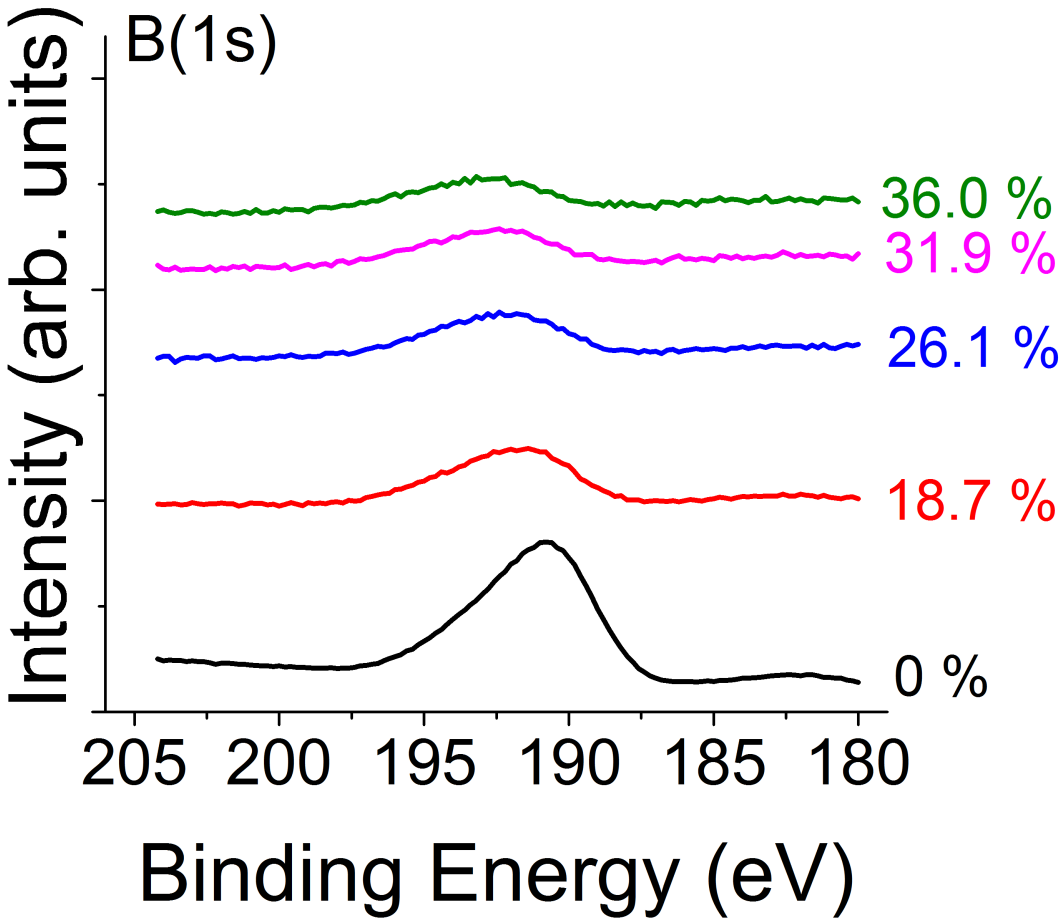

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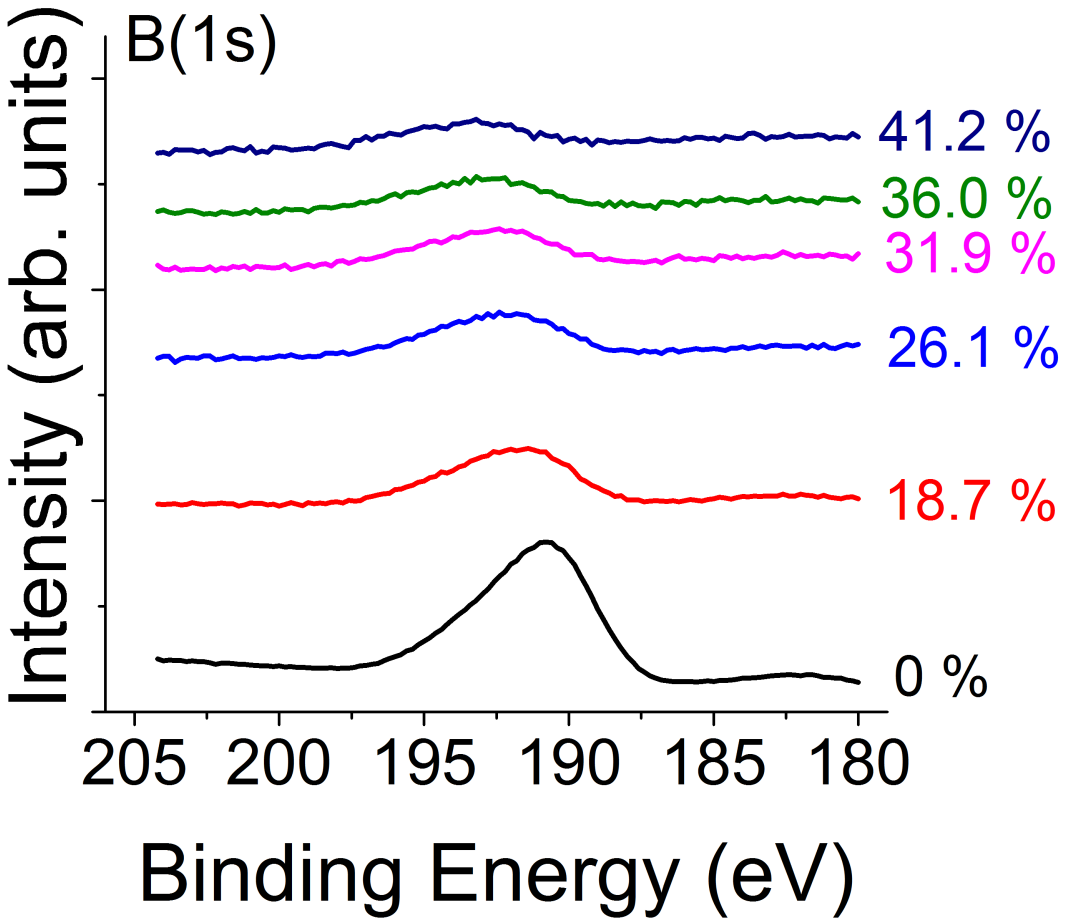

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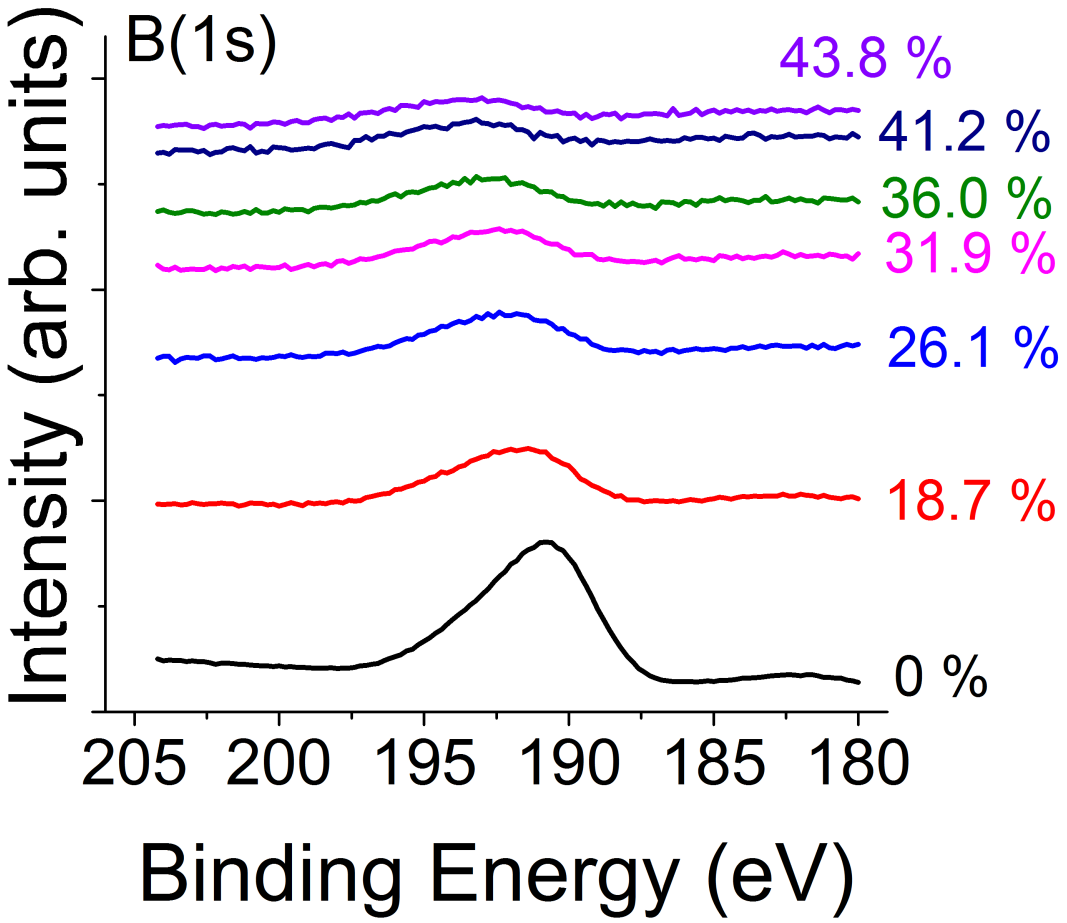

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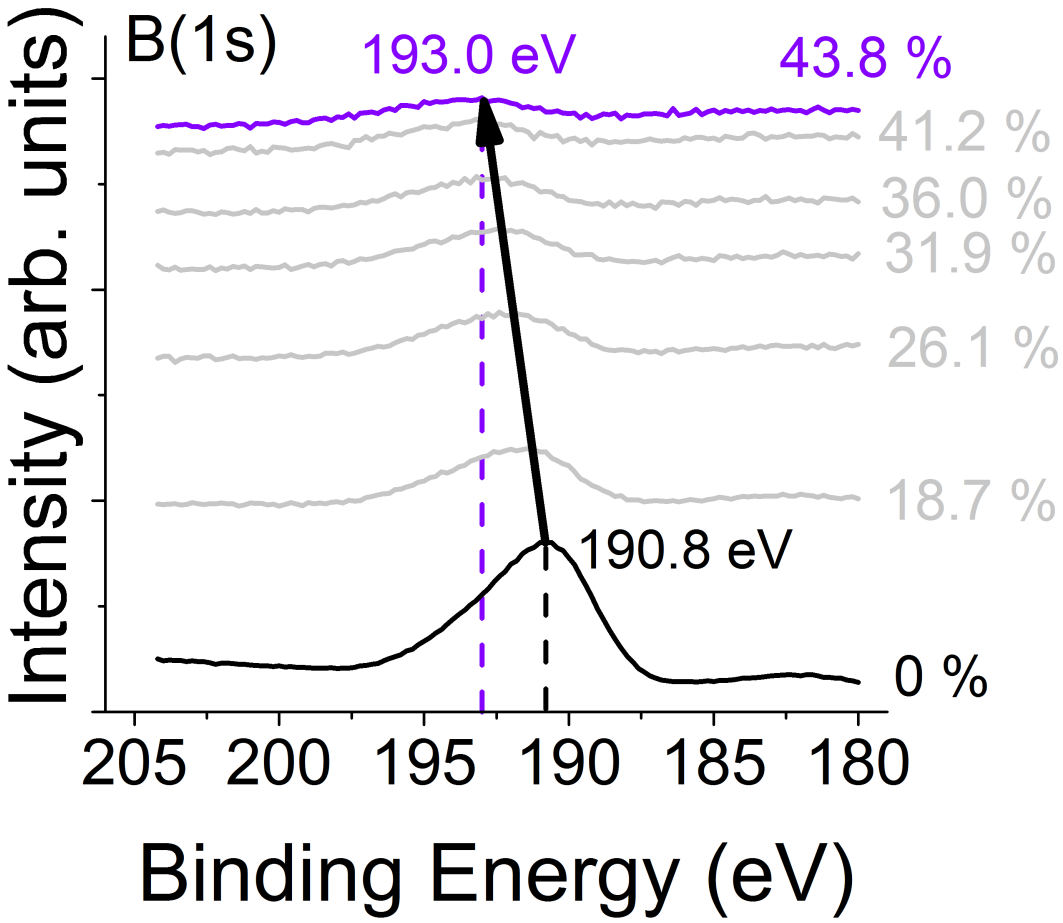

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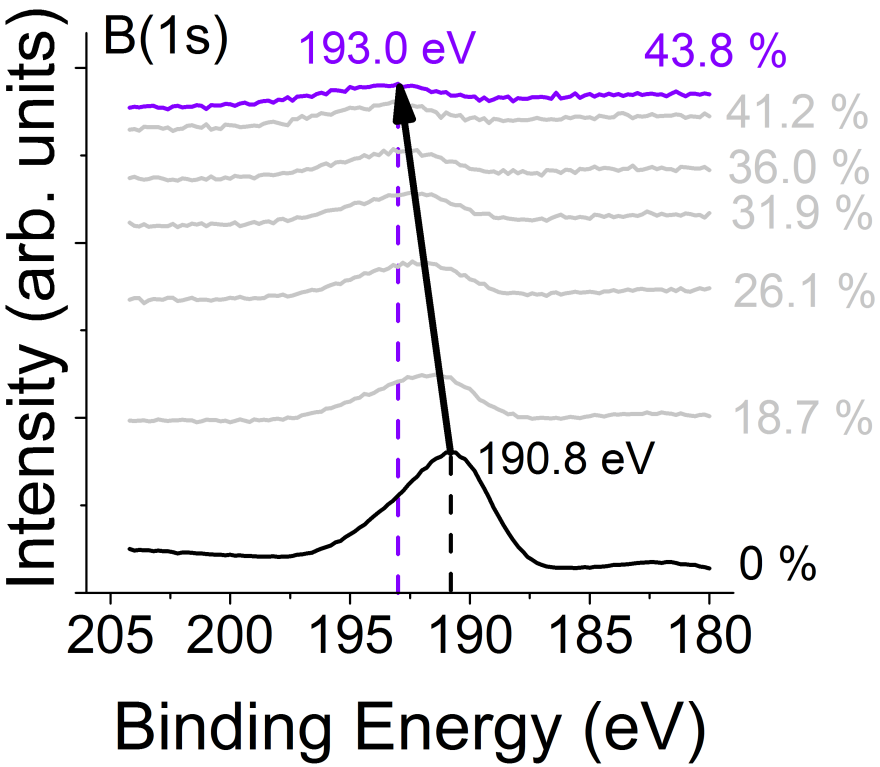

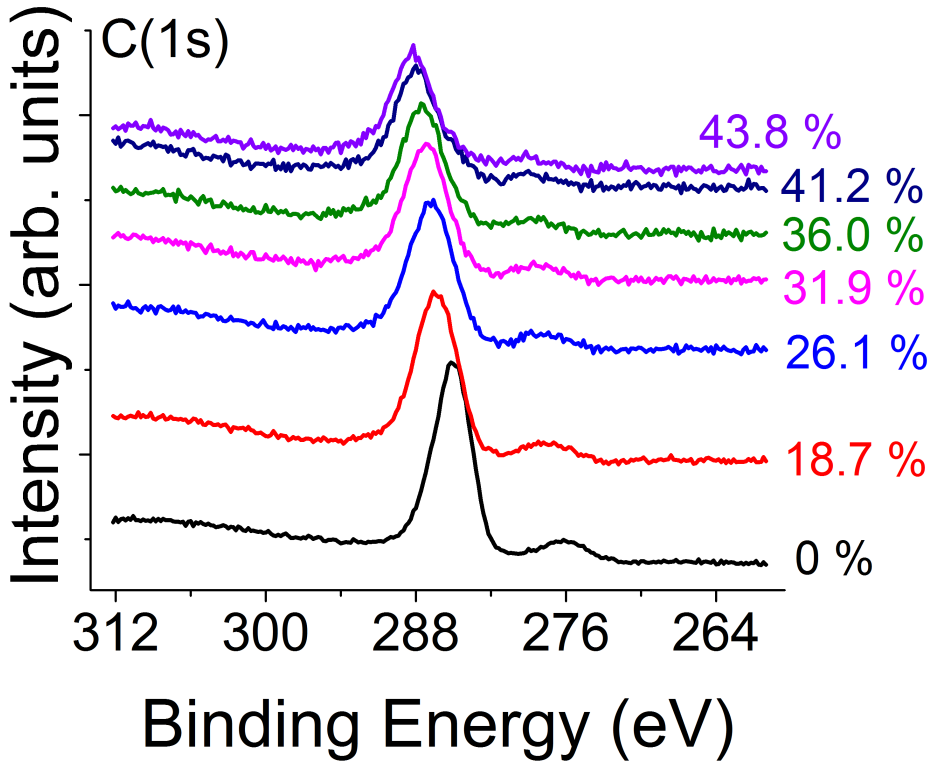

Binding energies shift to high values $\Rightarrow$ Schottky Barriers

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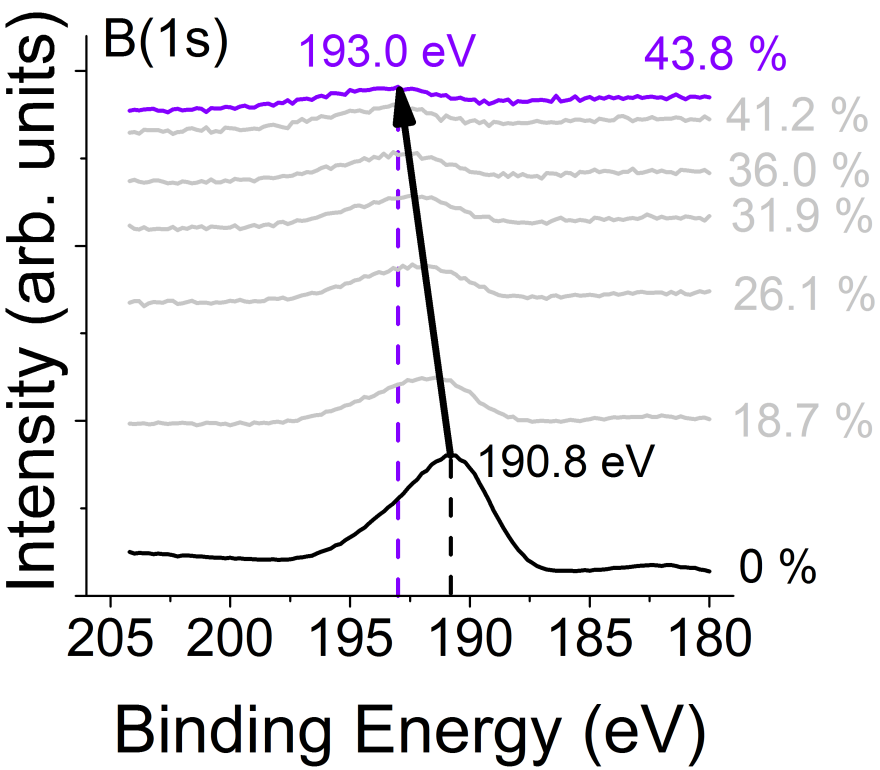
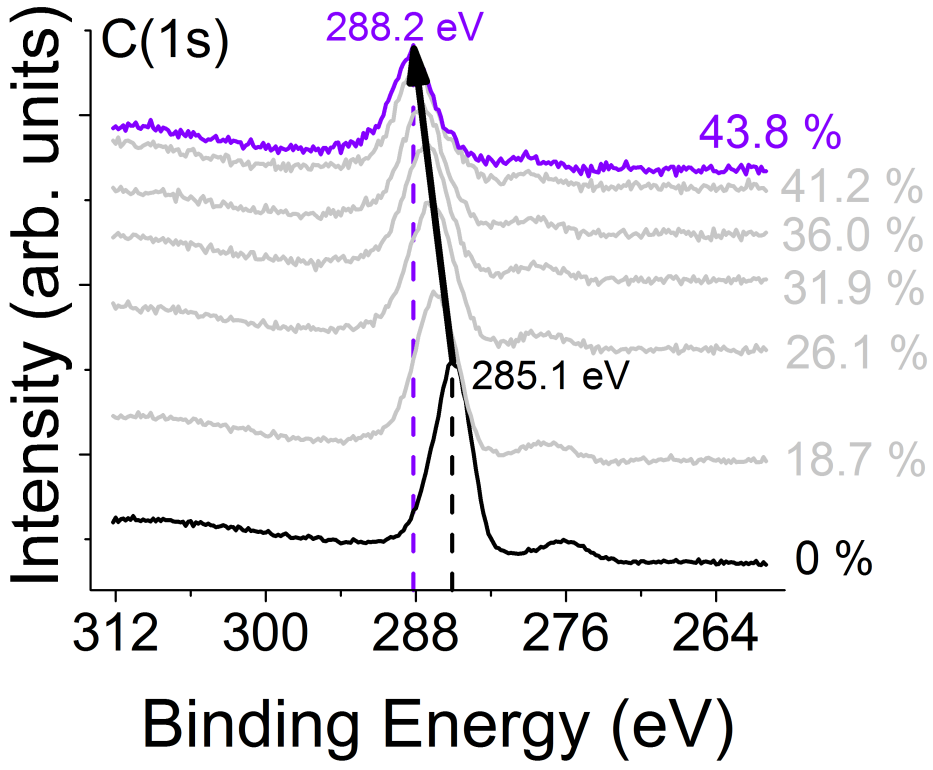
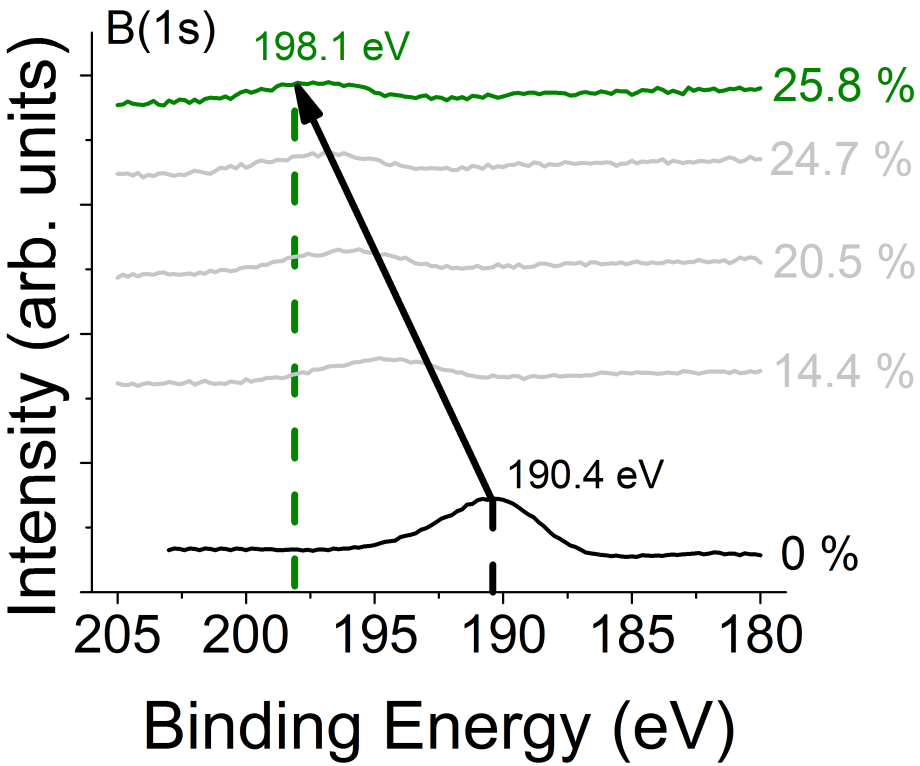


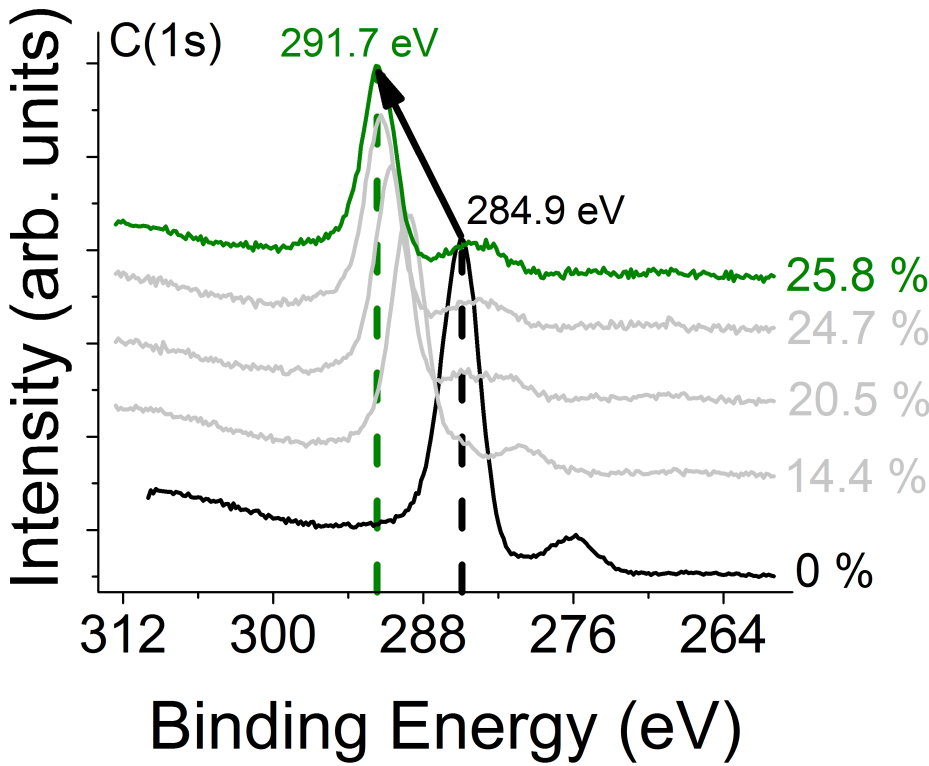


Binding energies shift to high values $\Rightarrow$ Schottky Barriers

Au/Semiconductor Interface With Aniline

Aniline-doped p-type semiconductor and $\Phi_M > \Phi_S$

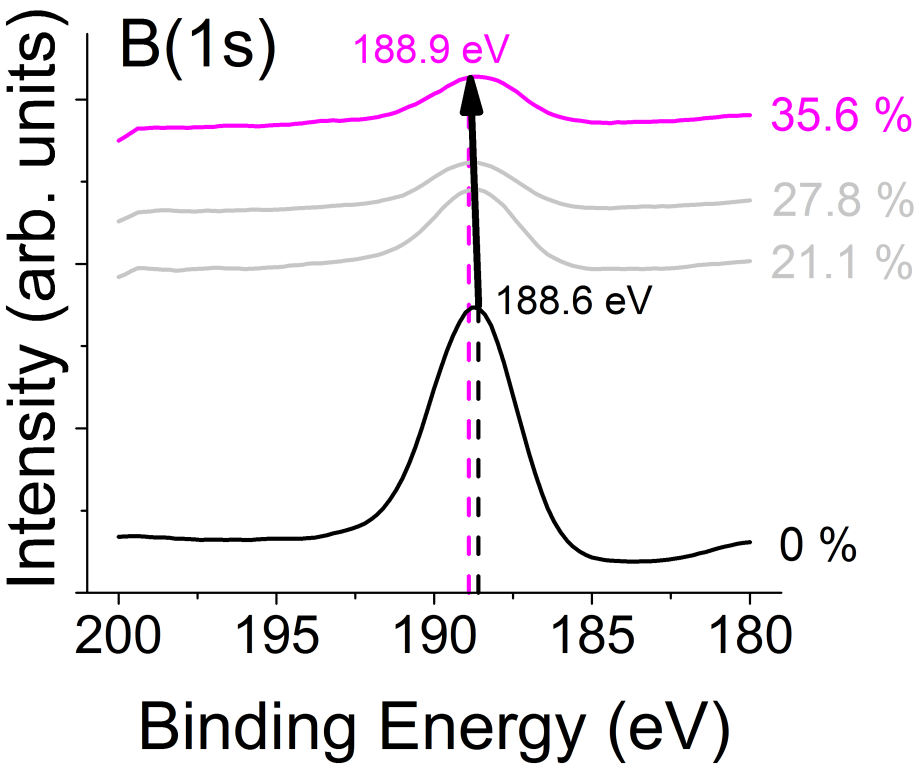


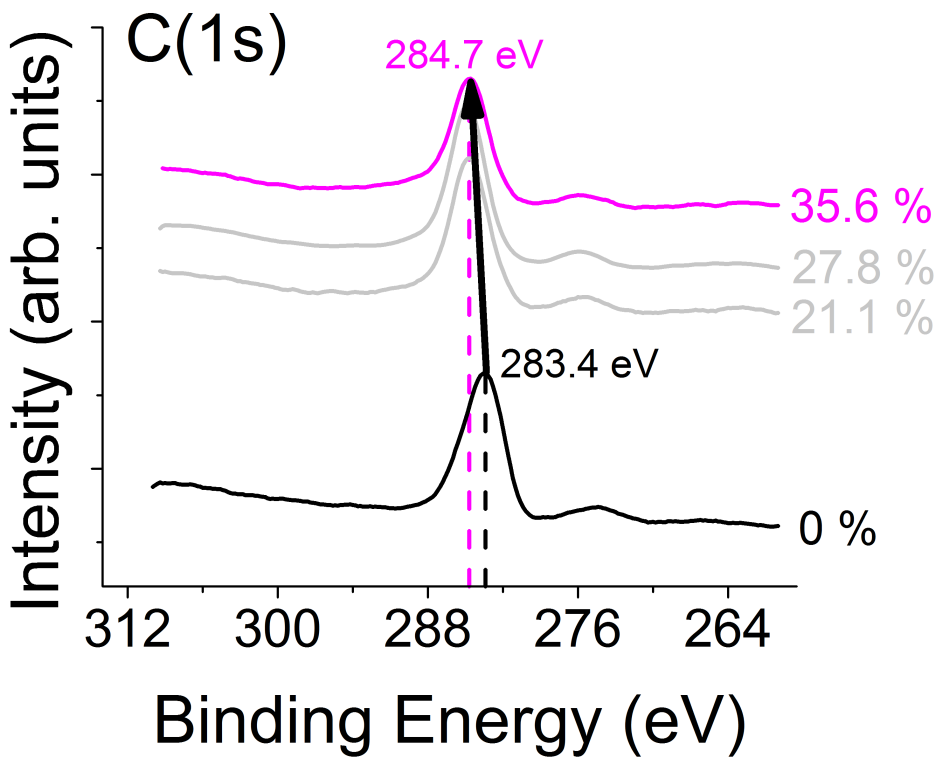


Bigger change in binding energies with aniline inclusion

Au/Semiconductor Interface

Pure n-type semiconductor and $\Phi_M > \Phi_S$

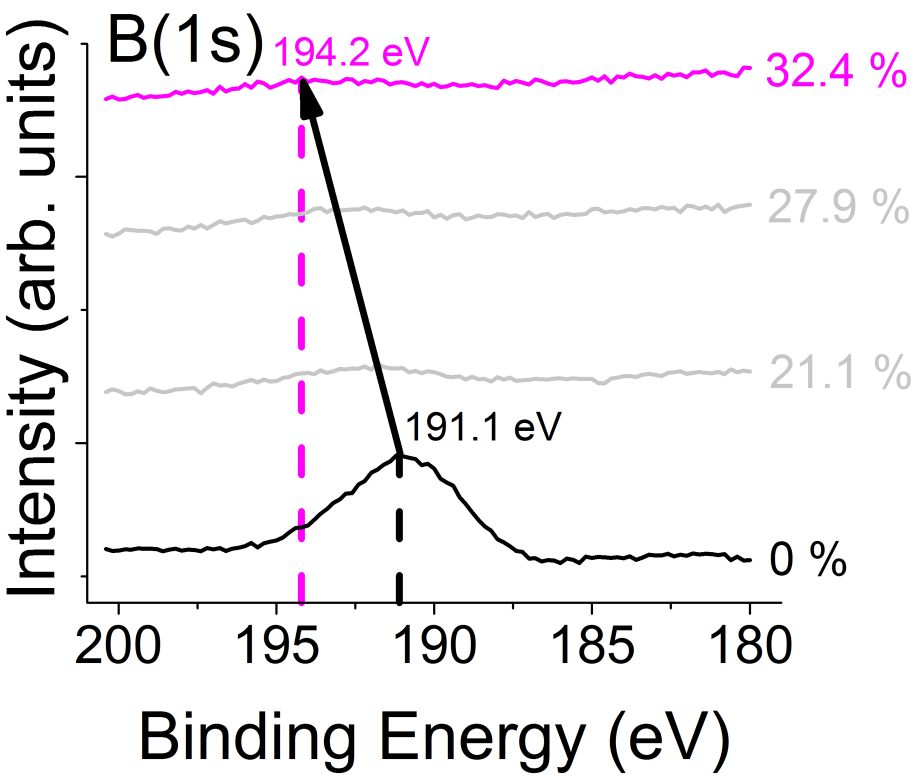


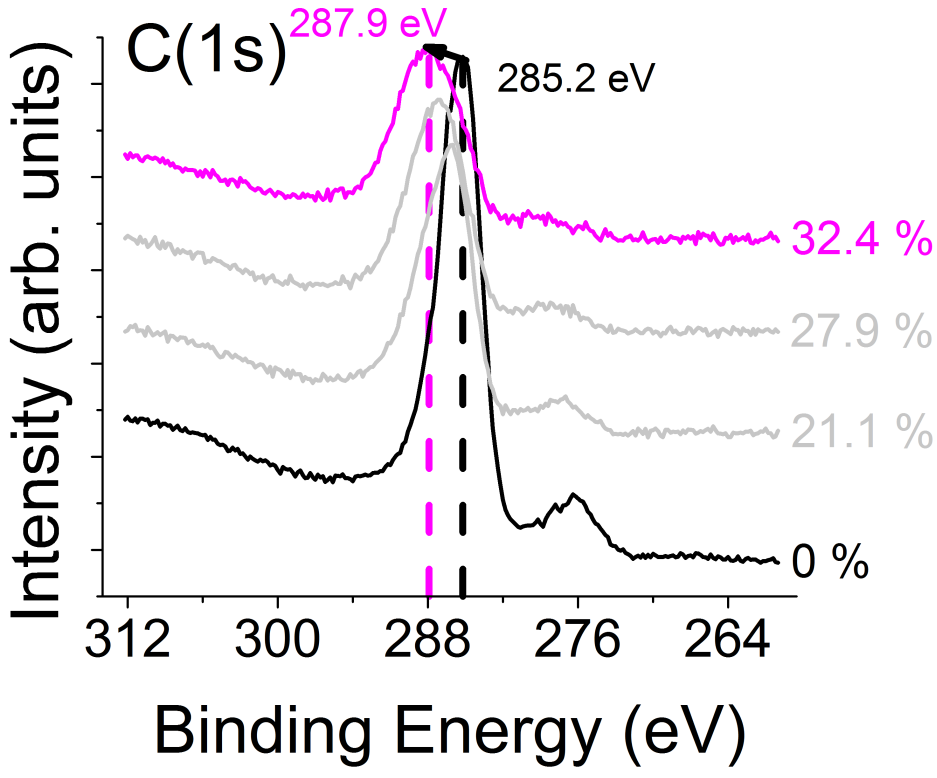


Slightly increase in binding energy $\Rightarrow$ Ohmic Contact

Au/Semiconductor Interface

Pyridine-doped n-type semiconductor and $\Phi_M > \Phi_S$





Bigger shifting towards high binding energies ⇒ Ohmic Contact

Au/Semiconductor Interface

Au/boron carbide-based semiconductors

- p-type semiconductor and $\Phi_M > \Phi_S \Rightarrow$ Schottky Barriers
- n-type semiconductor and $\Phi_M > \Phi_S \Rightarrow$ Ohmic Contact

Regular metal/semiconductor

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Boron carbide is not a regular semiconductor ...

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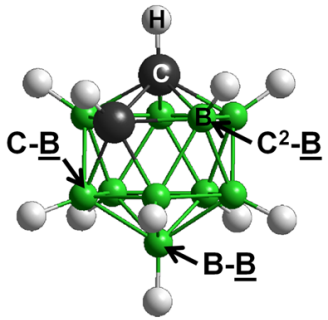
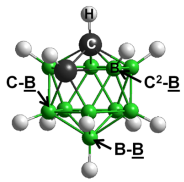
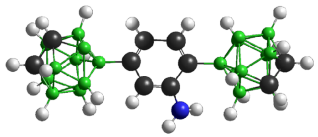


Boron carbide is not a regular semiconductor ...

Au deposition effects are reversible





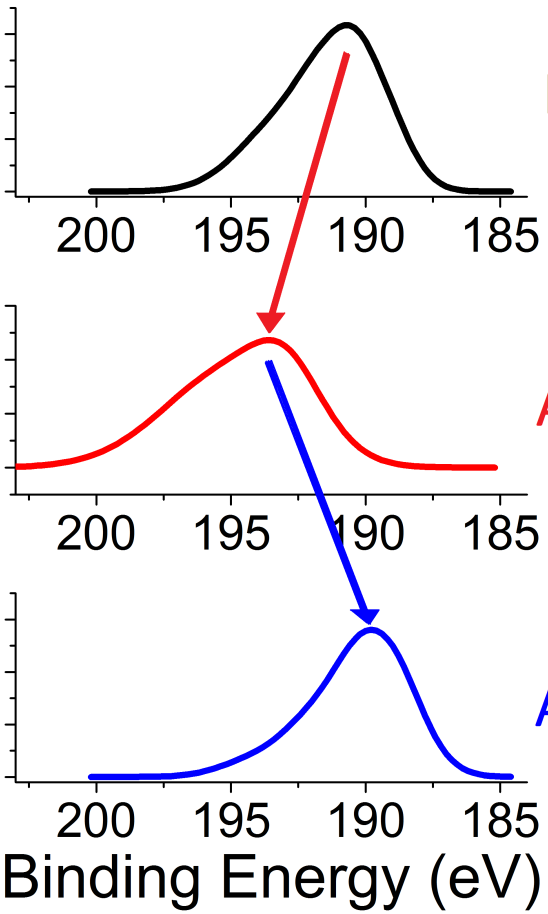
$B_{10}C_2H_X$: Aniline

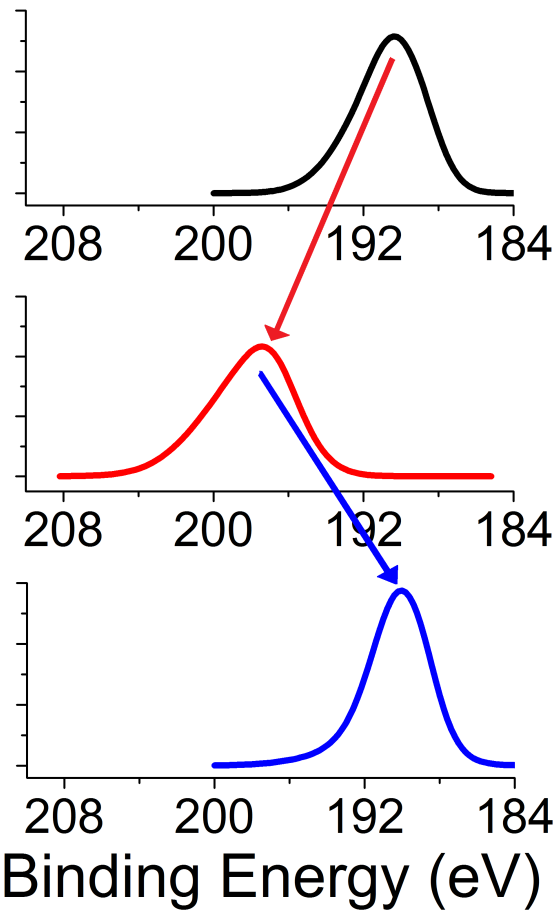
Before Au Deposition

After Au Deposition

After Removing Au

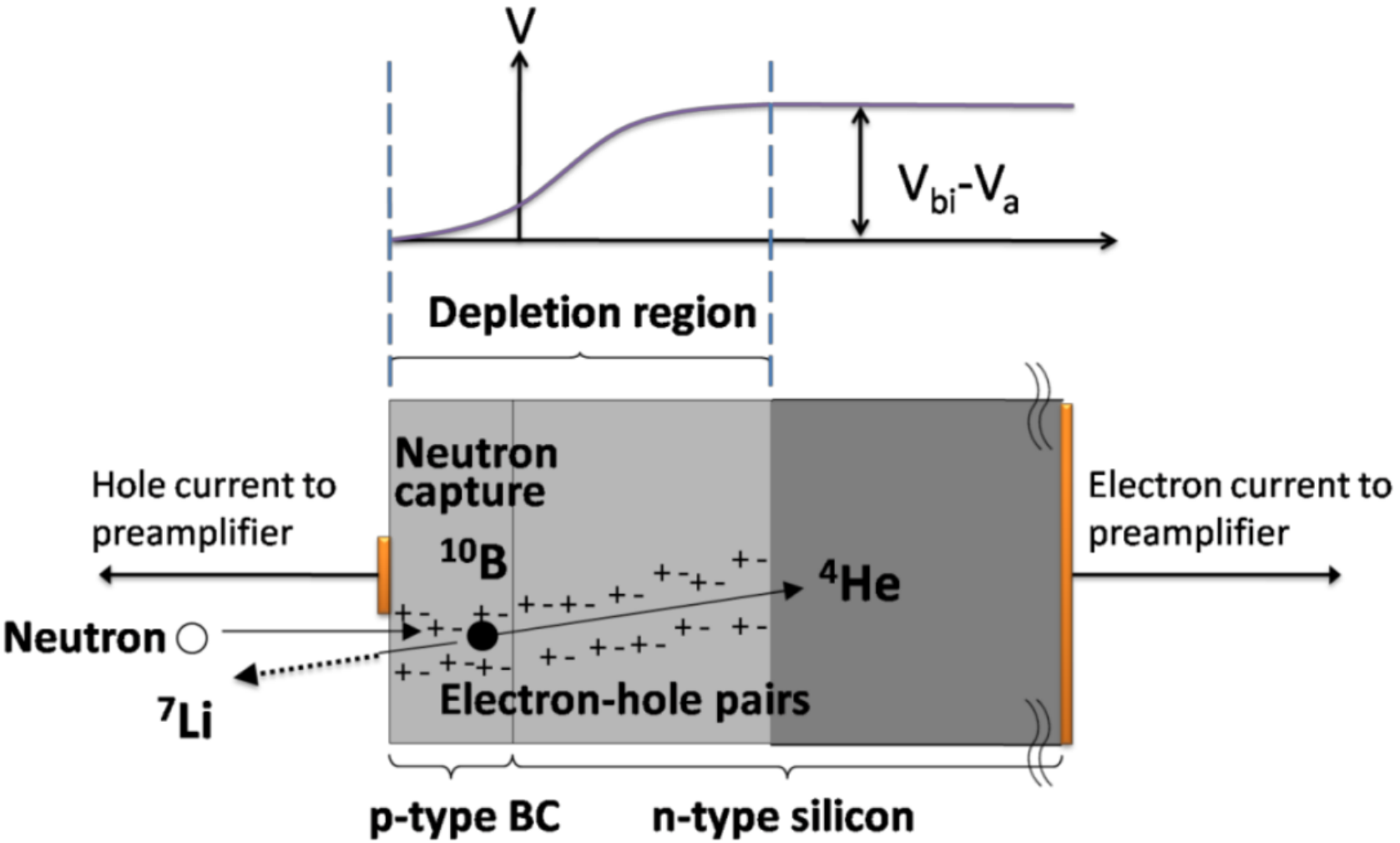
Intensity (arb. units)





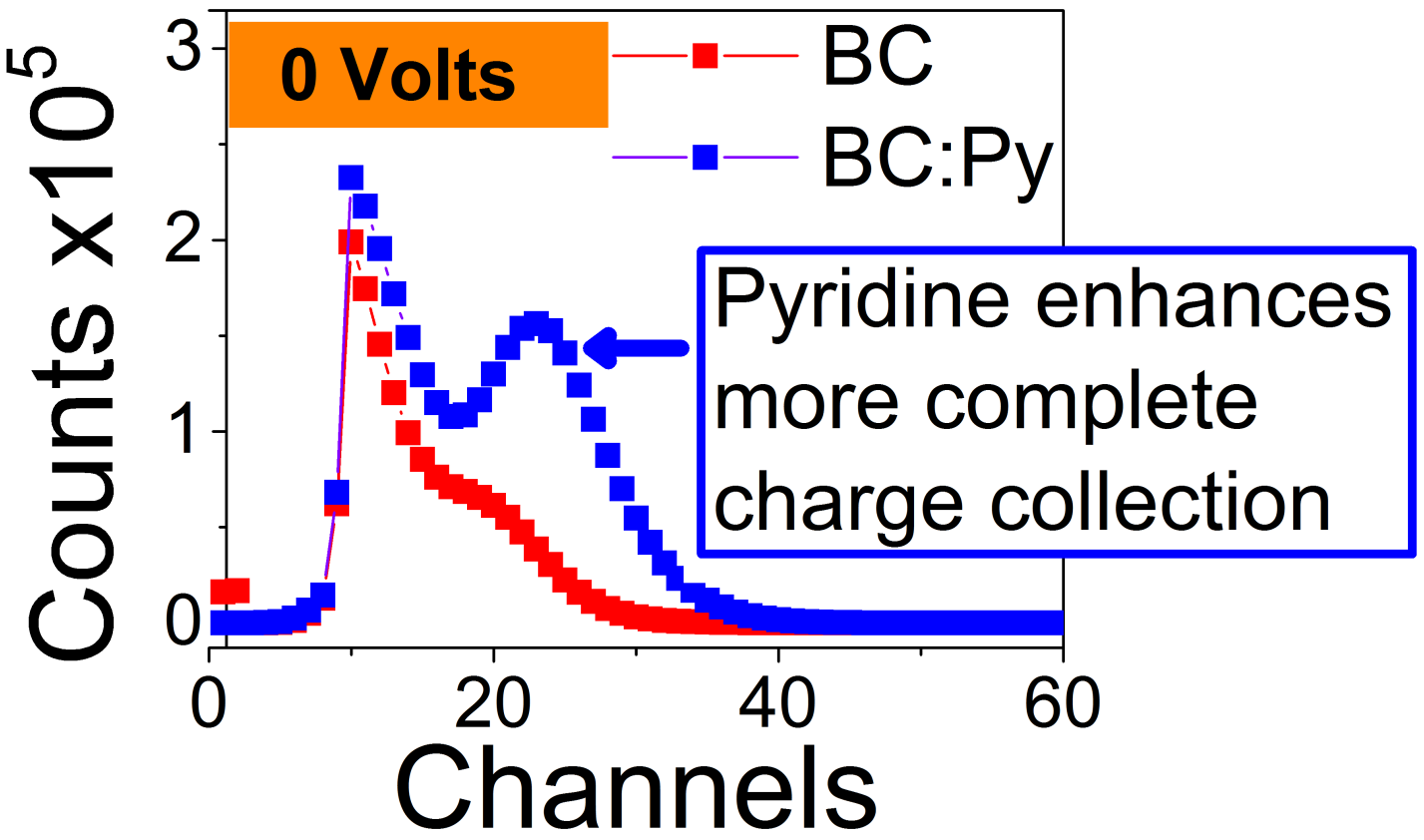
TEST FOR NEUTRON DETECTION

How does detection work?



Comparison: Neutron Detection on BC vs BC-Pyridine film

Devices exhibit neutron capture generated pulses at ZERO applied bias



Conclusions

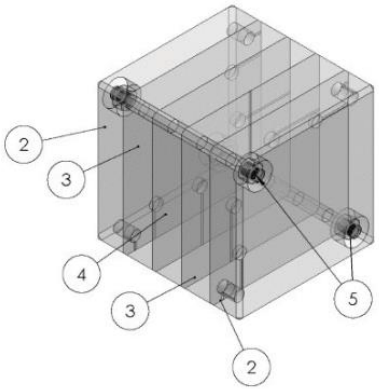
- Charge hole separation is improved by the inclusion of aromatic groups
- Carrier lifetimes increase from 35 μs for pure boron to 350 μs for pyridine inclusion or 2.5 ms with benzene.
- We have shown the addition of pyridine linking groups to boron carbine films increases the charge collection after neutron capture, at zero bias, compared to these samples with pure boron carbide.
- Au/boron carbide based-semiconductors present Schottky barrier formation when working with p-type heterojunctions, and ohmic contacts when n-type materials are used.

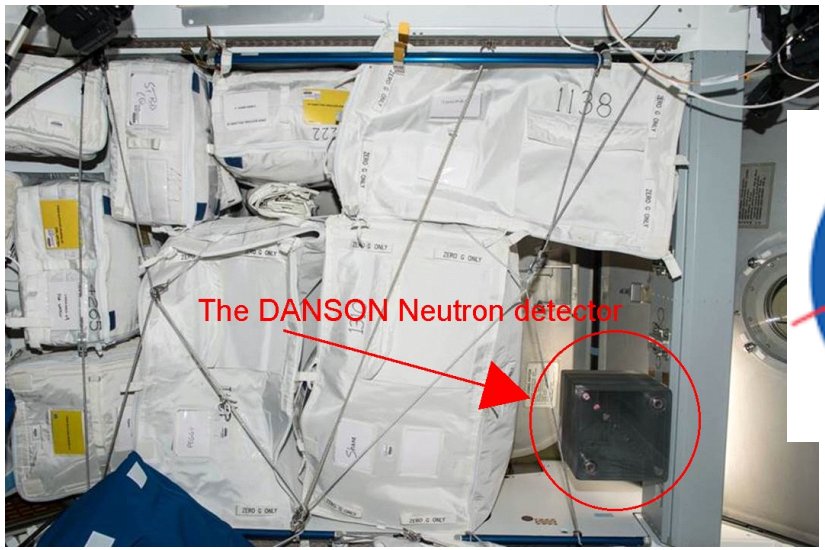
Publications

- Surfaces & Coatings Technology, **314** (2017) 51
- Journal of Physics D: Applied Physics, **49** (2016) 355302
- Mater. Res. Soc. Symp. Proc. **Vol.1** (2015)
- Appl. Phys. A; Vol. **118** issue 1 (2014) 113-118
- Materials Letters **110** (2013) 20-23

Next

- Determine radiation damage and materials fatigue by looking at the changes in the I(V) and C(V) curves $\Rightarrow$ detectors placed in the International Space Station (ISS) (**D**etector for the **AN**alysis of **SO**lar **N**eutrons)

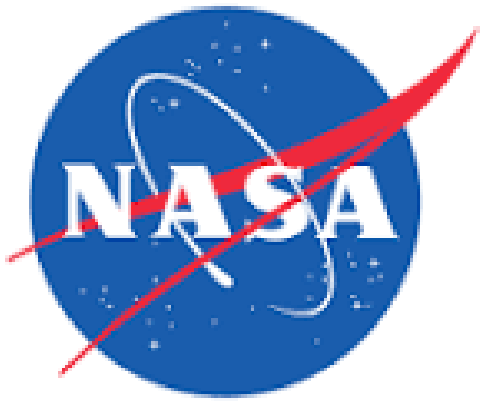




- More metal/semiconductor interface studies ... what about trying $\Phi_M < \Phi_S$?

Acknowledgments

This work was supported by the Defense Threat Reduction Agency, the National Aeronautics and Space Administration, National Science Foundation, and Semiconductor Research Corporation



Semiconductor Research Corporation

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- Dr. Wei-Ning Mei
- Dr. Michael Nastasi
- Dr. Tino Hofmann

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- Sean Knight
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- Nicole Benker
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Special Thanks to ...

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- Guanhua Hao
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- Amanda Lager
- Verona Skomski
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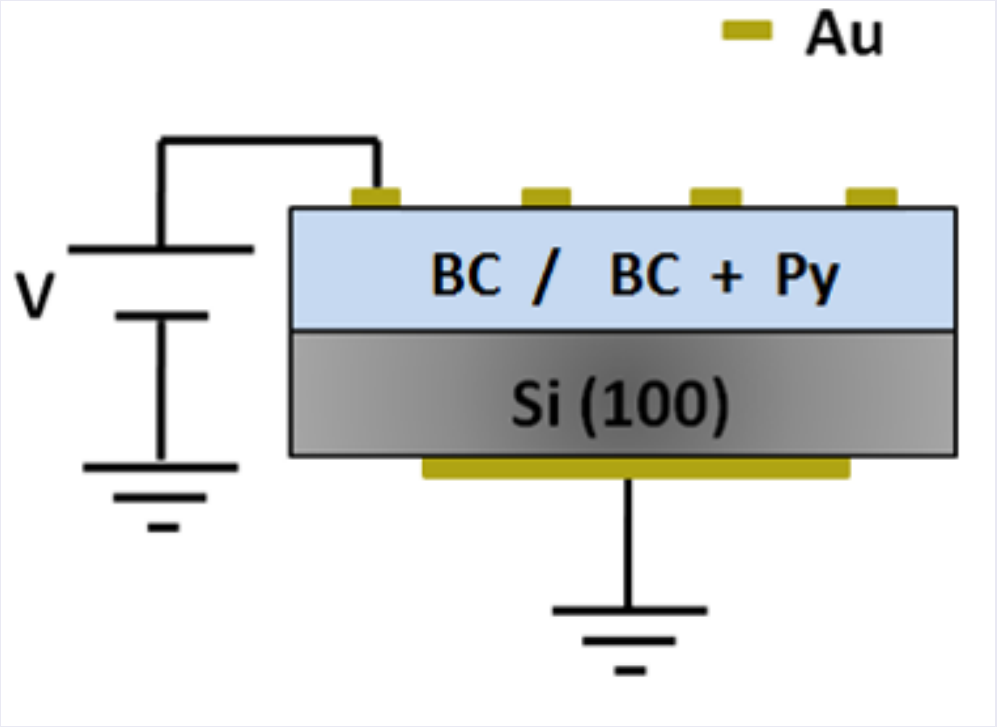
- John R. (Bob) Kelty
- Brian Farleigh

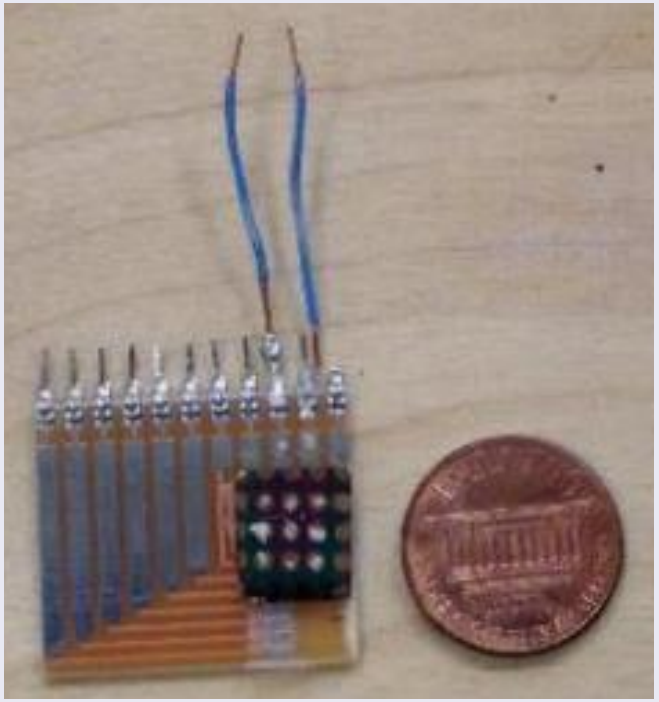
Friends

- Joaquin Siado
- Rami Kamaleindin
- Zahra Ahmadi
- Anil Rajapitamahuni
- Linda Kahler
- Colombiano@UNL

Last but not least ...

Devices: A 9-15 pixel detector

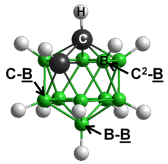


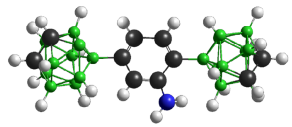


(i) pure boron carbide films

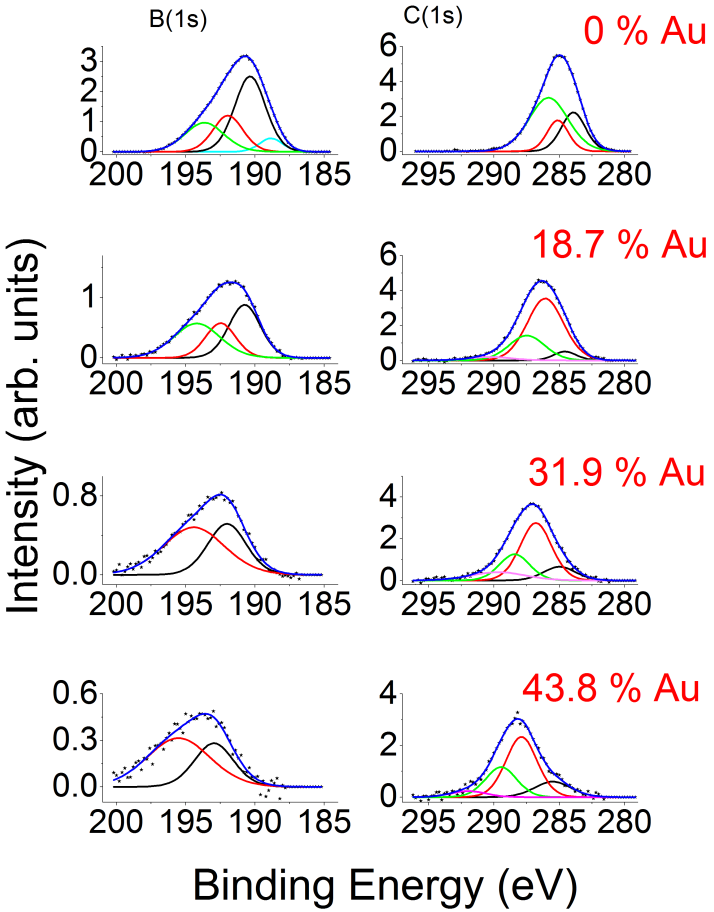
(ii) boron carbide films with different ratios aromatic/boron carbide

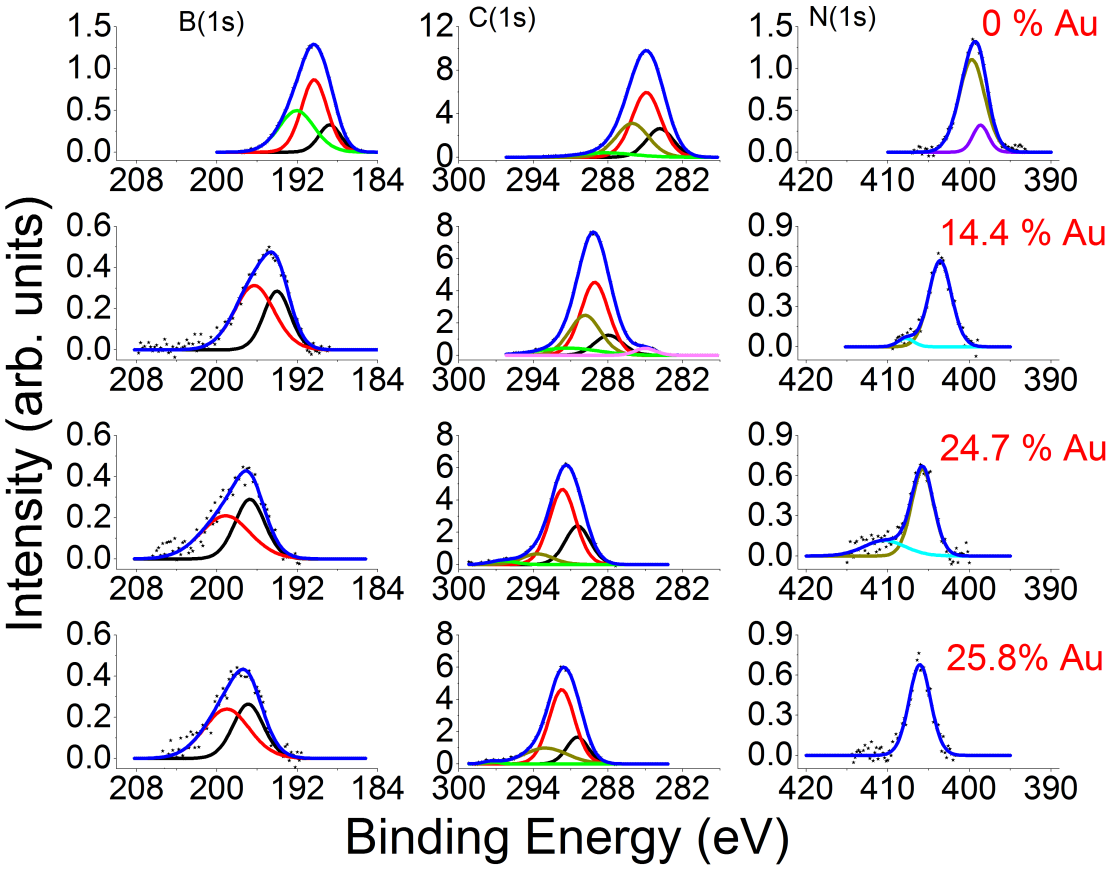
Au deposition effects by XPS analysis



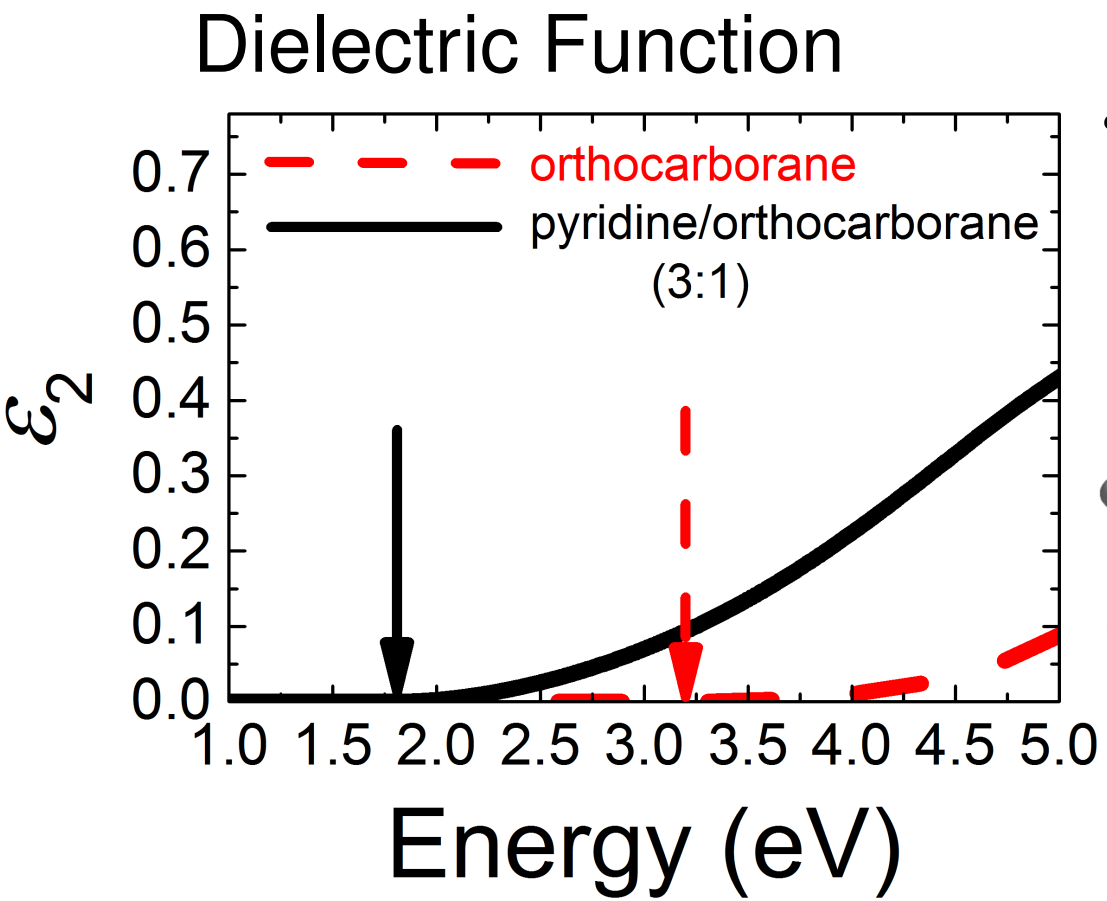


$B_{10}C_2H_X$: Aniline

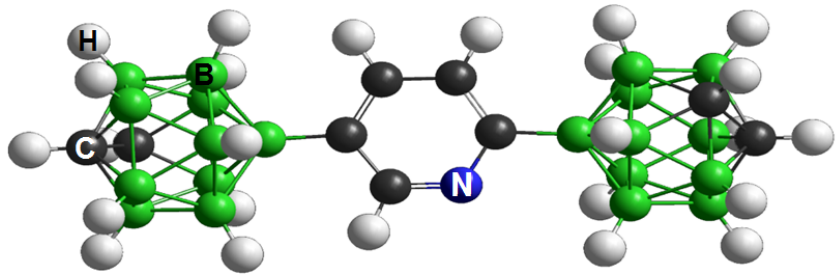




Effects of aromatic compound inclusion
Band Gap Decreases



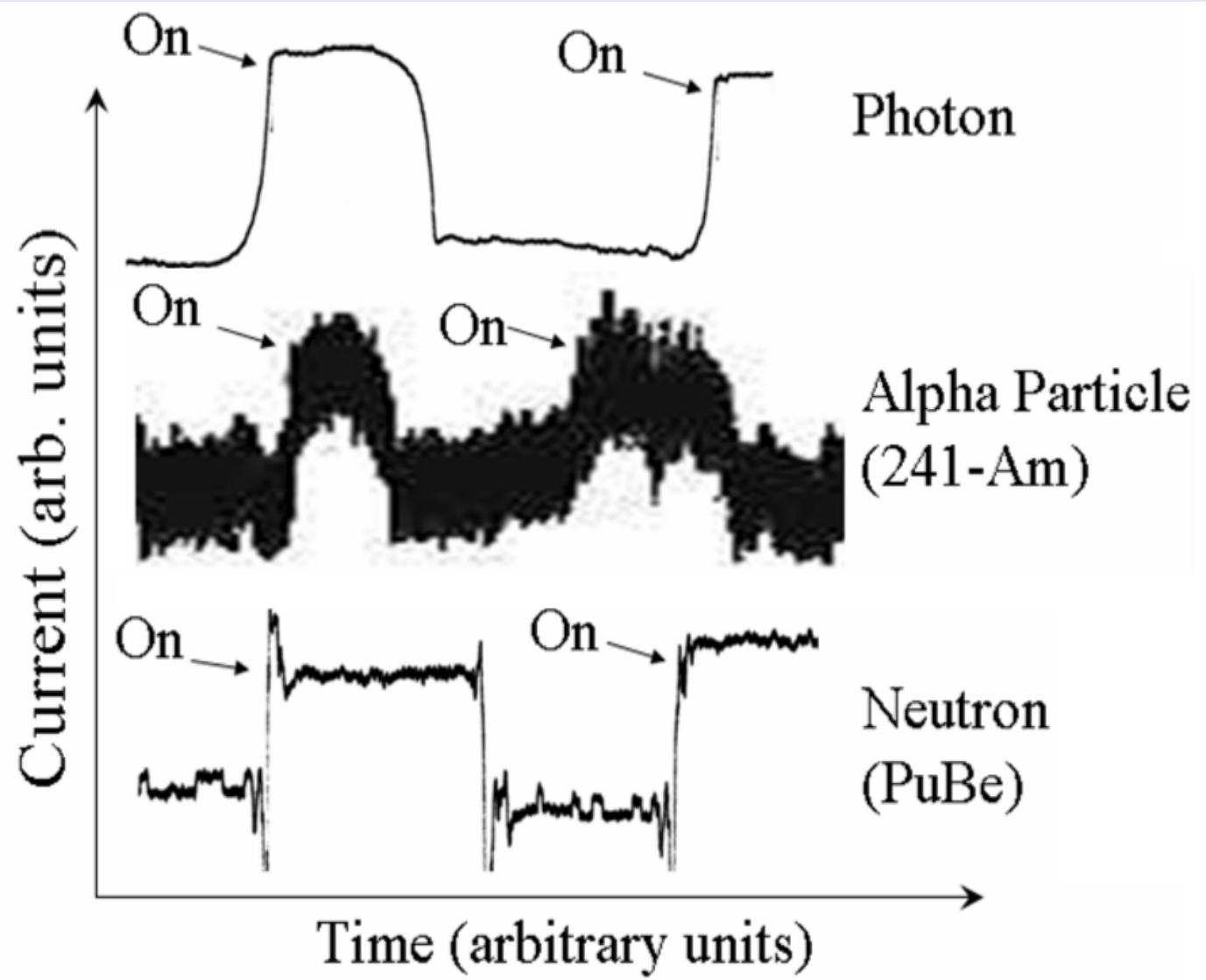
$$\varepsilon_2 = \begin{cases} \frac{AE_0C(E-E_g)^2}{(E^2-E_0^2)^2+C^2E^2}\frac{1}{E} & E > E_g \\ 0 & E \leq E_g \end{cases}$$



$B_{10}C_2H_X$: Py

from 3.2 eV → 1.8 eV

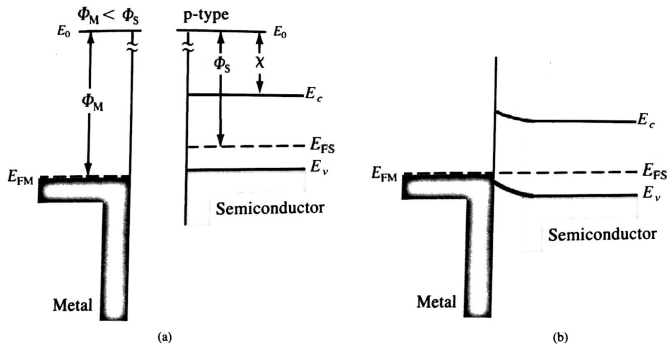
Neutron Voltaics are possible



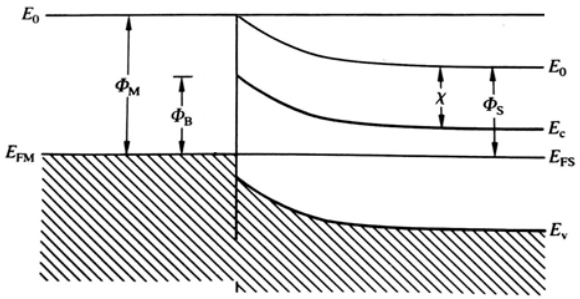
Metal/Semiconductor interface

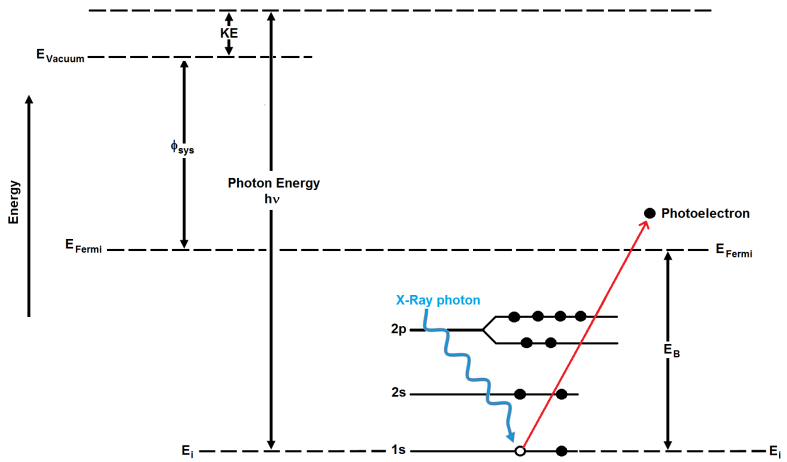
P-type semiconductor and

$$\Phi_M > \Phi_S$$



n-type semiconductor and $\Phi_M > \Phi_S$





XPS p-type BC:Aniline