SAND2011-2732C

Focused Ion Beam Fabrication Of Planar Diamond Nanowire Devices

2011 MRS Spring Meeting

April 27th, 2011

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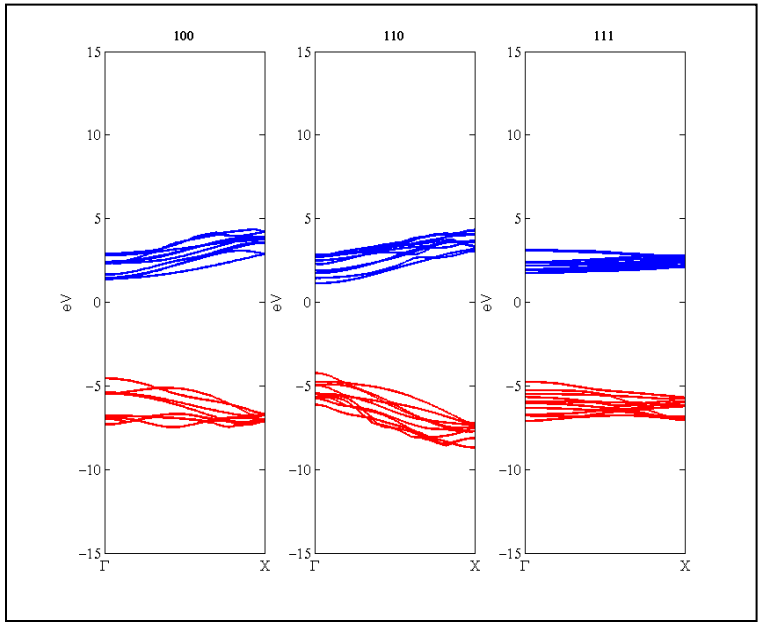
Diamond Bulk Properties May Result In Novel Applications

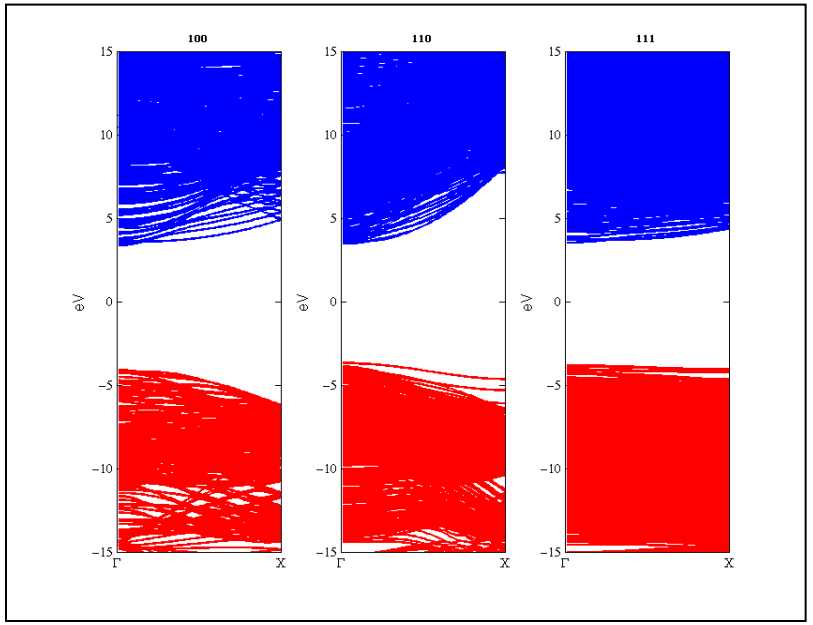
Property	Diamond	Si
Lattice Constant (Å)	3.57	5.43
Band Gap [eV]	5.5	1.12
Breakdown Field [V/cm]	10^7	3 X 10^5
Resistivity [Ω cm]	> 10^{11}	2.3 x 10^5
Intrinsic Carrier Density [cm^{-3}]	< 10^3	1.5 x 10^{10}
Electron Mobility [$cm^2V^{-1}s^{-1}$]	1800	1350
Hole Mobility [$cm^2V^{-1}s^{-1}$]	1200	480
Saturation Velocity [km/s]	220	82
Mass Density [g cm^{-3}]	3.52	2.33
Atomic Charge	6	14
Dielectric Constant	5.7	11.9
Displacement Energy [eV/atom]	43	13-20
Energy to create e-h pair [eV]	13	3.6
Radiation Length [cm]	12.2	9.4

Modeling Predicts Direct Band Gap For Diamond Nanowires

Valence (red) and conduction (blue) bands for various single crystal diamond nanowire orientations.



Computed with density functional theory using the HSE06 DFT method.



Computed with the self consistent tight binding approach.

• To systematically explore the properties of diamond and in order to explore possible size effects, a deterministic method to fabricate diamond transistor devices with ohmic contacts is needed.

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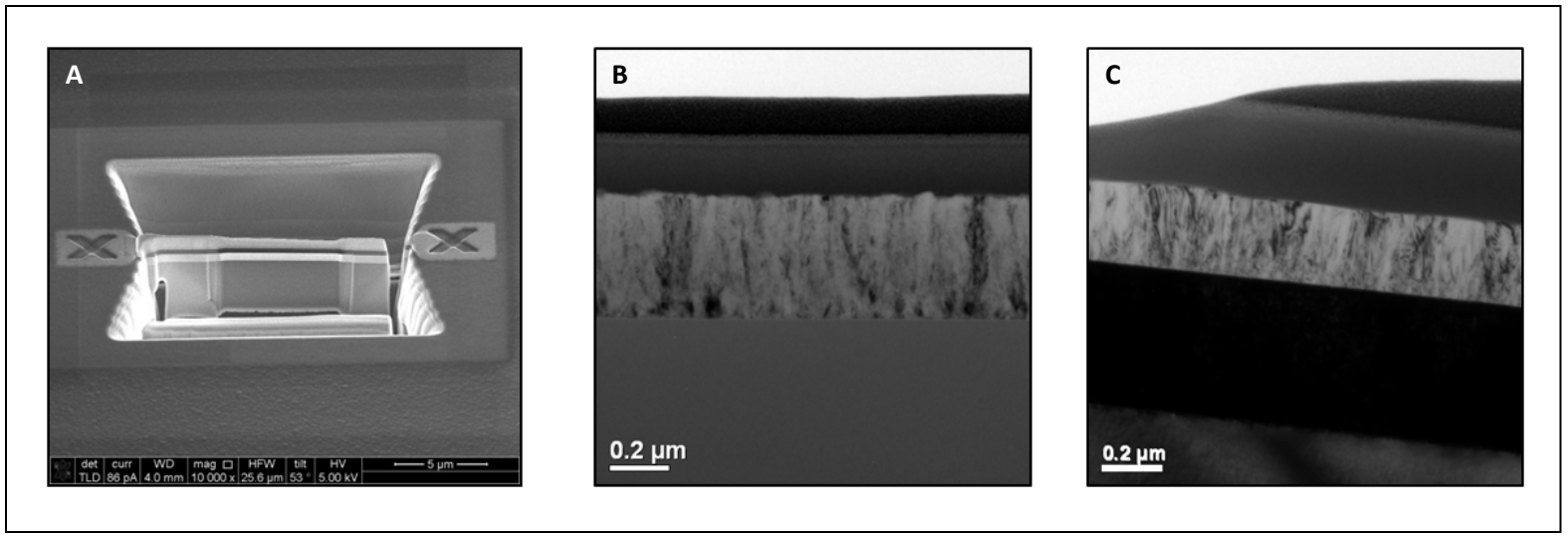
Focus Ion Beam TEM Sample Prep Inspired Nanowire Patterning



(a) TEM samples prepared via FIB etching. Low magnification TEM micrographs of (b) PC diamond and (c) SC diamond films.

- Tight crystal structure of diamond may prevent Ga (FIB ion) from contaminating the diamond sample.
- FIB can deposit, register, and pattern the nano-to-micro metallic contacts

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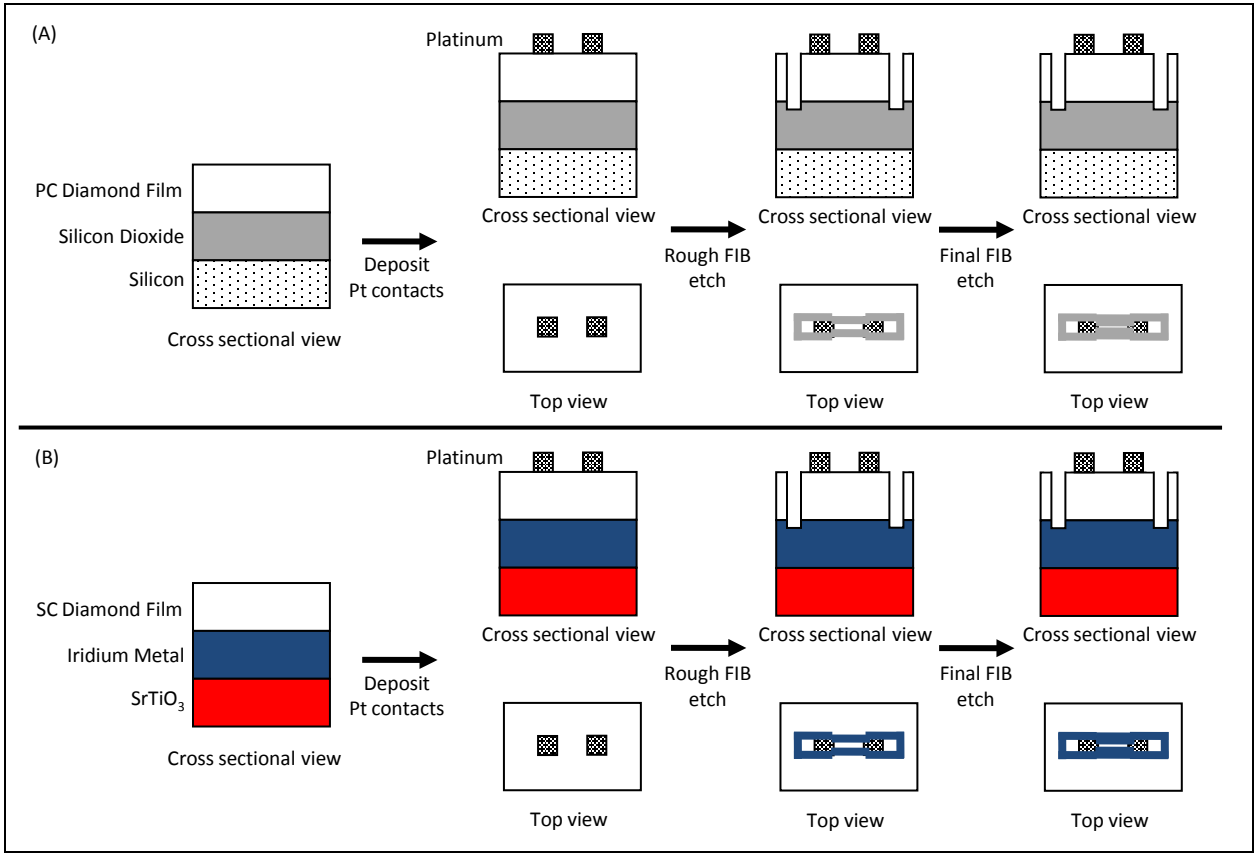
FIB Patterns Nanowire and Contacts



Processing schematics for FIB patterning of (a) PC diamond and of (b) SC diamond nanowire devices.

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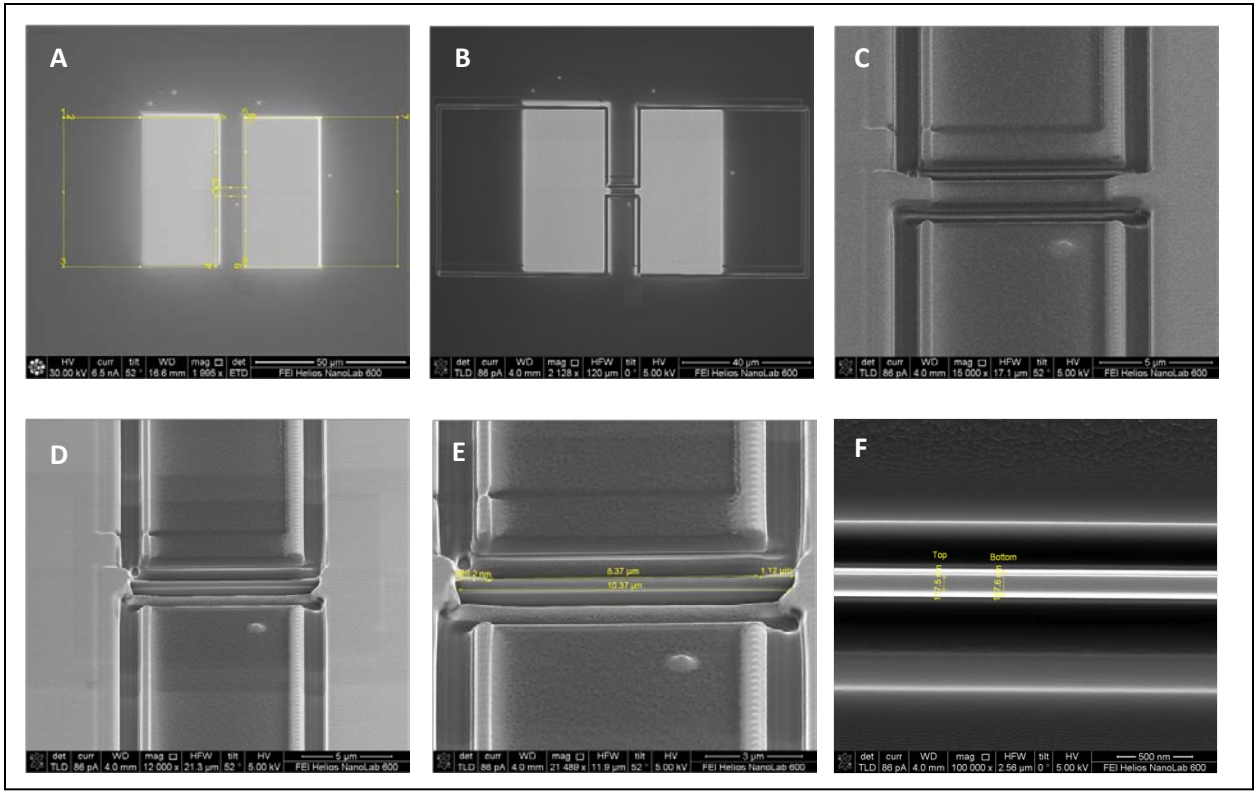
FIB Nanowire Patterning Carried Out Successfully On PC Diamond



FIB micrographs of different stages in the patterning of a PC diamond nanowire device showing: (a) Pt contact pads and CAD definition of etched trench; (b) rough FIB etch; (c) close up of wide wire defined by rough FIB etch; (d) nanowire defined by final FIB etch; close up of nanowire (e) showing its full length and (f) its midsection.

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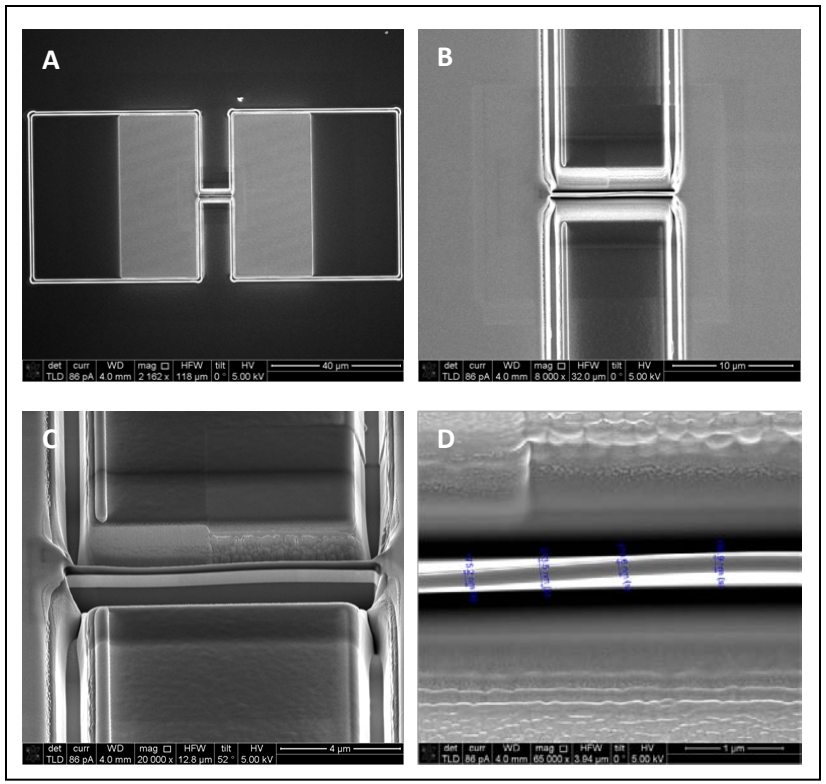
FIB Nanowire Patterning Carried Out Successfully On SC Diamond



FIB micrographs of different stages in the patterning of a SC diamond nanowire device showing: (a) Pt and diamond contact pads after rough FIB etch; (b) after final FIB etch; and (c) deformed nanowire defined by final FIB etch. (d) higher magnification view of deformed nanowire.

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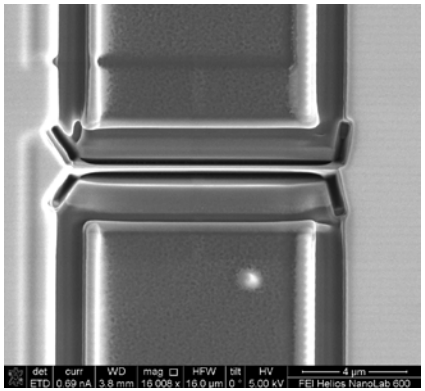
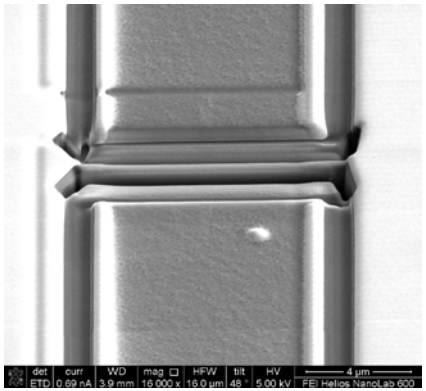
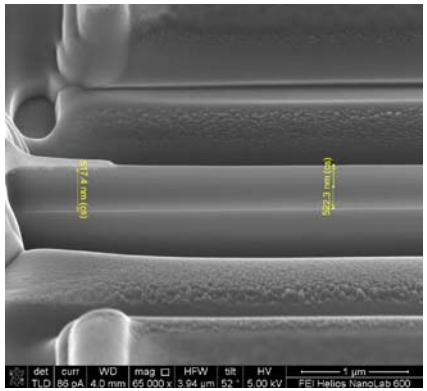
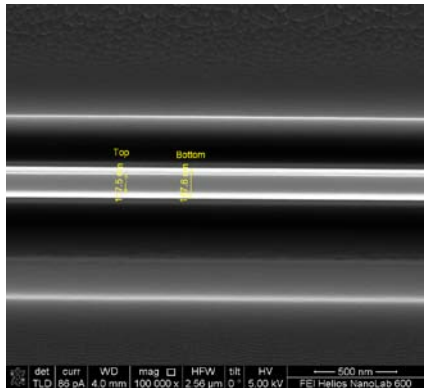
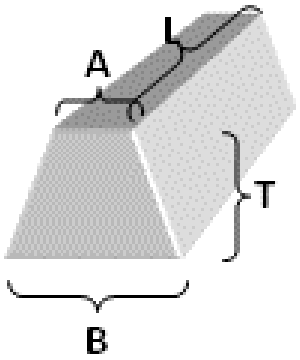
Successfully Fabricated Sub-200 nm Nanowire Devices





	Dimensions (nm)			
	A	B	T	L
PC	118	188	410	8370
SC	175-180	~315	305	8370

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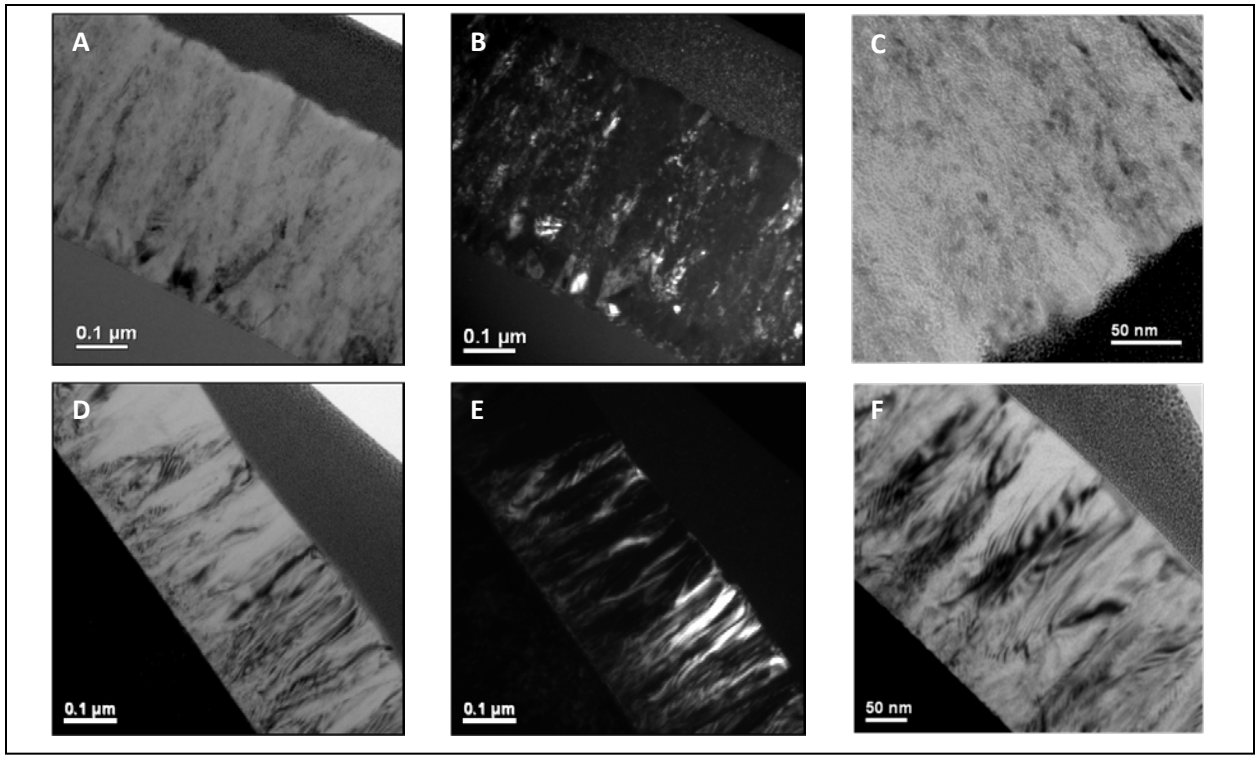
Diamond Integrity Preserved By FIB Patterning



(a) Bright field, (b) dark field and (c) high magnification TEM micrographs of PC diamond film. (d) Bright field, (e) dark field and (f) high magnification TEM micrographs of SC diamond film.

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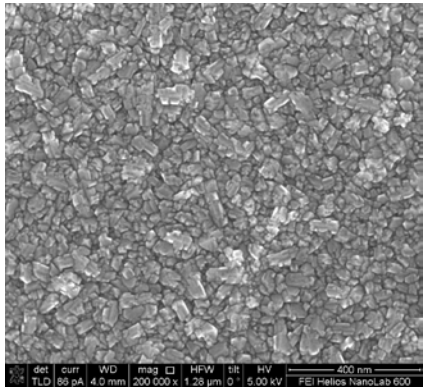
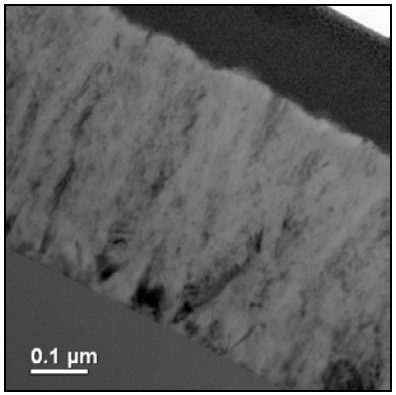
PC Diamond Remained Chemically Pured After FIB Patterning

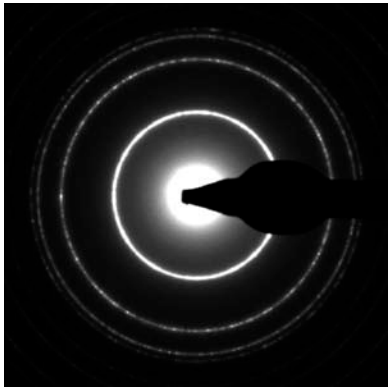
SEM

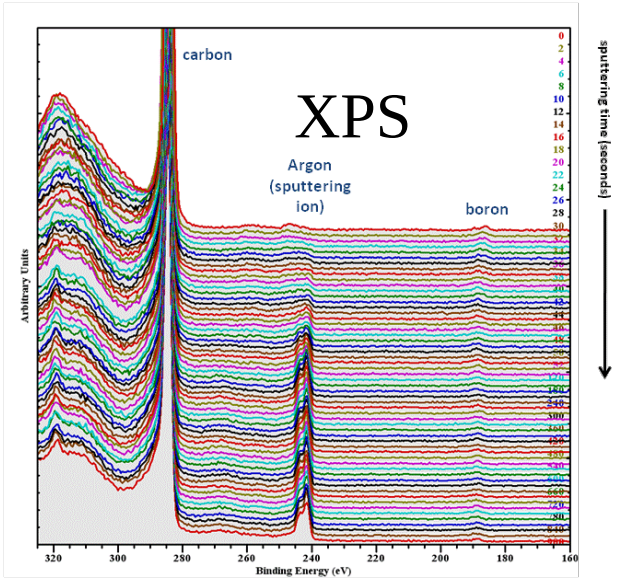


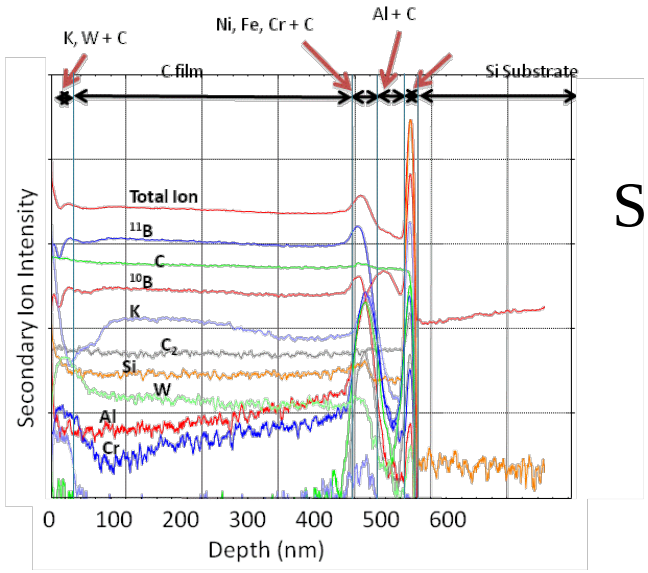
TEM



ED







SIMS

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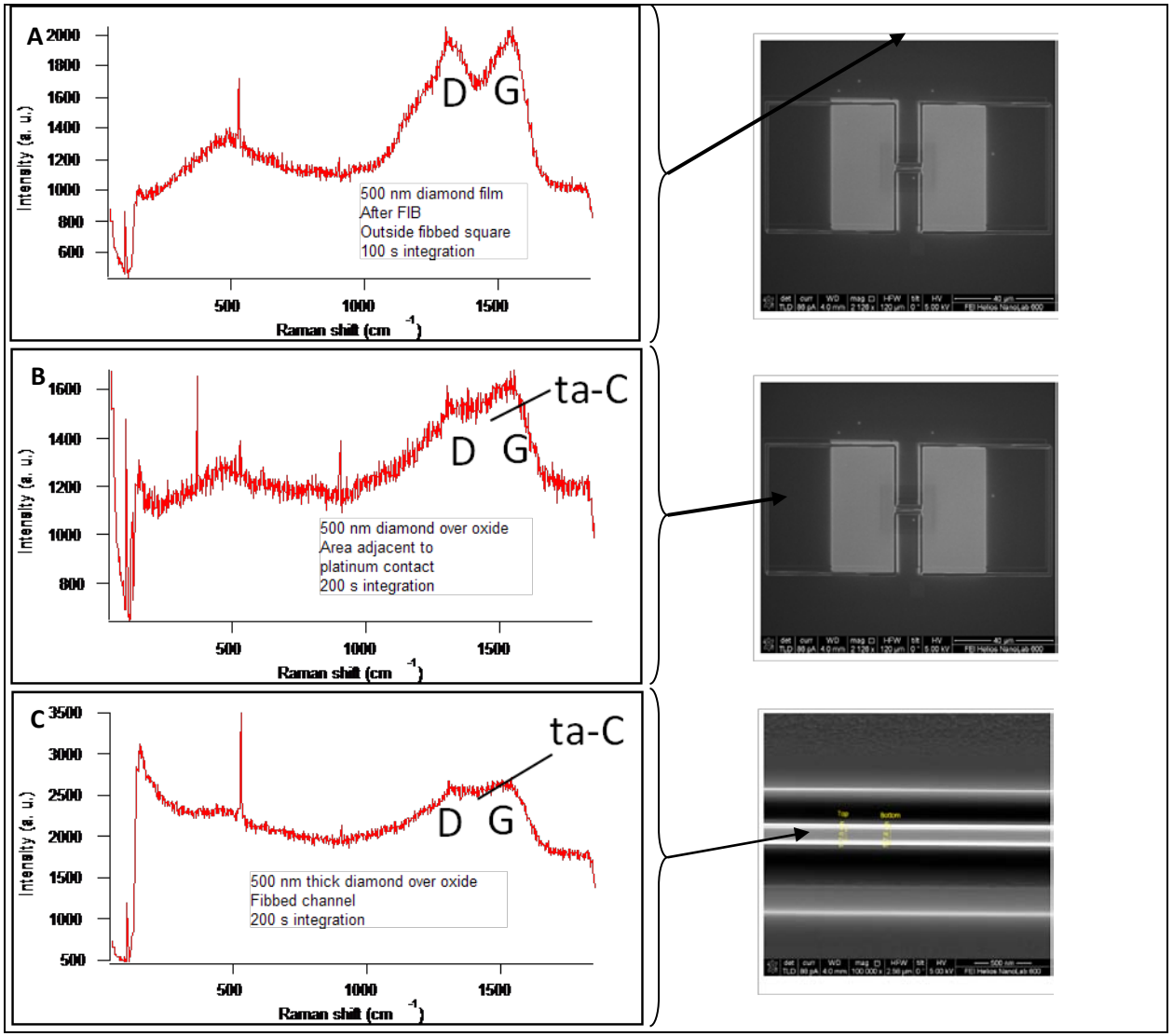
. The Raman Indicated FIB Etching and Imaging Create Tetrahedral Amorphous sp^3 Carbon



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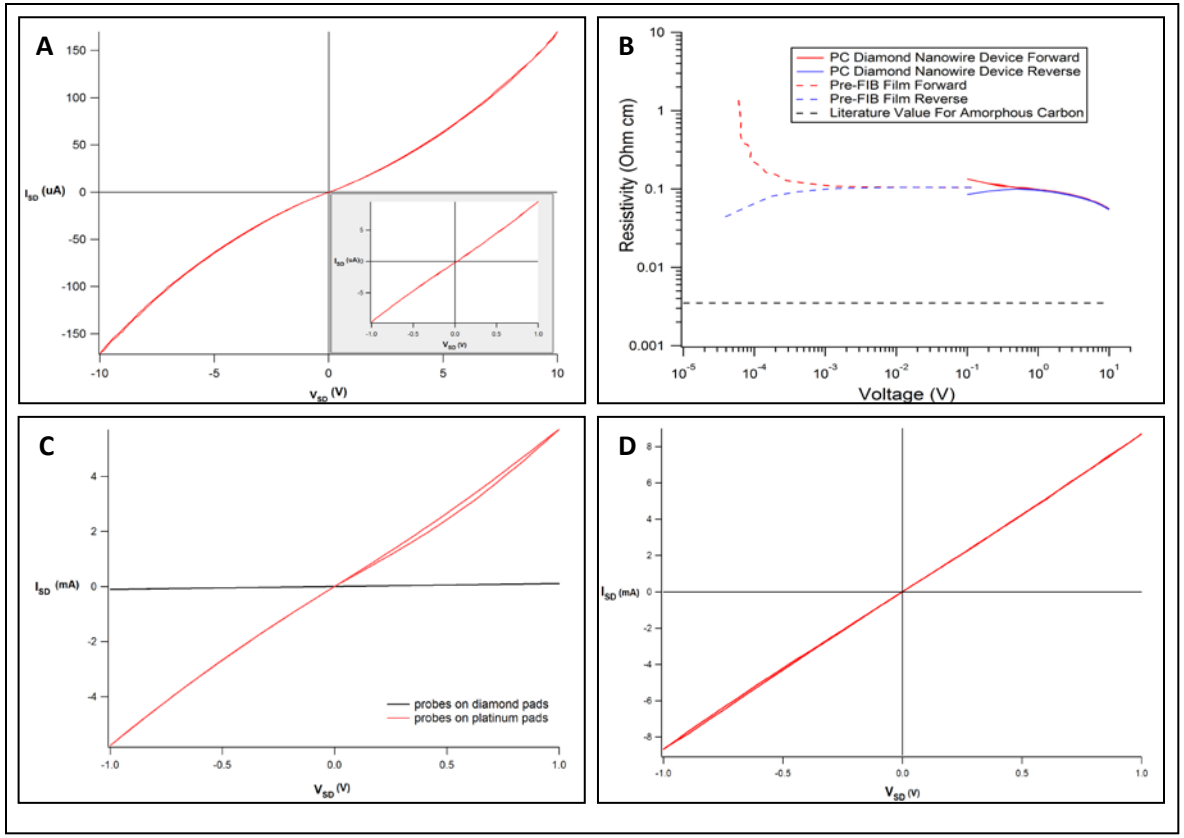
Pt-Contacts Exhibited Low Contact Resistance



The resistivity of the nanowire devices is similar to that of the unpatterned film and higher than that of amorphous carbon.

This indicates that the non-diamond phases in the device are probably not altering (ie. increasing) the electrical conductivity of the nanowire device.

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Conclusions

1) Explored modeling methods that allow us to predict the effects of size on the electronic properties of diamond nanowires and have shown that a direct bandgap may develop in sufficiently small diamond nanowires.

2) Developed a novel FIB patterning method to fabricate sub-200 nm diamond nanowire devices with ohmic metal contacts.

3) Carried out transport measurements on the diamond nanowire devices showing that the devices display semiconductor behavior when current is injected across an ohmic Pt-to-diamond interface.

Acknowledgments

We would like to thank Prof. Brage Golding from the Physics and Astronomy department at Michigan State University for supplying the single crystal diamond sample. Tyler Westover is gratefully acknowledged for assisting in the transport measurements. Michael Rye, William Wallace, and Joseph Michael assisted with the FIB, XPS, and TOF-SIMS instruments. Peter Sharma and Andy Vance helped review the manuscript.

Work funded under LDRD# 149559.