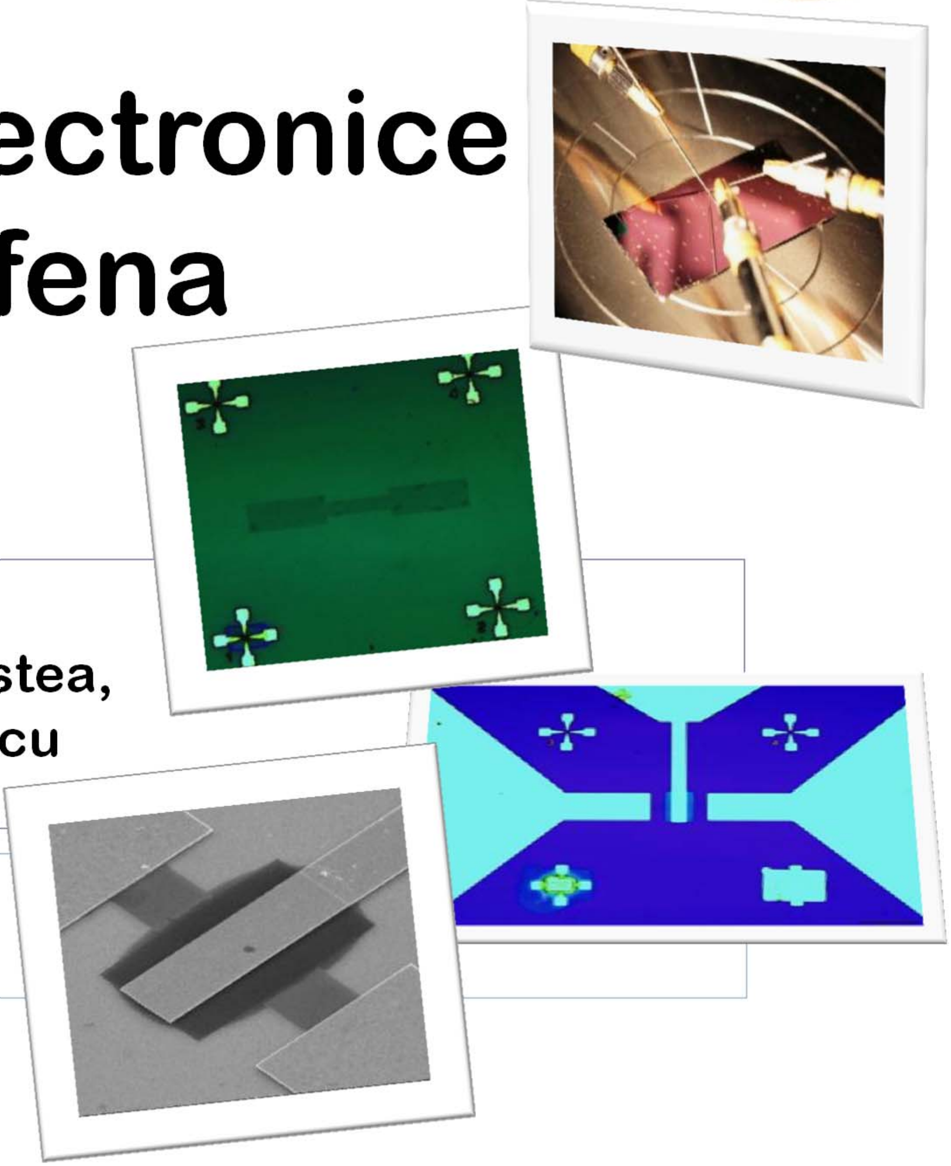
Academia Romana

Dispozitive nanoelectronice bazate pe grafena



A. Dinescu, M. Dragoman, D. Cristea,
A. Avram, R. Gavrila, F. Comanescu

IMT Bucuresti

Seminarul National de Nanostiinta si Nanotehnologie, Editia a 14-a, 26 martie 2015

Research Centre for Integrated Systems Nanotechnologies and Carbon Based Nanomaterials

CENASIC

Development of a research center within IMT-Bucharest, dedicated to technologies based on carbon nanomaterials: SiC, graphene, nanocrystalline diamond

PE CVD

Nanofab1000 Agile

Graphene Growth

Carbon Nanotubes (CNT, single and multiwall) Growth

Si Nanowire Growth

PECVD of Si, SiN, SiO, SiC at low and high temperatures

a- Si, μc - Si, polySi, SiGe

PECVD and CVD growth using the flexible
vapour delivery system (FVD)

ALD

OpAL

400 °C Aluminium substrate holder with PID control, 240 mm diameter

PC Control with OPT software under Windows 7

ICP 65 remote plasma source for radical assisted ALD

up to 5 liquid or solid precursors (incl H_2O), bubbled or vapour draw

up to 10 gaseous precursors, with MFC and fast ALD valve controlled delivery lines

RF sputtering

Plasmalab System 400

Circular magnetrons with optional sizes to 200mm round
RF/DC/Pulsed DC sputtering (Switched)

RF bias to substrate table

Heated substrate table to 300°C

Load lock

Static, rotation or oscillation modes for deposition

Up to 4 gas channels

Cryo pump option

IMT Bucharest - processing facilities

(Furnaces, RTP, CVD, PECVD, PVD, DWL, RIE, DRIE, wafer bonding, etc.)

IMT Bucharest – characterization facilities

(Ellipsometry, NSOM, WLI, micro Raman and TERS, XRD, SECM, FTIR, wafer probing stations, network analyzer, etc.)

Nanoscale Structuring and Characterization Laboratory

Raith - e_Line - dedicated EBL equipment

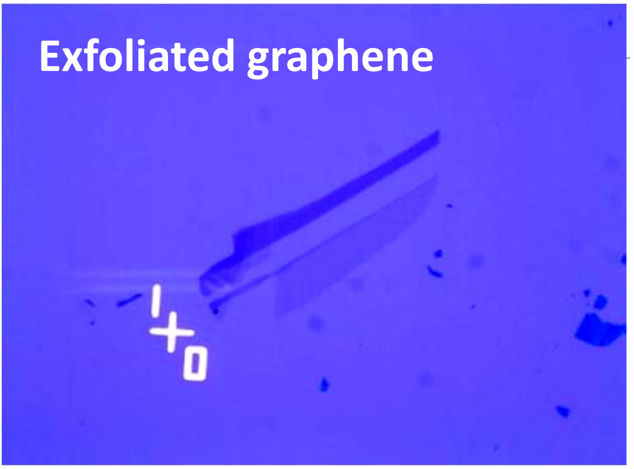
NanoInk Nscriptor - DPN

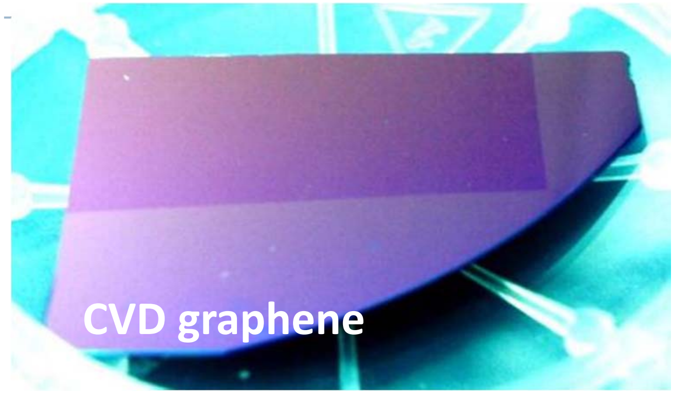
NT-MDT Ntegra Aura - AFM & STM

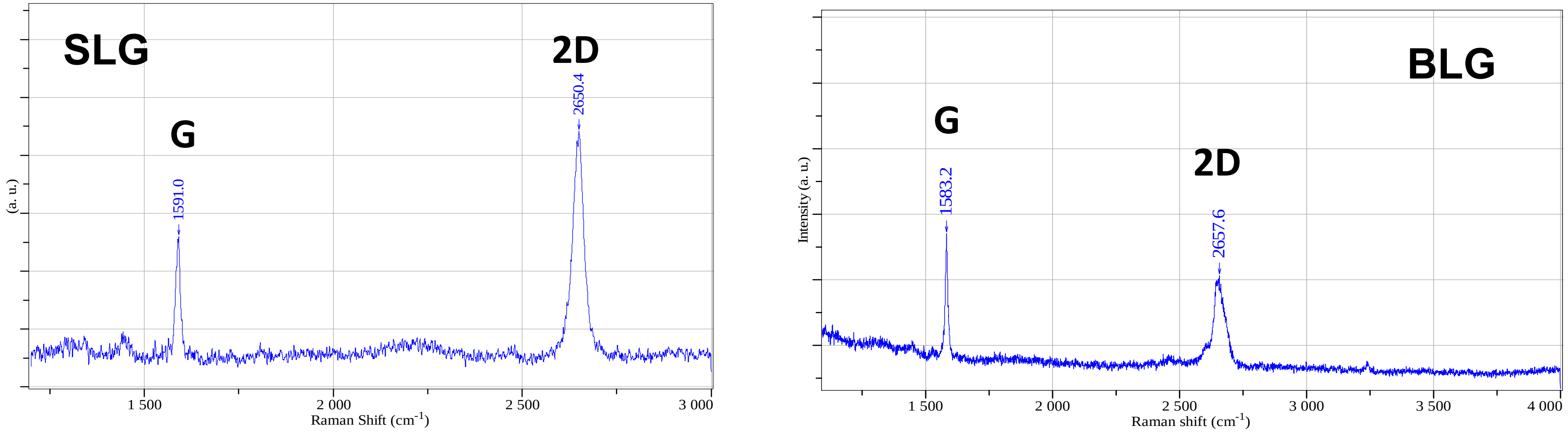
Tescan Vega LMU II - SEM

FEI Nova NanoSEM630 - FEG-SEM

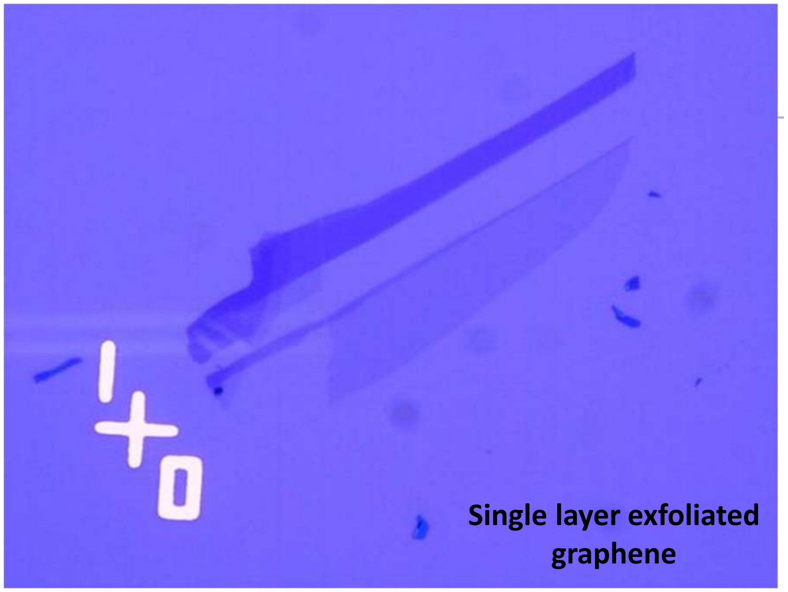
Agilent G200 - Nanoindenter



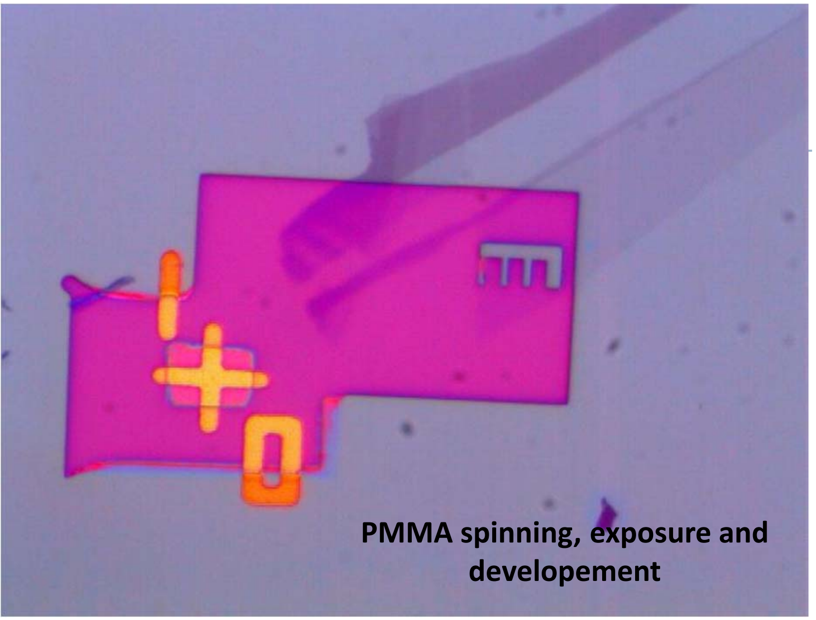




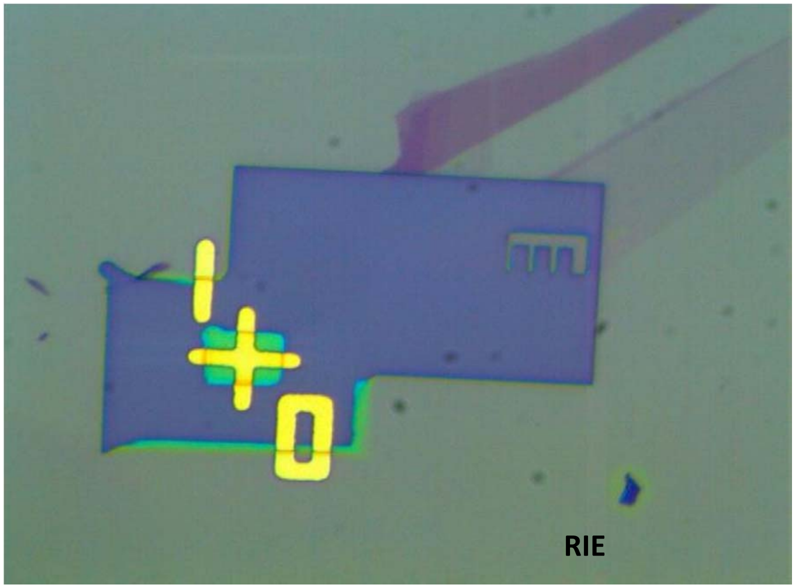
Raman spectra of single and double layer graphene



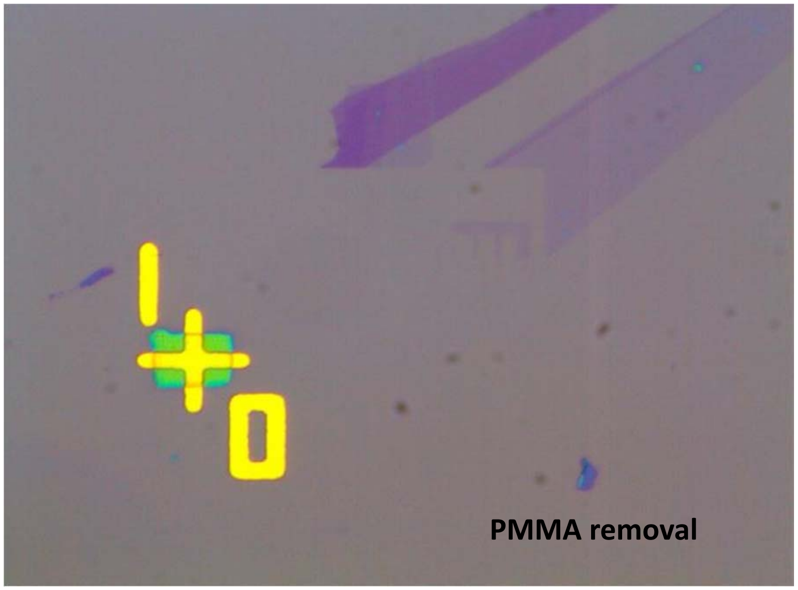
Single layer exfoliated graphene



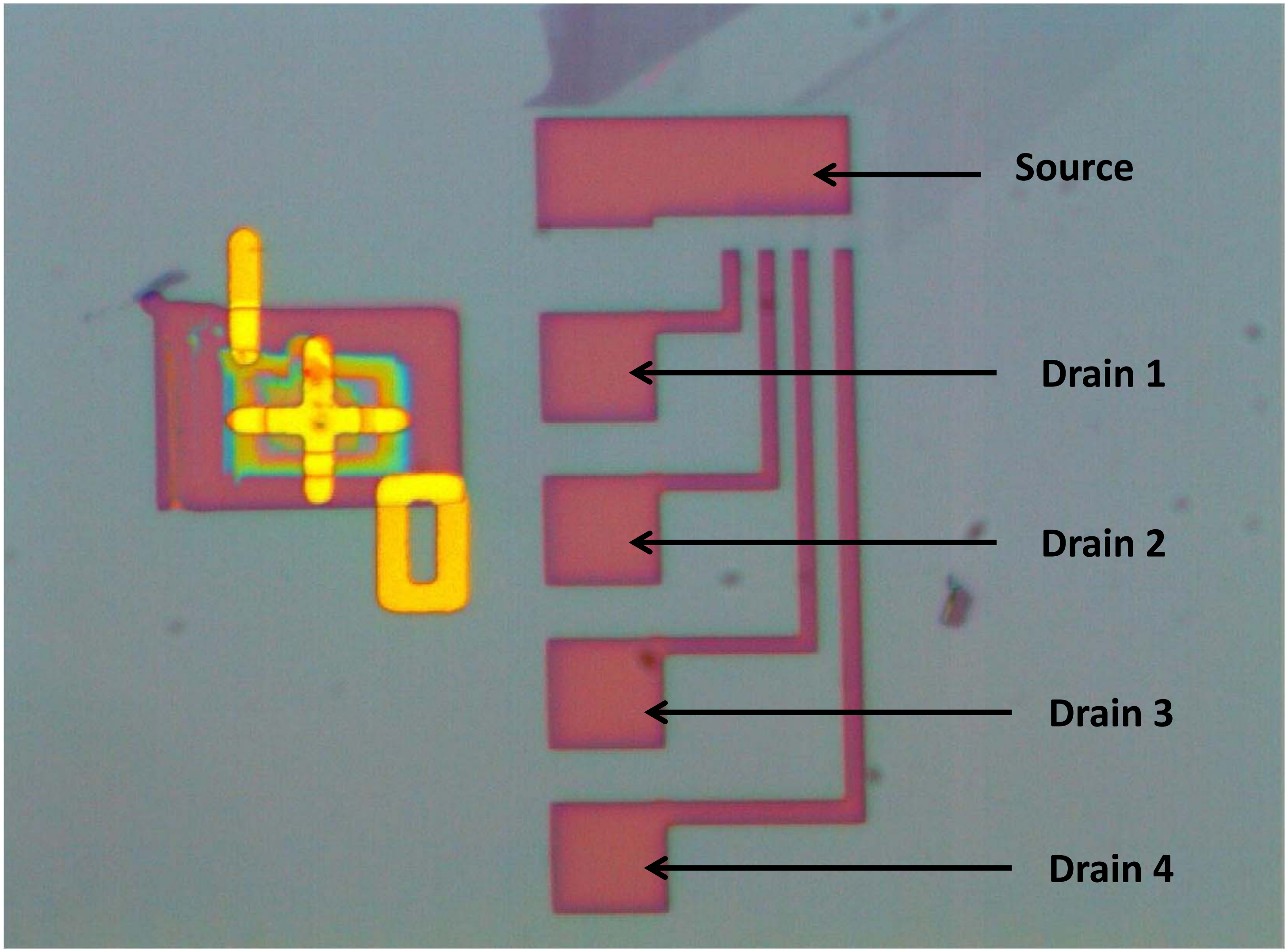
PMMA spinning, exposure and developement

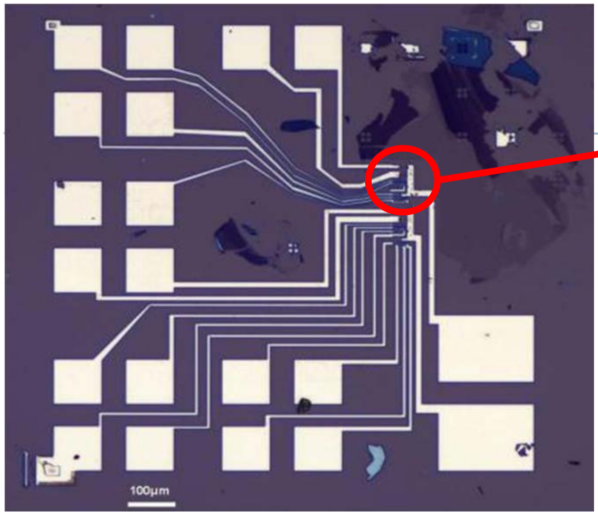


RIE

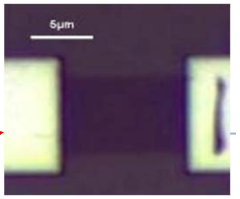


PMMA removal

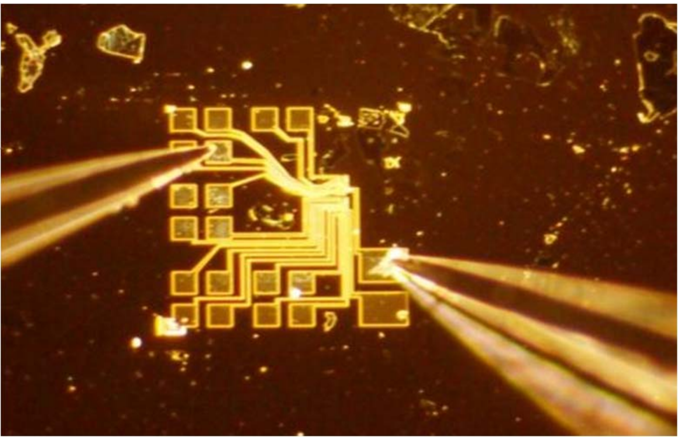

Source
Drain 1
Drain 2
Drain 3
Drain 4



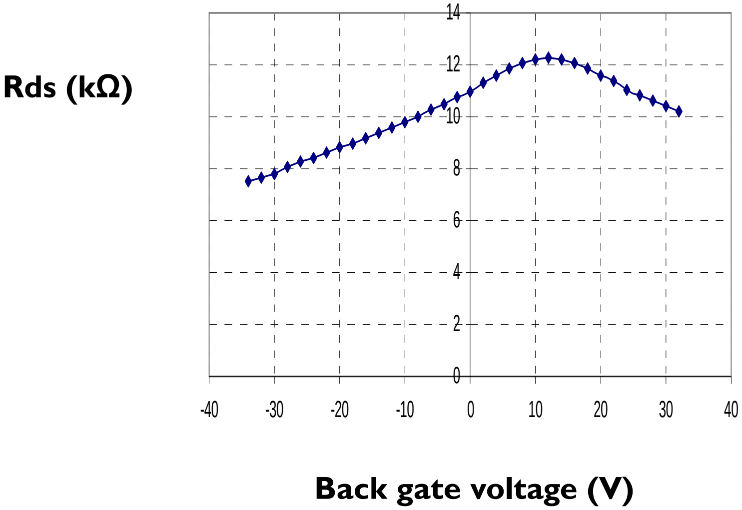
Array of 18 BG-FETs on graphene

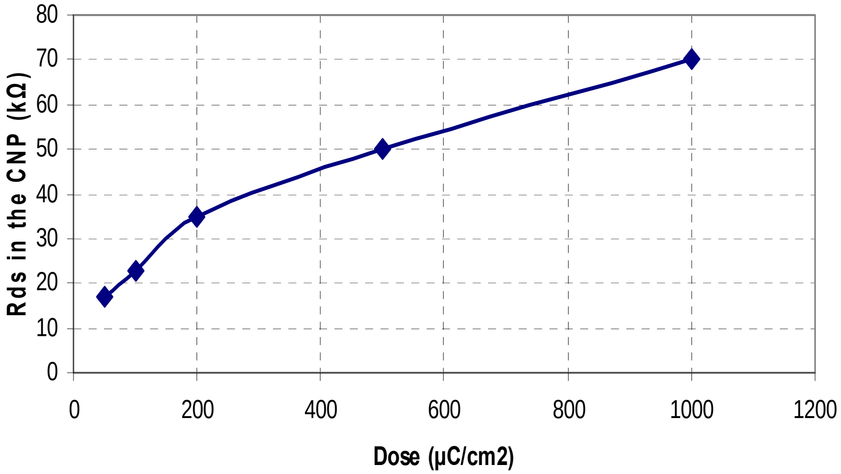


A back gated FET on graphene ribbon



The device under test, on the probing station

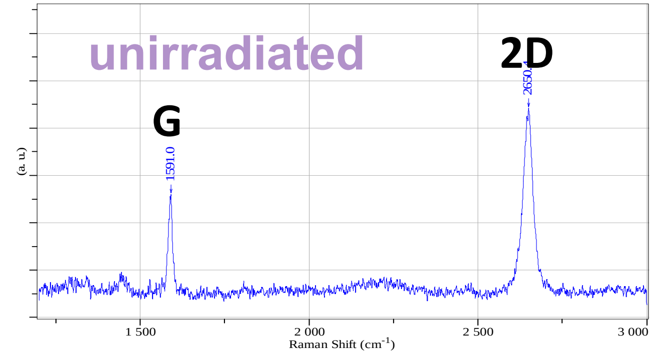




Rds in the CNP vs irradiation dose (HV = 200V)

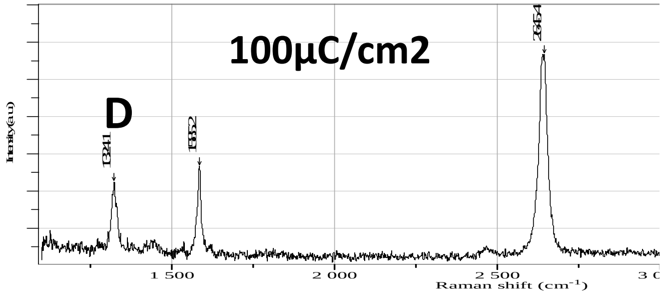
Similar behavior at 500V and 1kV

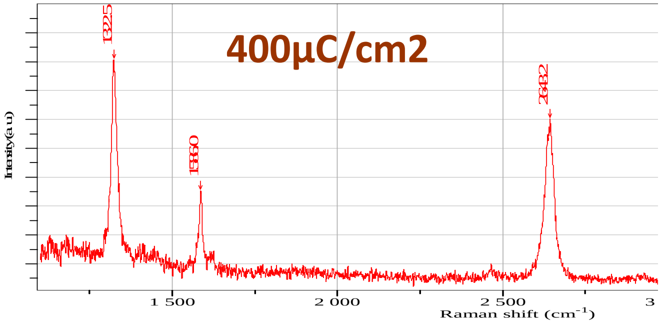
*A. Dinescu, M. Purica, R. Gavrila, A. Avram and R. Muller "**Influence of Low Energy Electron Beam Irradiation of Graphene Ribbon Based Back Gated Field Effect Transistors**", **MRS 2012** spring meeting, April 9-13, San Francisco, California*

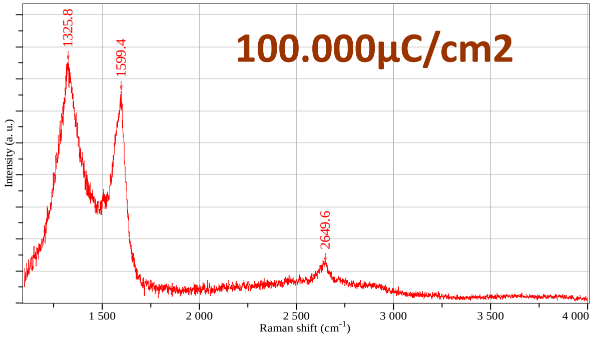


Typical exposure doses in Scanning Electron Microscopy and Electron Beam Lithography

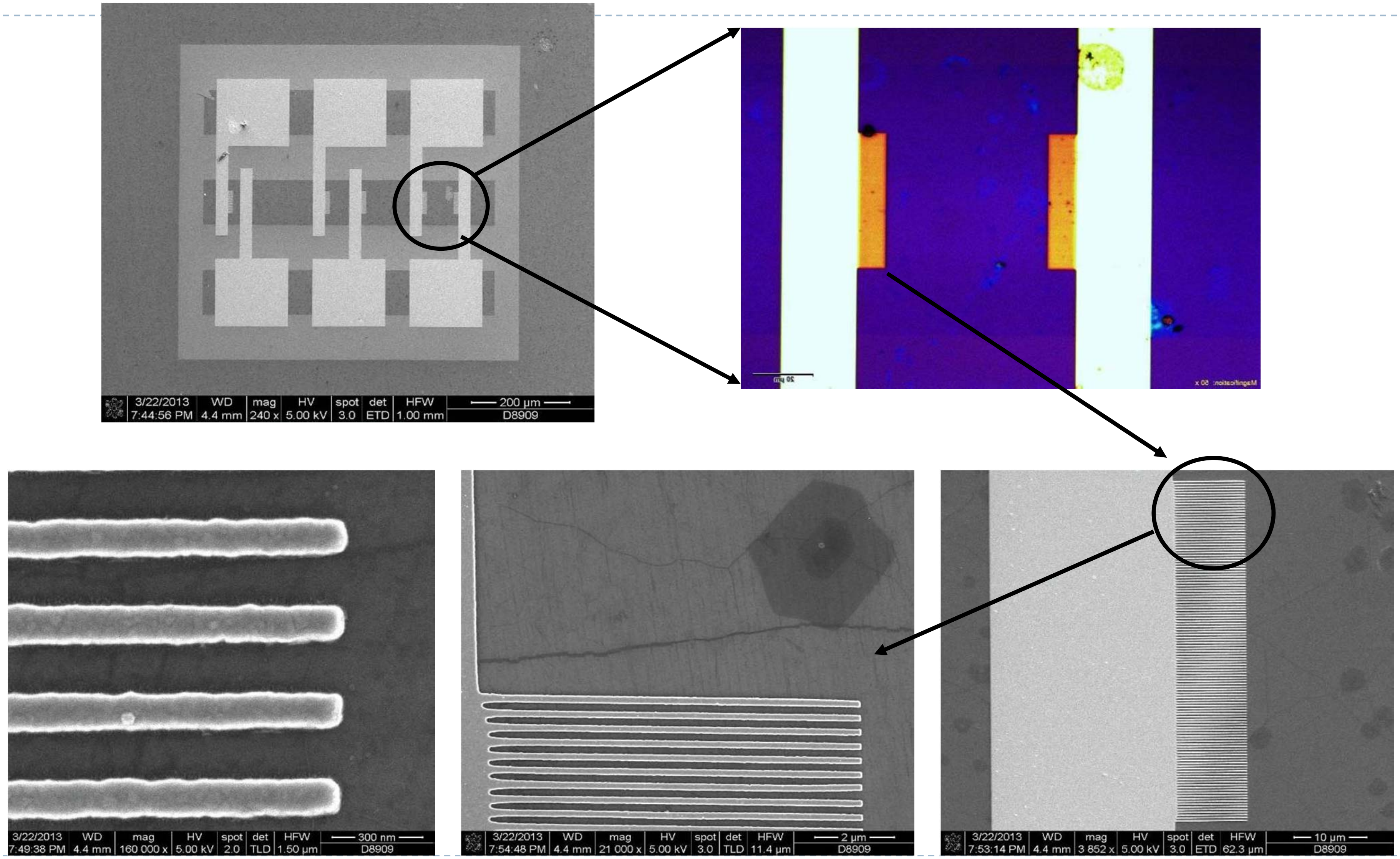
- Acquiring a SEM image on 100µm X 100µm, in 10 sec at 100pA – 10 µC/cm2
- Clearing Dose for PMMA at 10kV accelerating voltage: 100 µC/cm2
- Clearing Dose for PMMA at 30kV accelerating voltage: 300µC/cm2
- Clearing Dose for HSQ at 30kV accelerating voltage: 3000µC/cm2
- Acquiring the SEM image an area of 1µm X 1µm, in 10 sec at 100pA – 100.000 µC/cm2



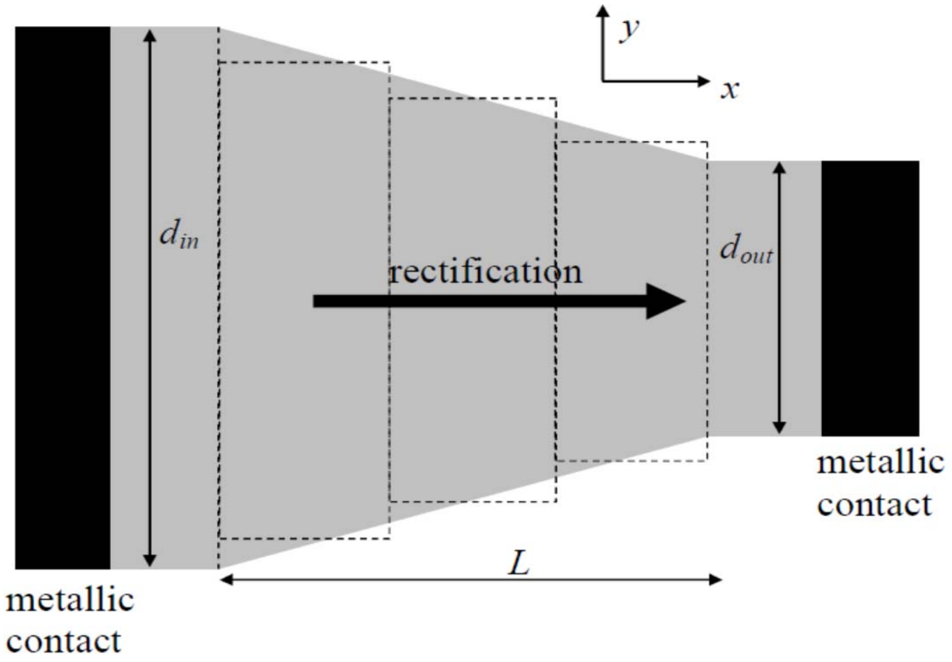


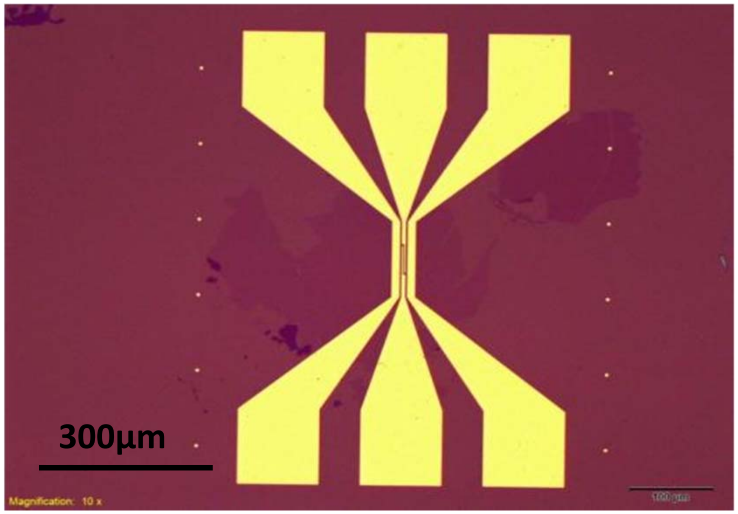


Plasmonic Nanostructure Enhanced Graphene -Based Photodetectors



GEOMETRICAL-INDUCED RECTIFICATION IN TWO-DIMENSIONAL BALLISTIC NANODEVICES

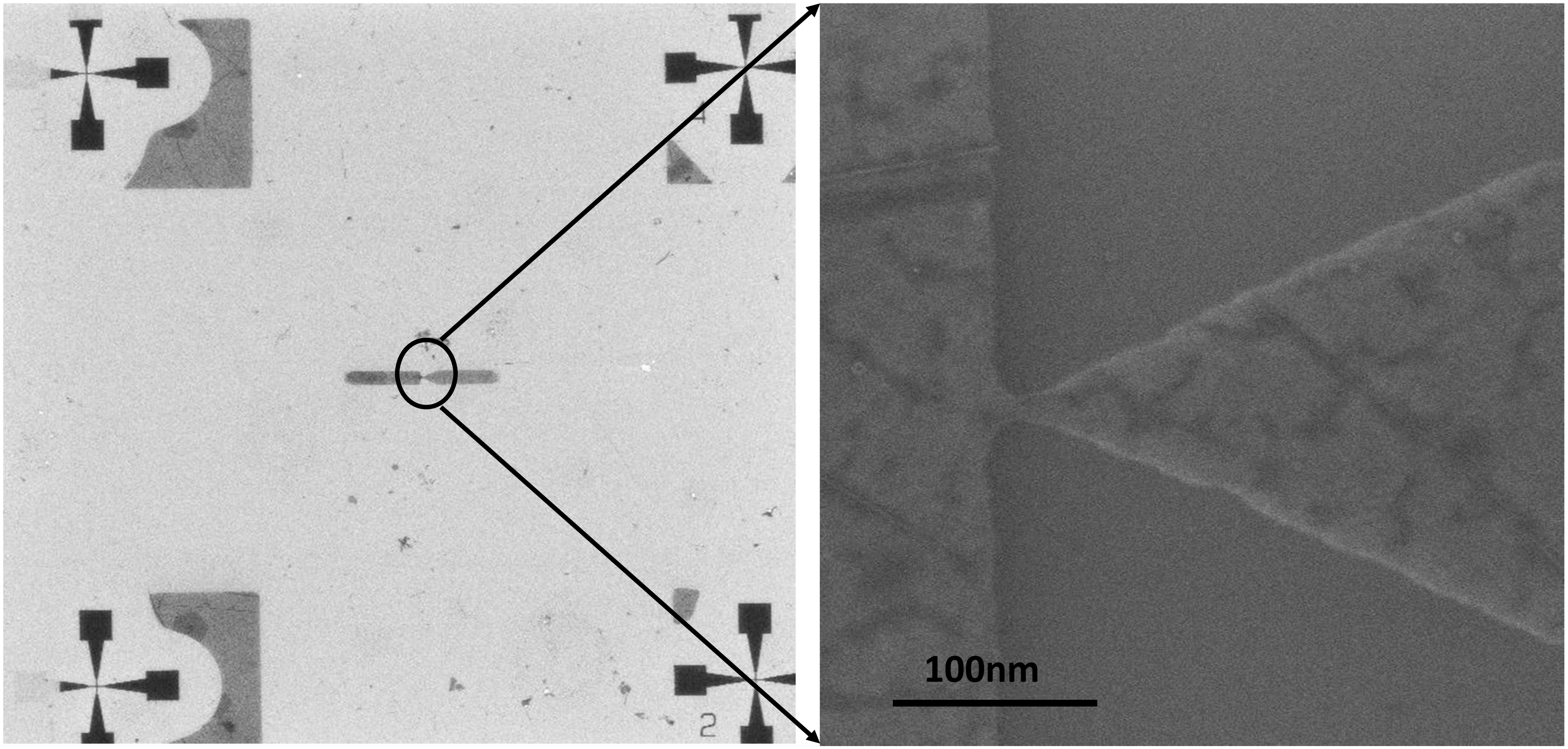




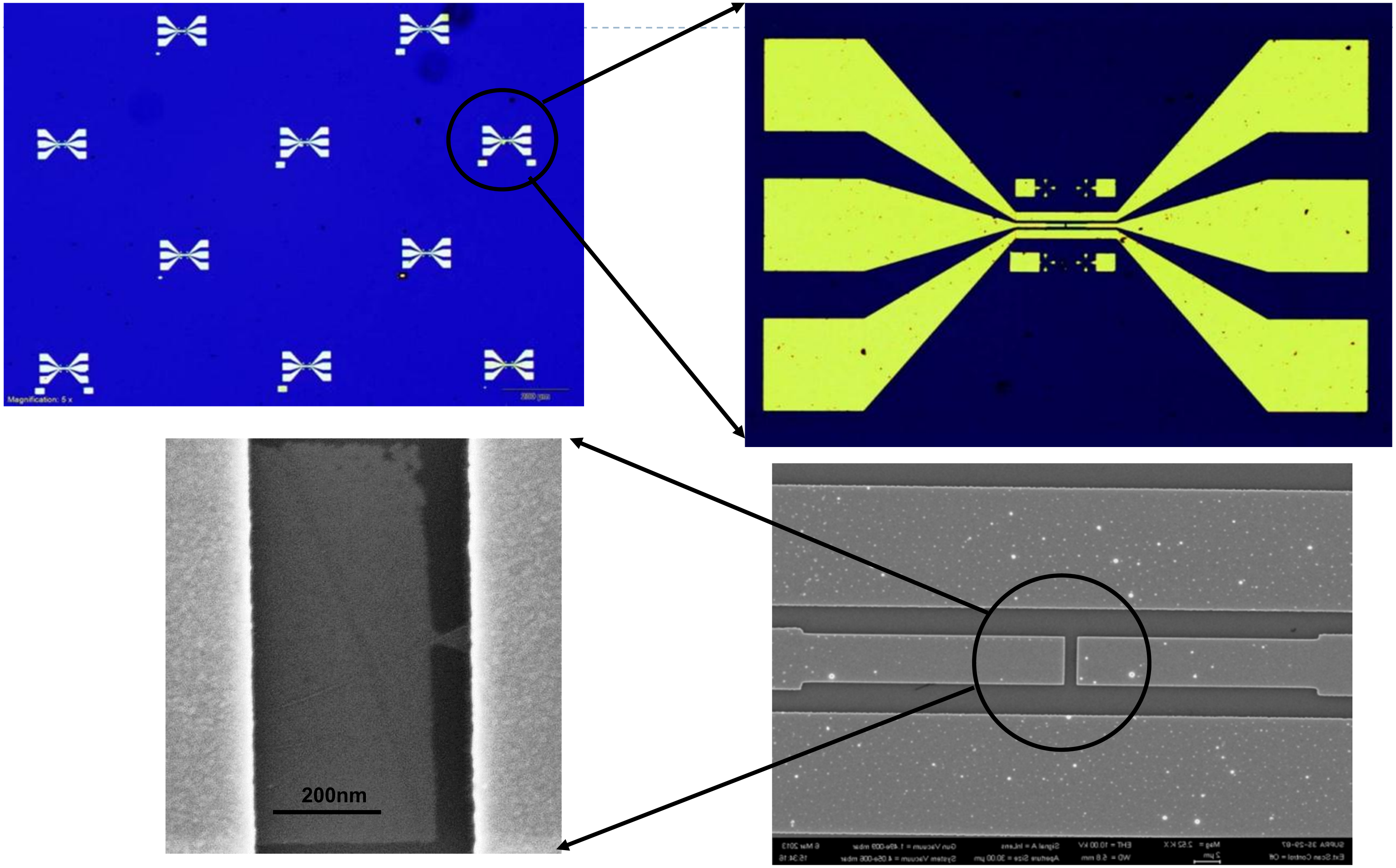
CPW structure for microwave measurements

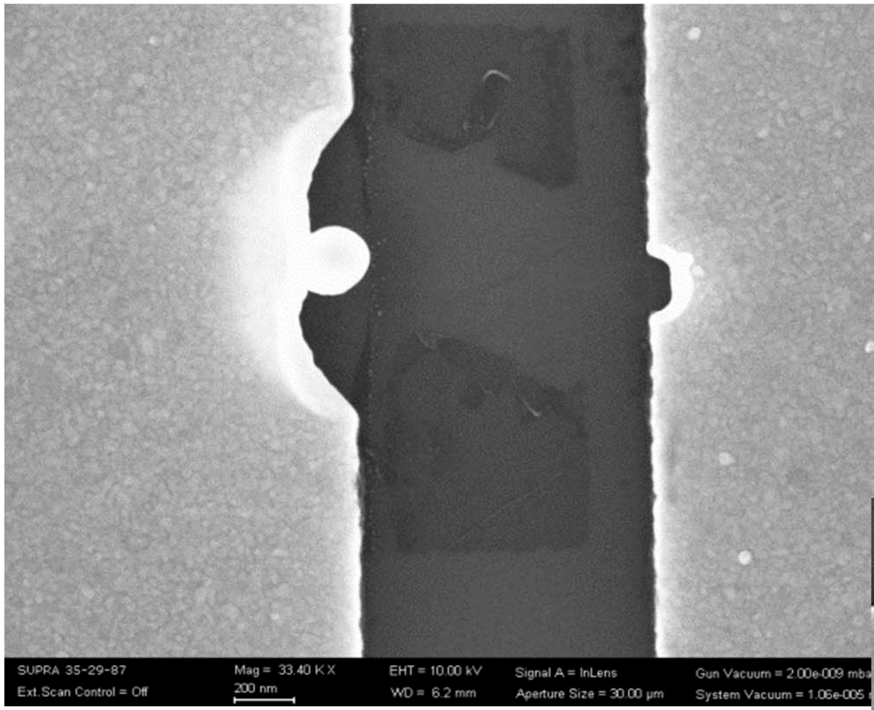
dout **< 30 nm,** ***din*** **/** ***dout*** **> 3 and** ***L*** **< 300 nm**

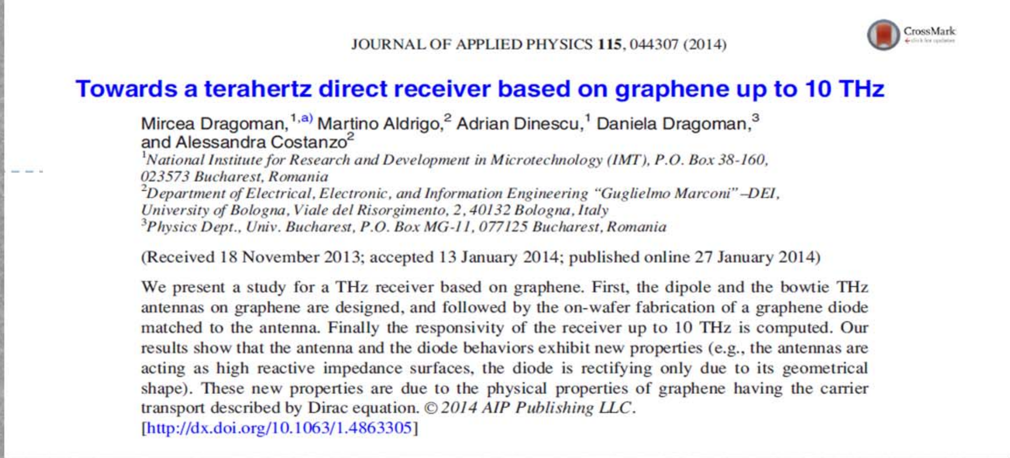
M Dragoman, M Aldrigo, **A Dinescu**, D Dragoman, A Costanzo Towards a terahertz direct receiver based on graphene up to 10 THz. *Journal of Applied Physics 115 (4)*, 044307, (2014).



SEM micrographs of graphene rectifier after RIE


Magnification: 5 x
200nm



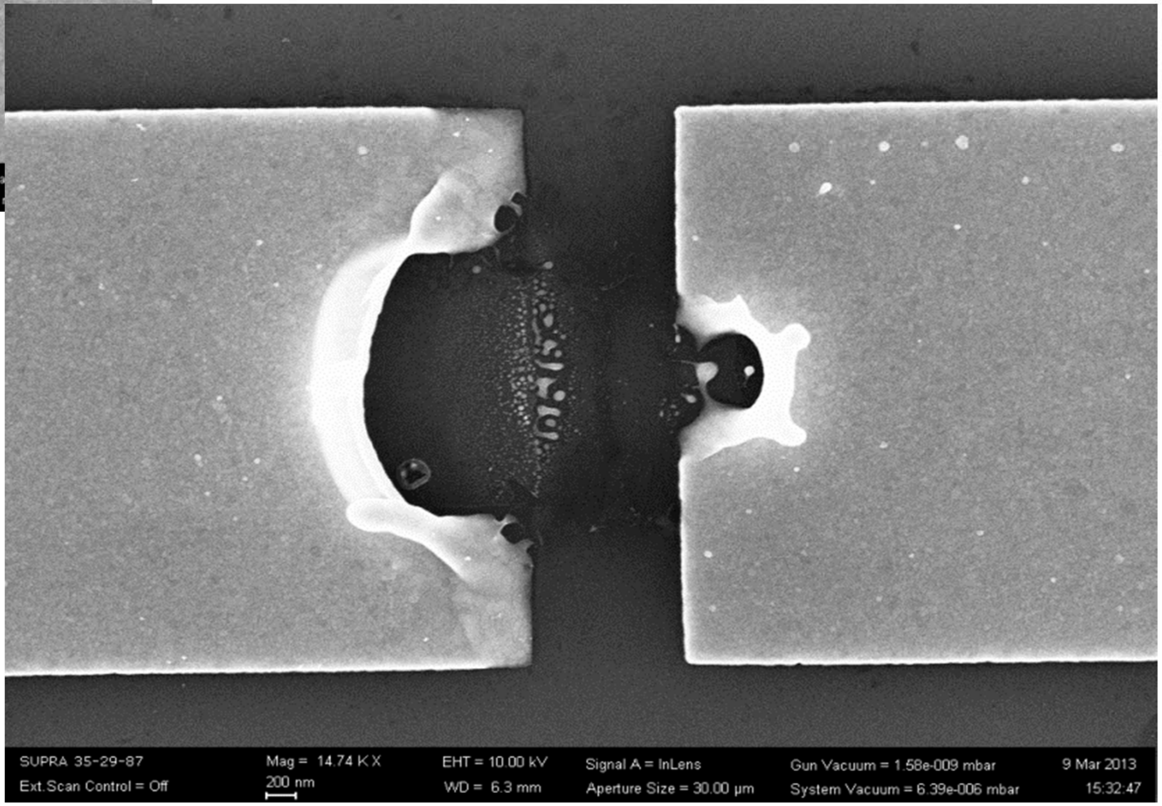

JOURNAL OF APPLIED PHYSICS **115**, 044307 (2014)

Towards a terahertz direct receiver based on graphene up to 10 THz

Mircea Dragoman,[1,a)] Martino Aldrigo,[2] Adrian Dinescu,[1] Daniela Dragoman,[3] and Alessandra Costanzo[2]
[1]*National Institute for Research and Development in Microtechnology (IMT), P.O. Box 38-160, 023573 Bucharest, Romania*
[2]*Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi" –DEI, University of Bologna, Viale del Risorgimento, 2, 40132 Bologna, Italy*
[3]*Physics Dept., Univ. Bucharest, P.O. Box MG-11, 077125 Bucharest, Romania*

(Received 18 November 2013; accepted 13 January 2014; published online 27 January 2014)

We present a study for a THz receiver based on graphene. First, the dipole and the bowtie THz antennas on graphene are designed, and followed by the on-wafer fabrication of a graphene diode matched to the antenna. Finally the responsivity of the receiver up to 10 THz is computed. Our results show that the antenna and the diode behaviors exhibit new properties (e.g., the antennas are acting as high reactive impedance surfaces, the diode is rectifying only due to its geometrical shape). These new properties are due to the physical properties of graphene having the carrier transport described by Dirac equation. © *2014 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4863305]



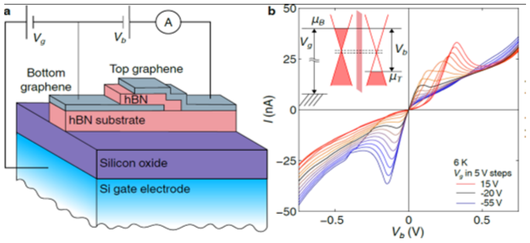
NDR applications: frequency multipliers, mixers, fast switches, high frequency oscillators
Classic NDR devices: Esaki and Gunn diodes

NDR in nanostructures:

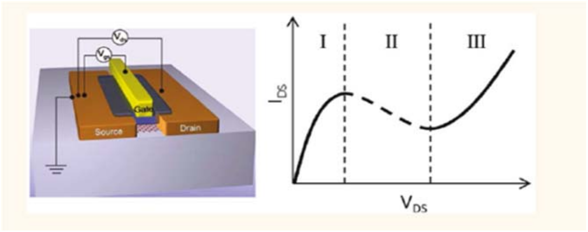
- X.Q. Deng et al. “Electrode conformation-induced negative differential resistance and rectifying performances in a molecular device,” Appl. Phys. Lett. 95, 163109 (2009).
- Y. Ya et al. “Electrical instability and negative differential resistance in single Sb-doped ZnO nanobelts/SiO$_x$/p-Si heterostructure device,” Appl. Phys. Lett. 96, 093107 (2010).
- N.M. Park et al. ”Negative differential resistance in silicon quantum dot metal-insulator semiconductor structure,” Appl. Phys. Lett. 89, 153117 (2006).
- M. Dragoman et al. ”Negative differential resitance in GaN nanowire network,” Appl. Phys. Lett. 96, 053119 (2010).

NDR in Graphene FETs:

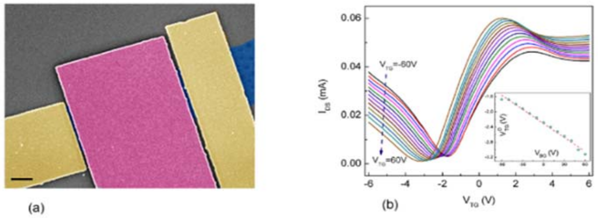
-L. Britnell et al “Resonant tunneling and negative differential conductance in graphene transistors,” Nature Communications 4, 1794 (2013).



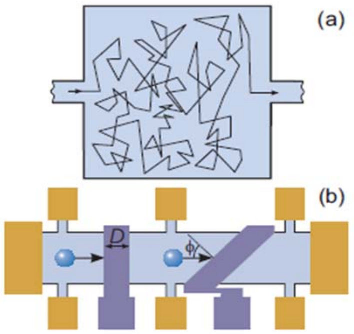
-Y. Wu et al “Three terminal graphene negative differential resistance devices,” ACS Nano 4, 2610-2616 (2012).



-G. Liu et al “Graphene-based non-Boolean logic circuits,” J. Appl. Phys. 114, 154310 (2013).



M.I. Katsnelson, K.S. Novoselov, A. K. Geim, “Chiral tunnelling and the Klein paradox in graphene,” Nature Physics 2, 620 (2006).



APPLIED PHYSICS LETTERS **90**, 143111 (2007)

Negative differential resistance of electrons in graphene barrier

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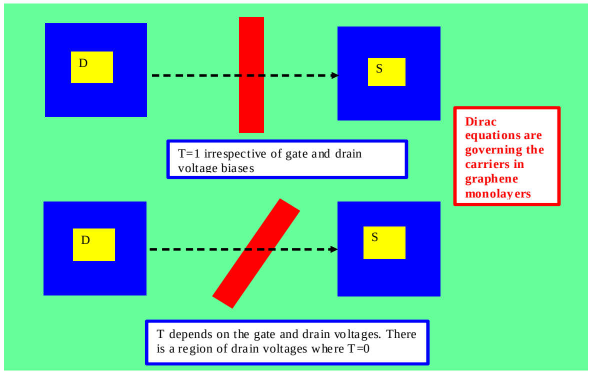
National Institute for Research and Development in Microtechnology (IMT), P.O. Box 38-160, 023573 Bucharest, Romania

(Received 30 December 2006; accepted 4 March 2007; published online 4 April 2007)



T=1 irrespective of gate and drain voltage biases

Dirac equations are governing the carriers in graphene monolayers

T depends on the gate and drain voltages. There is a region of drain voltages where T=0

$$I=\frac{2e}{h}\int T(E)[f_L(E)-f_R(E)]dE$$

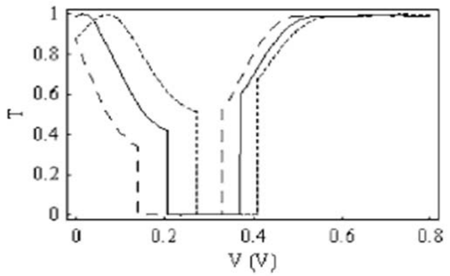


FIG. 2. Transmission of the graphene barrier as a function of the applied voltage at various Fermi wave numbers: $k_F=0.25\,k_{F0}$ (dotted line), $k_F=0.3\,k_{F0}$ (solid line), and $k_F=0.35\,k_{F0}$ (dashed line).

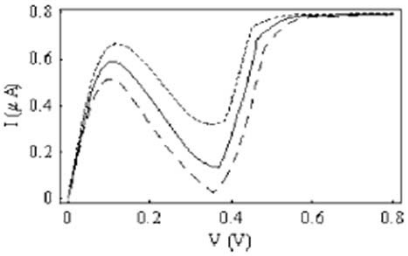
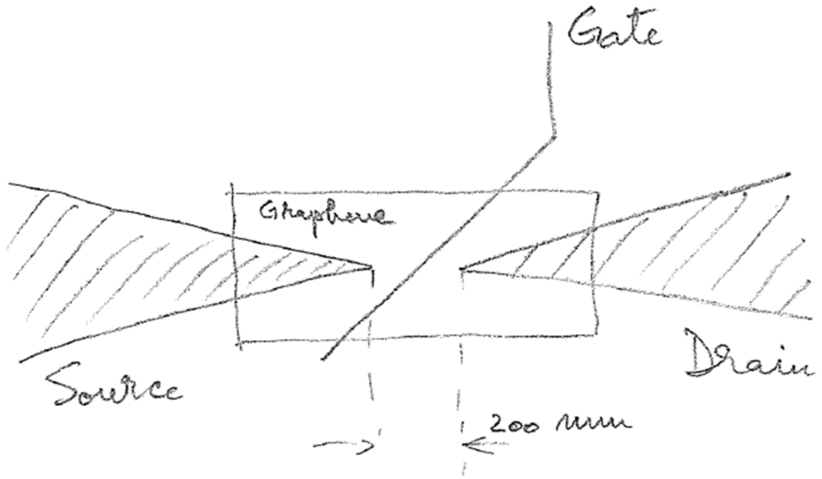
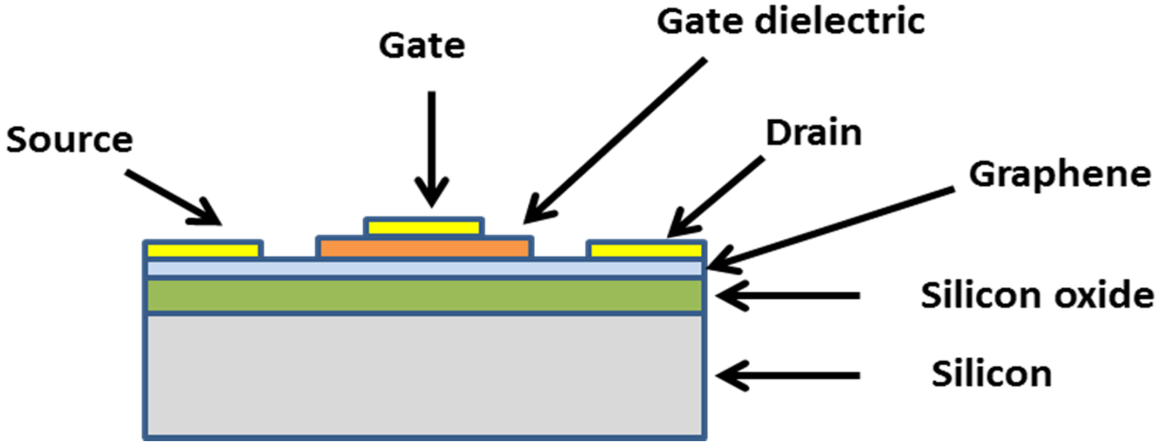


FIG. 4. *I-V* characteristics of graphene barrier at various incident angles: $\varphi_1=10°$ (dotted line), $\varphi_1=15°$ (solid line), and $\varphi_1=20°$ (dashed line).



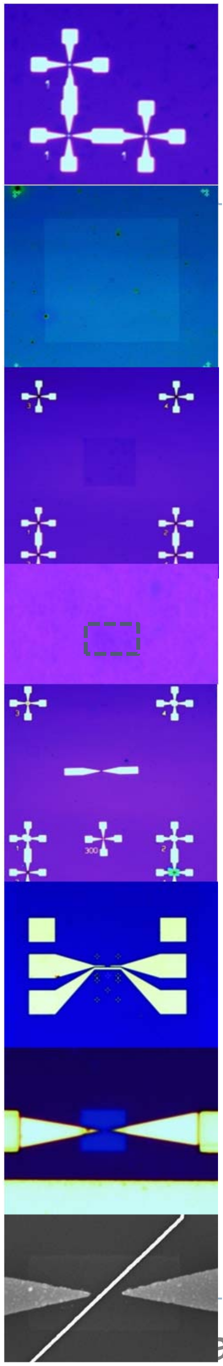


IOP Publishing Nanotechnology

Nanotechnology **25** (2014) 415201 (5pp) doi:10.1088/0957-4484/25/41/415201

Negative differential resistance in graphene-based ballistic field-effect transistor with oblique top gate

Mircea Dragoman[1], **Adrian Dinescu**[1] **and Daniela Dragoman**[2]



Device fabrication

Global alignment marks patterning (e-beam)

-Global alignment marks metallization and lift-off

-Graphene patterning (1) (e-beam)

-RIE (1)

-Local alignment marks patterning (e-beam)

-Local alignment marks metallization and lift-off

-Graphene patterning (2) (e-beam)

-RIE (2)

-S and D patterning (e-beam)

-S and D metallization and lift-off

-S and D contact pads patterning (e-beam)

-S and D contact pads metallization and lift-off

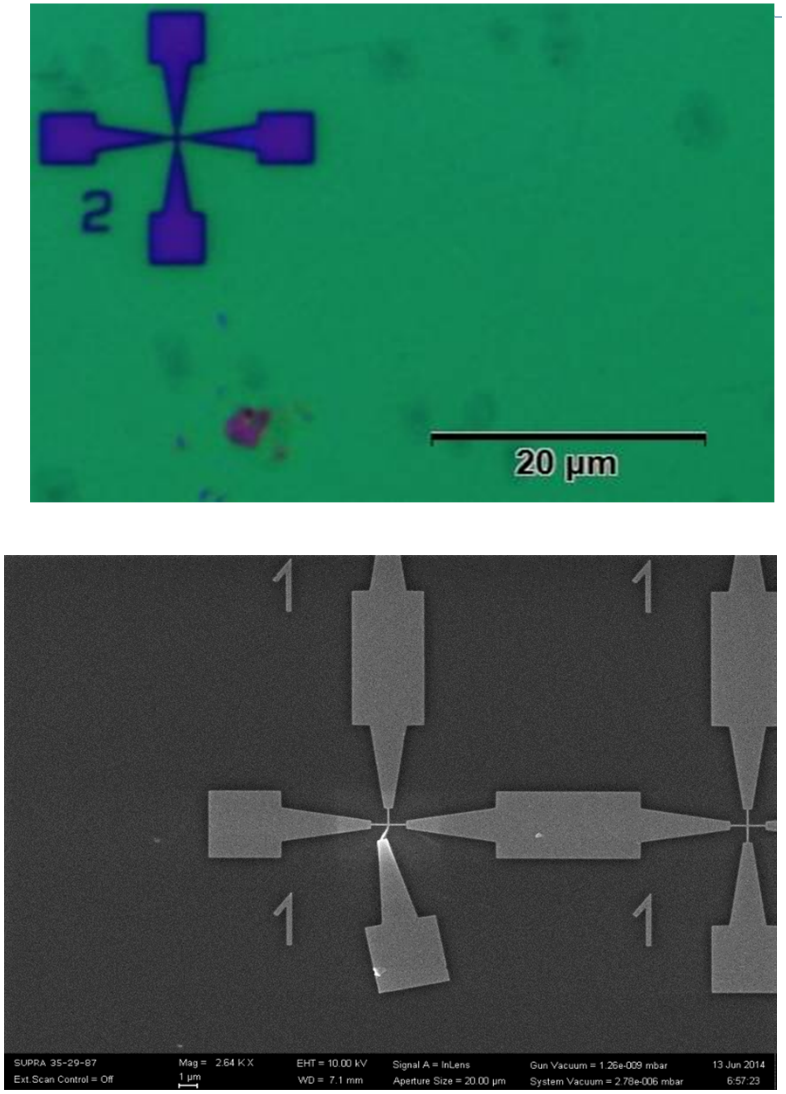
-Gate dielectric deposition and patterning (e-beam)

-Gate patterning (e-beam)

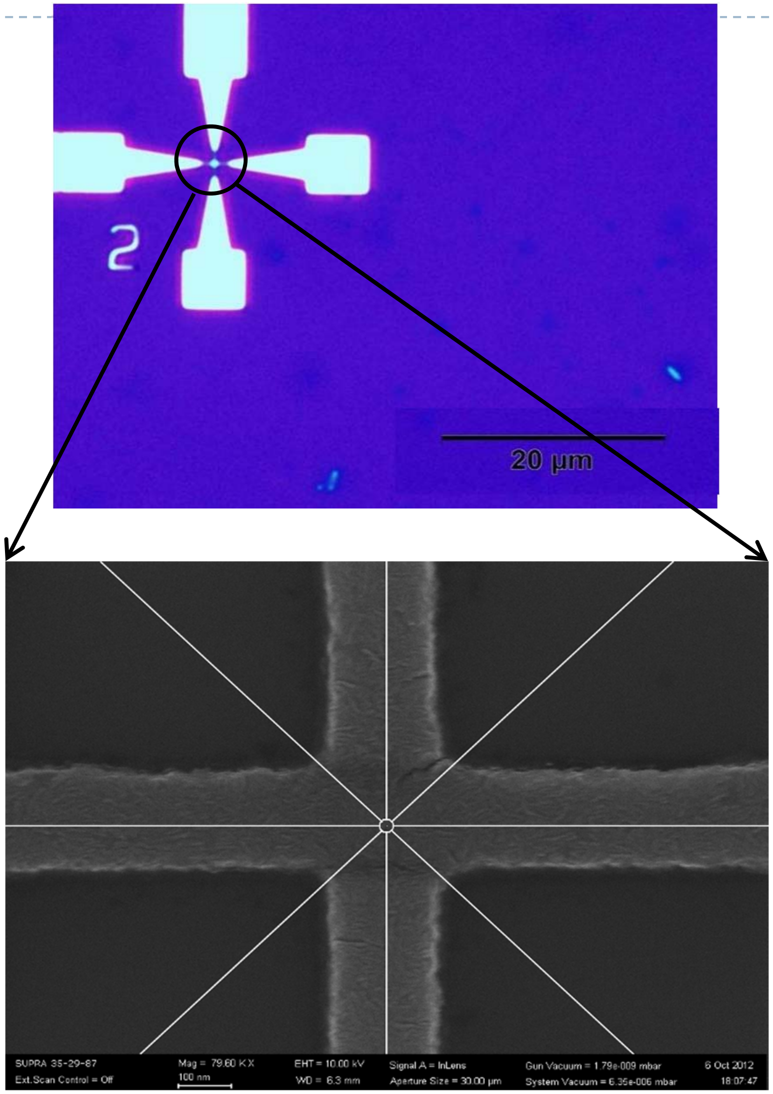
-Gate metallization and lift-off

Device fabrication

Global alignment marks patterning

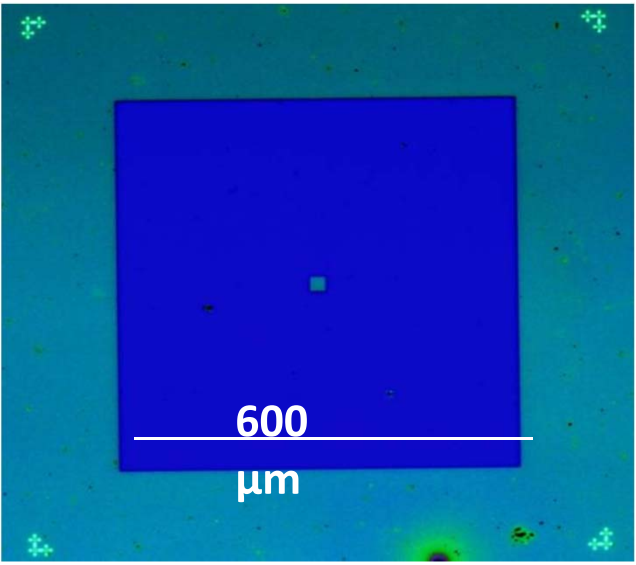


Global alignment marks metallization and lift-off

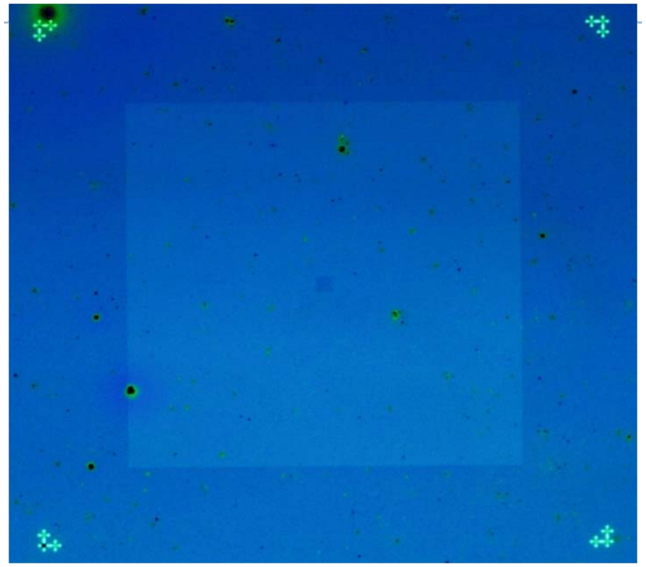


Device fabrication

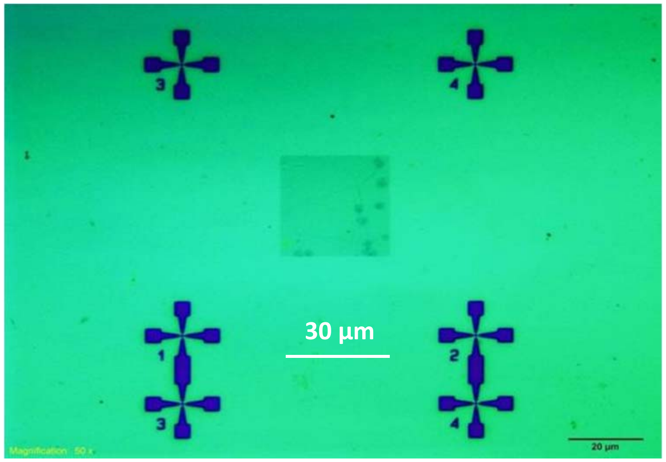
Graphene patterning (1)



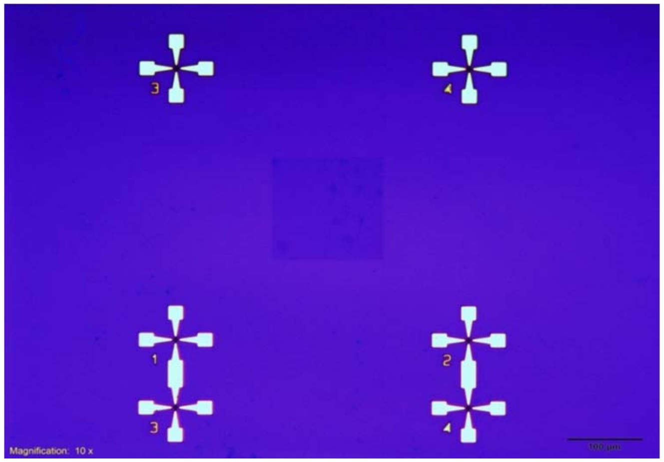
RIE (1)



Local alignment marks patterning

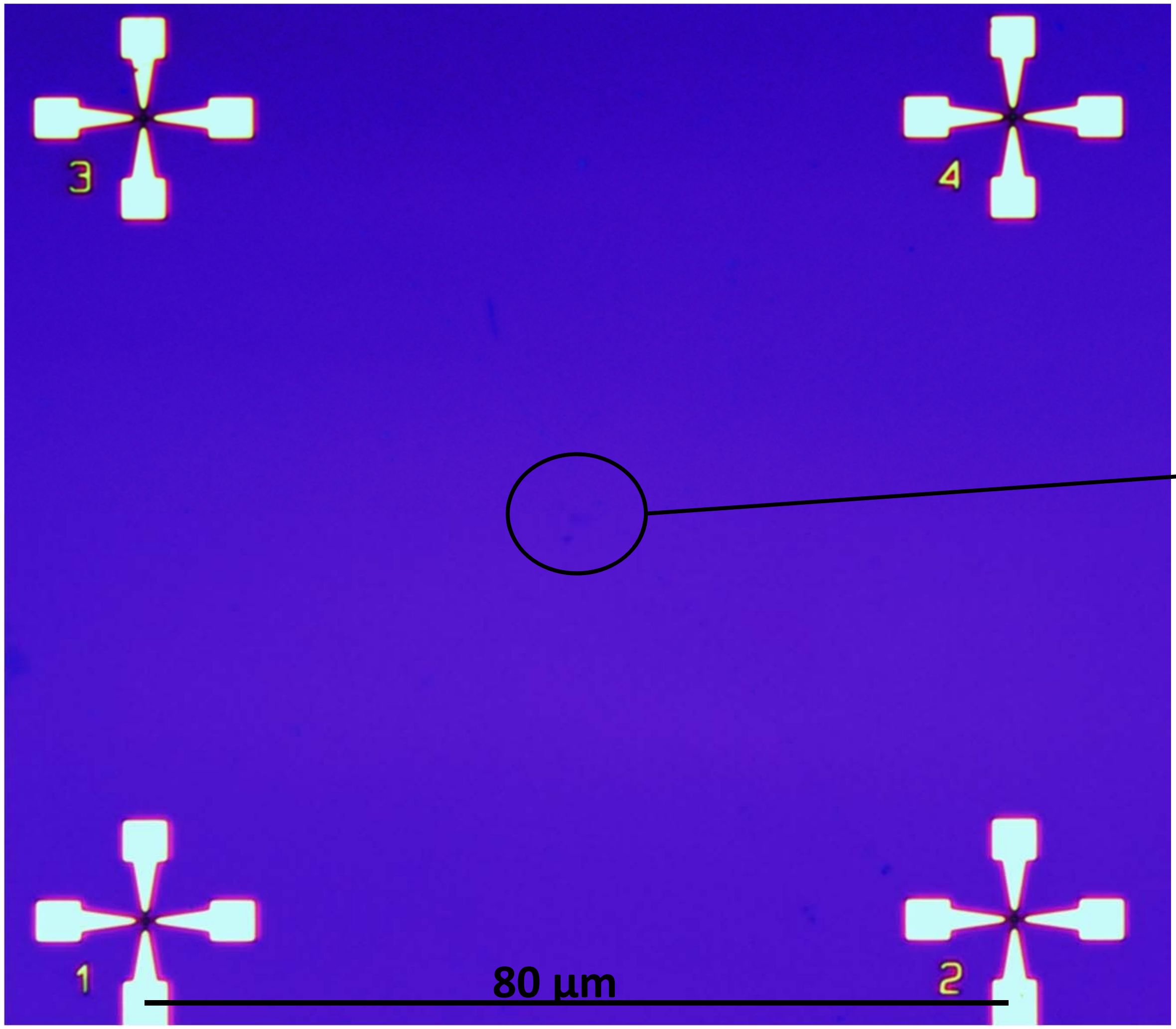


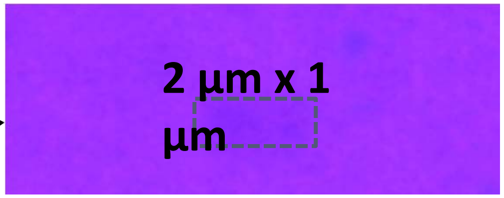
Local alignment marks metallization and lift-off

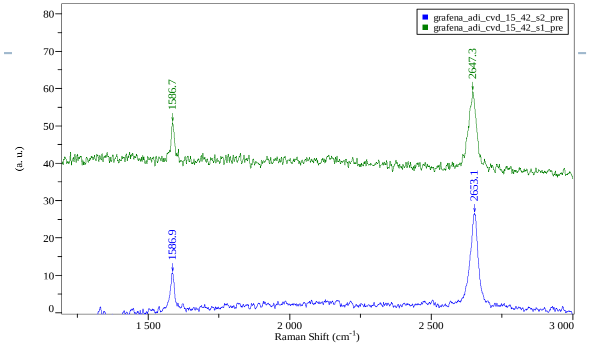


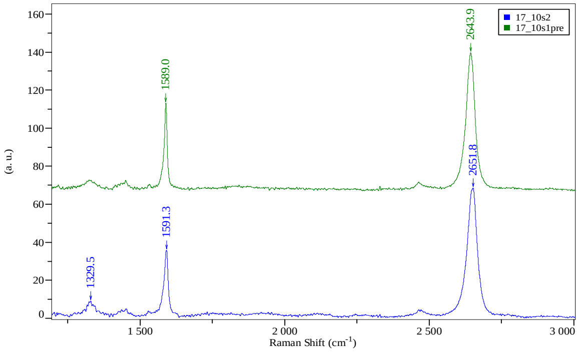
Device fabrication

- **Graphene patterning (2) and RIE (2)**



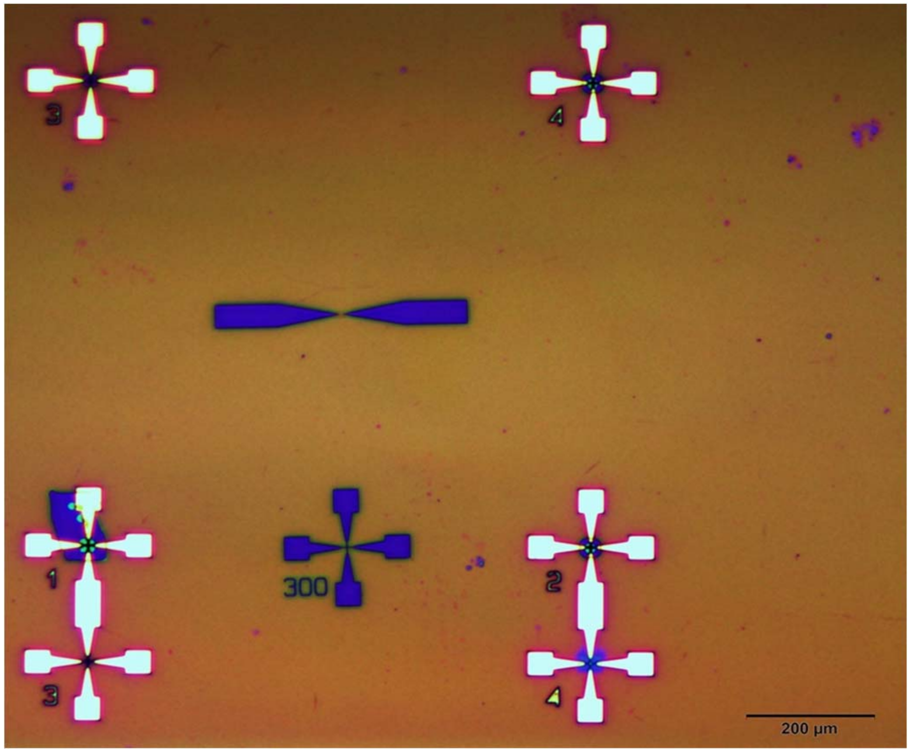




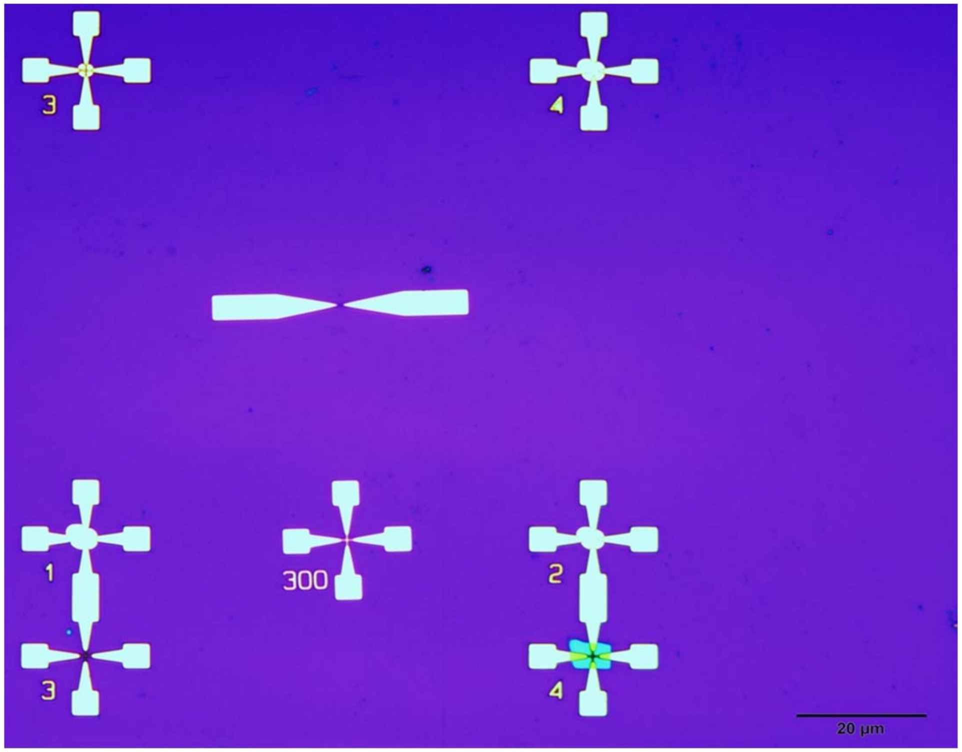


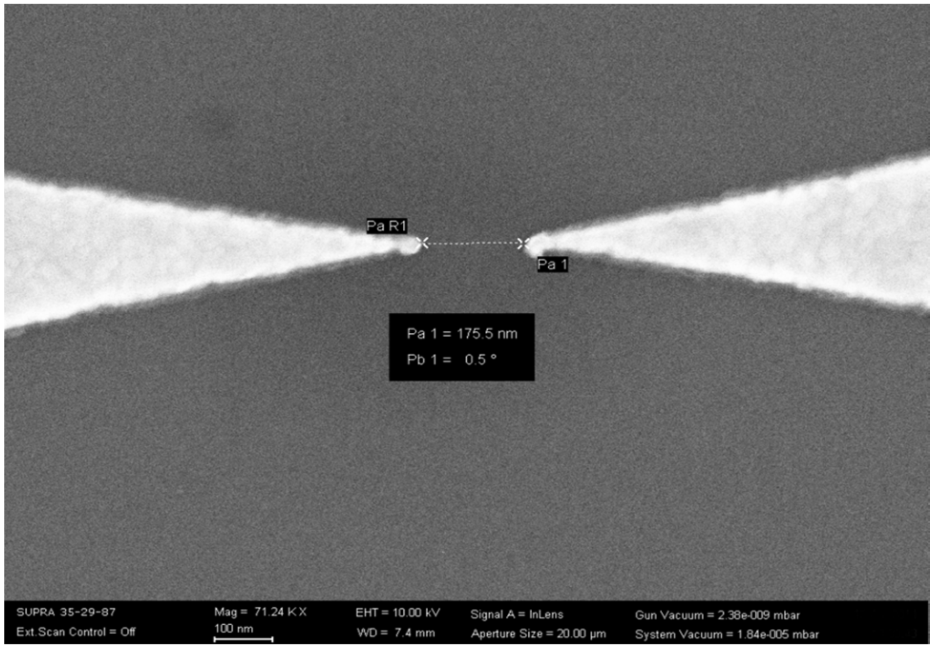
Device fabrication

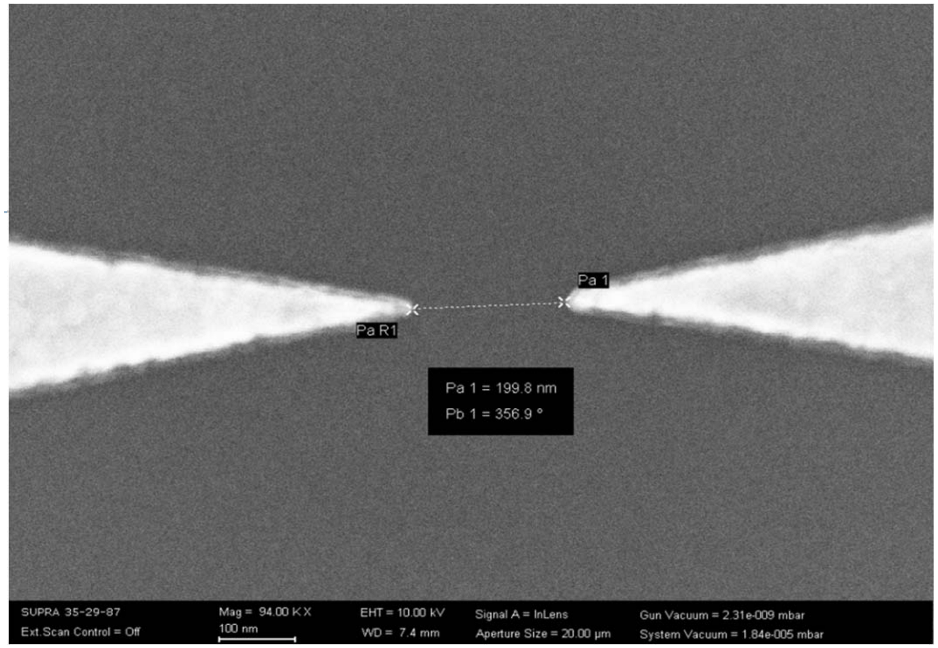
S and D patterning

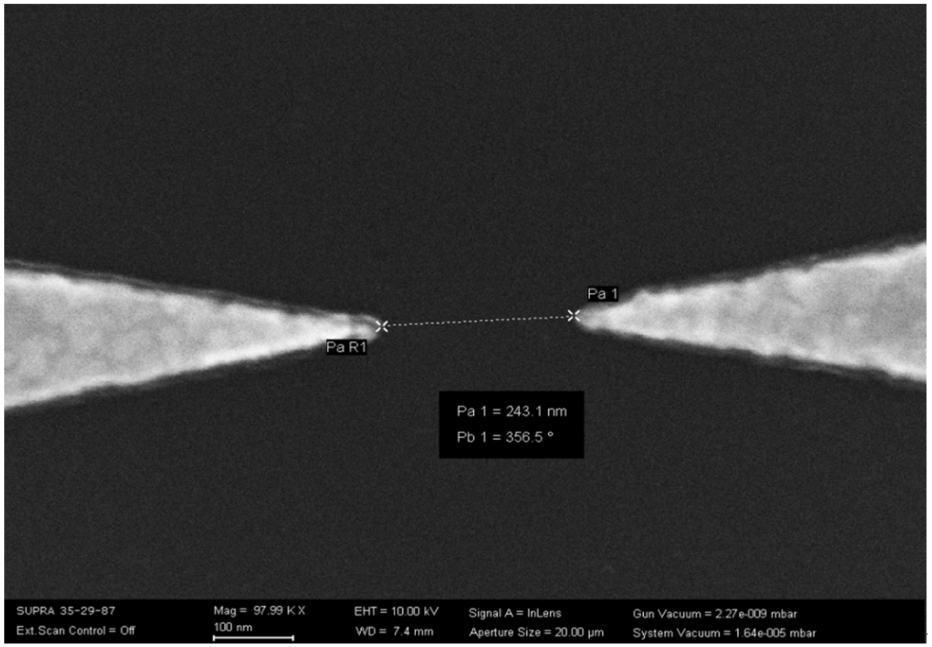


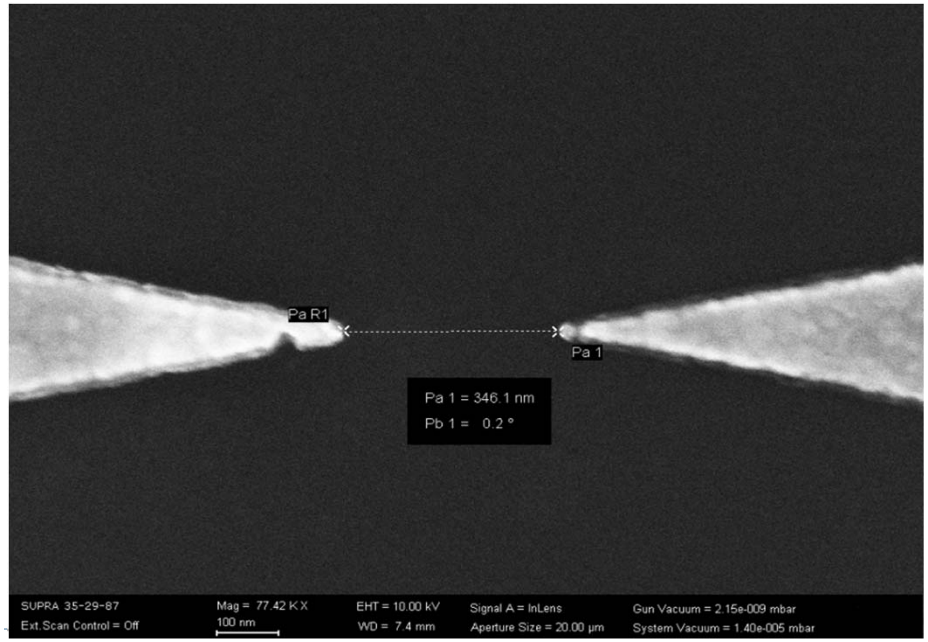
S and D metallization and lift-off
5nm Ti/30nm Au




Pa R1
Pa 1
Pa 1 = 175.5 nm
Pb 1 = 0.5 °
SUPRA 35-29-87
Ext.Scan Control = Off
Mag = 71.24 K X
100 nm
EHT = 10.00 kV
WD = 7.4 mm
Signal A = InLens
Aperture Size = 20.00 µm
Gun Vacuum = 2.38e-009 mbar
System Vacuum = 1.84e-005 mbar

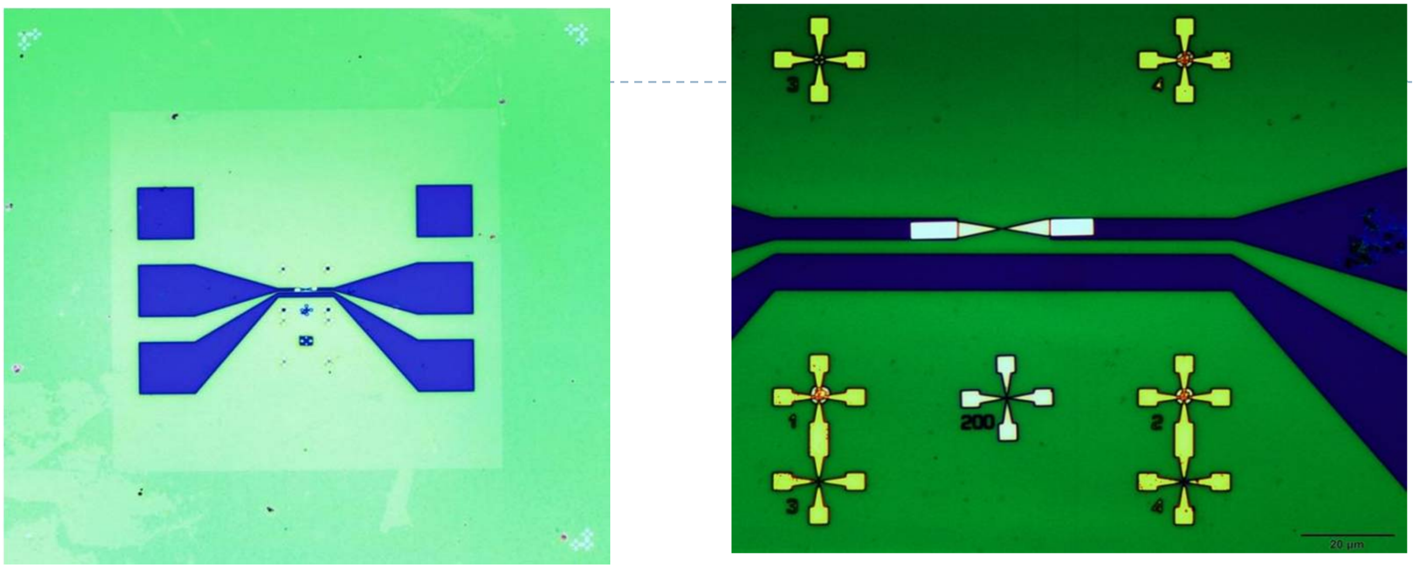

Pa 1
Pa R1
Pa 1 = 199.8 nm
Pb 1 = 356.9 °
SUPRA 35-29-87
Ext.Scan Control = Off
Mag = 94.00 K X
100 nm
EHT = 10.00 kV
WD = 7.4 mm
Signal A = InLens
Aperture Size = 20.00 µm
Gun Vacuum = 2.31e-009 mbar
System Vacuum = 1.84e-005 mbar


Pa 1
Pa R1
Pa 1 = 243.1 nm
Pb 1 = 356.5 °
SUPRA 35-29-87
Ext.Scan Control = Off
Mag = 97.99 K X
100 nm
EHT = 10.00 kV
WD = 7.4 mm
Signal A = InLens
Aperture Size = 20.00 µm
Gun Vacuum = 2.27e-009 mbar
System Vacuum = 1.64e-005 mbar

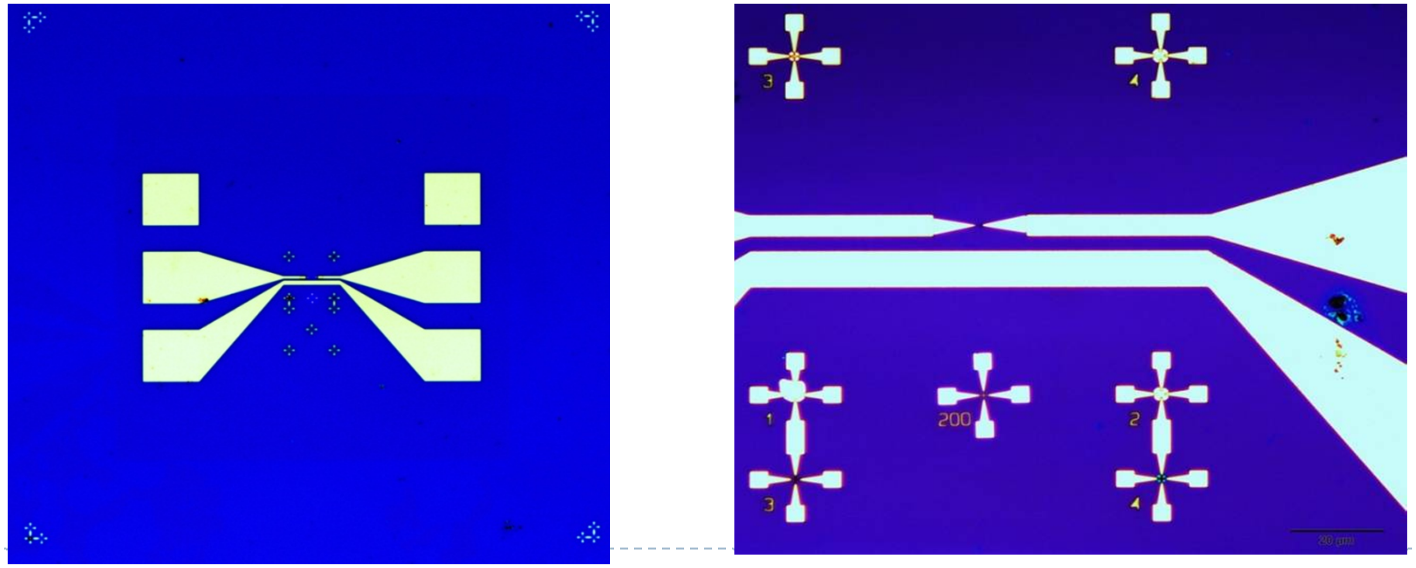

Pa R1
Pa 1
Pa 1 = 346.1 nm
Pb 1 = 0.2 °
SUPRA 35-29-87
Ext.Scan Control = Off
Mag = 77.42 K X
100 nm
EHT = 10.00 kV
WD = 7.4 mm
Signal A = InLens
Aperture Size = 20.00 µm
Gun Vacuum = 2.15e-009 mbar
System Vacuum = 1.40e-005 mbar

Device fabrication

S and D contact pads patterning

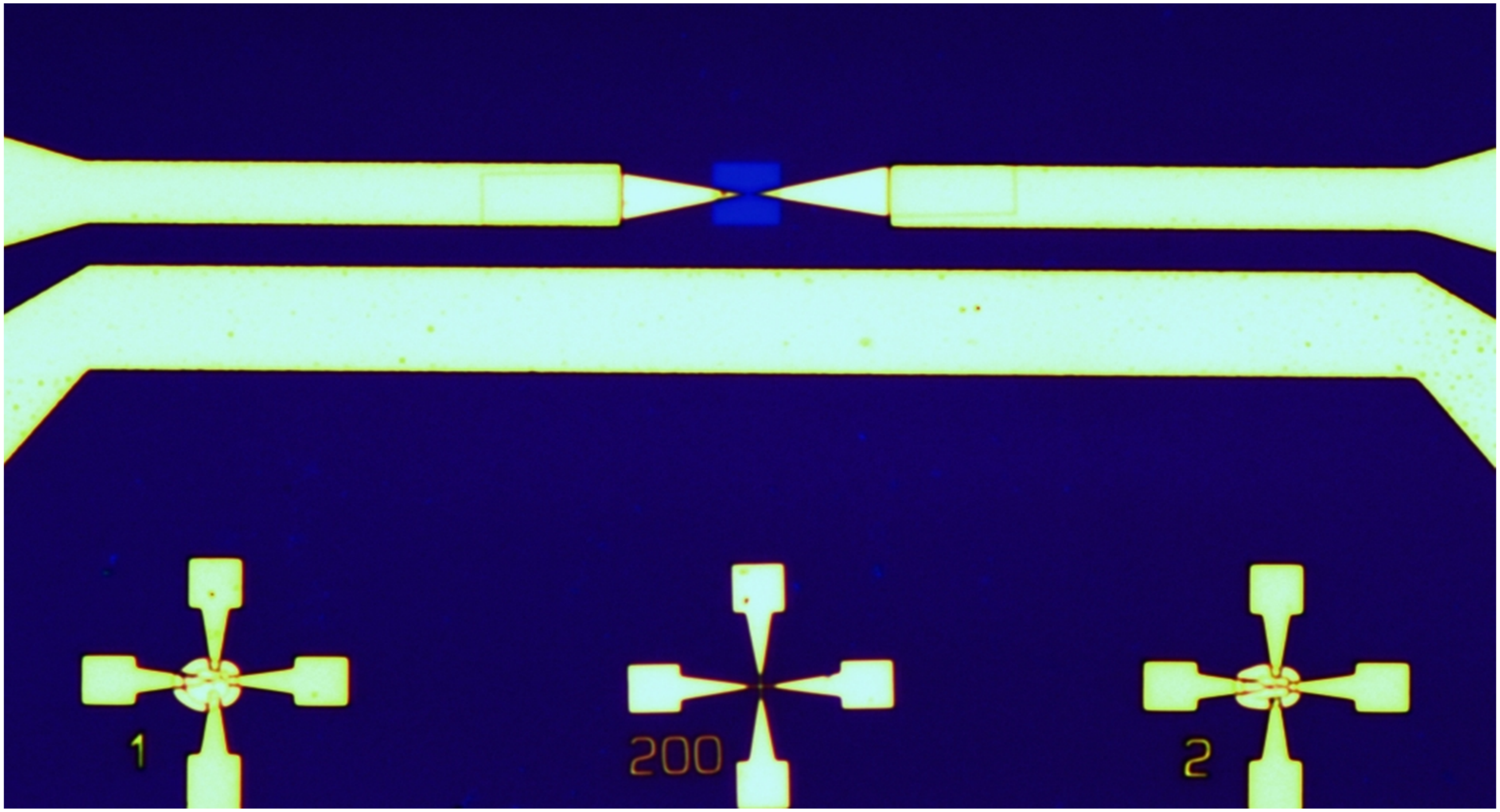


S and D contact pads metallization and lift-off (5nm Ti/ 150nm Au)



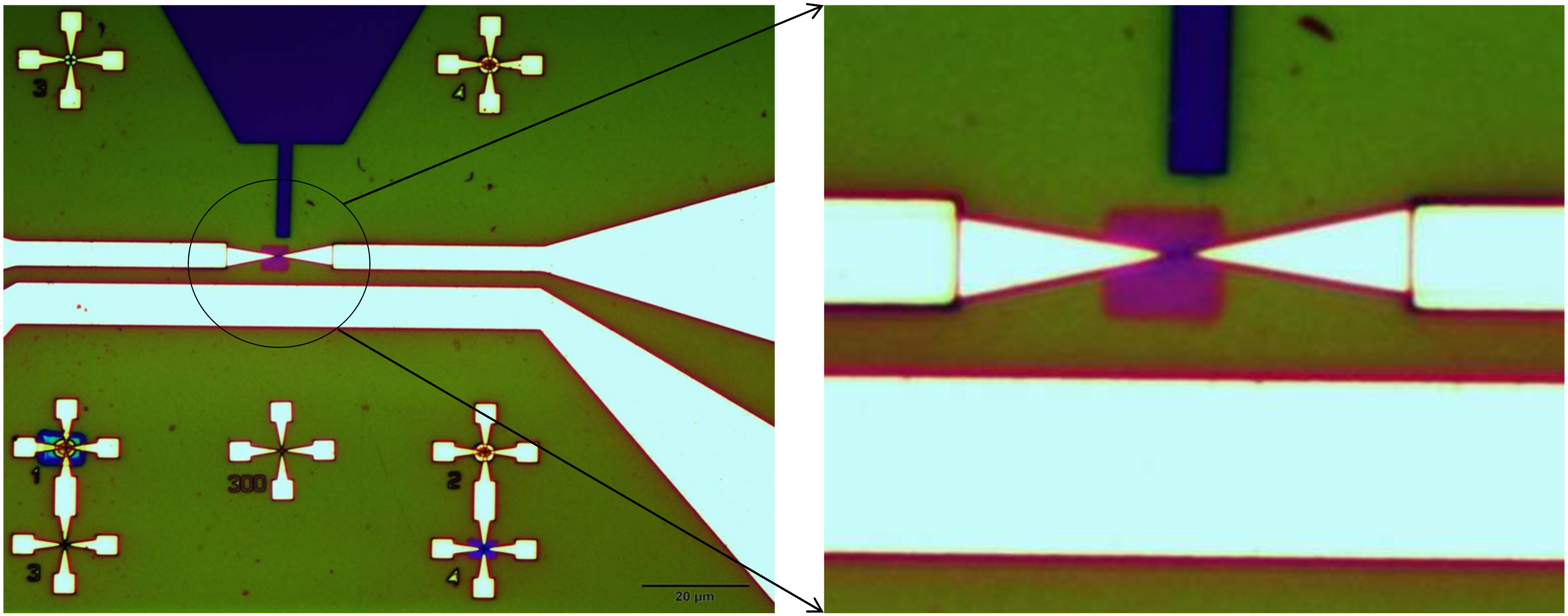
Device fabrication

Gate dielectric deposition and patterning
HSQ - 25nm thickness



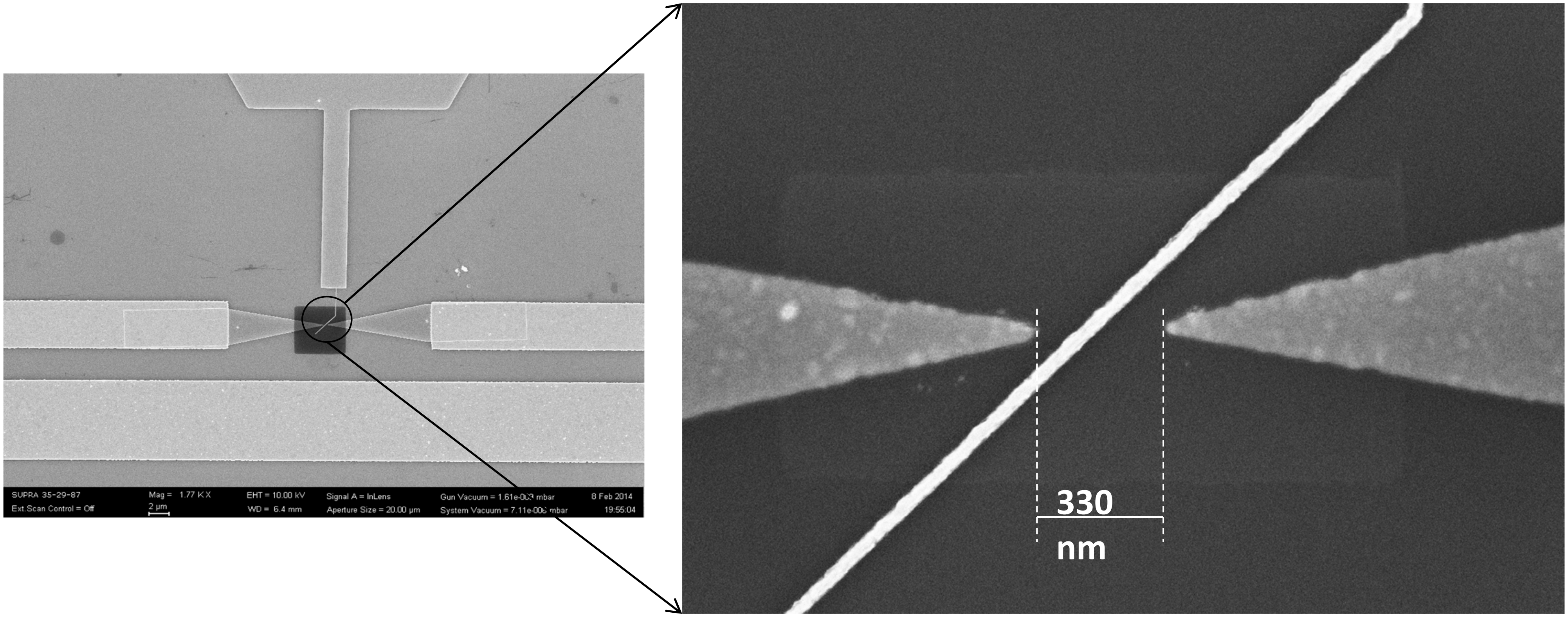
Device fabrication

Gate patterning

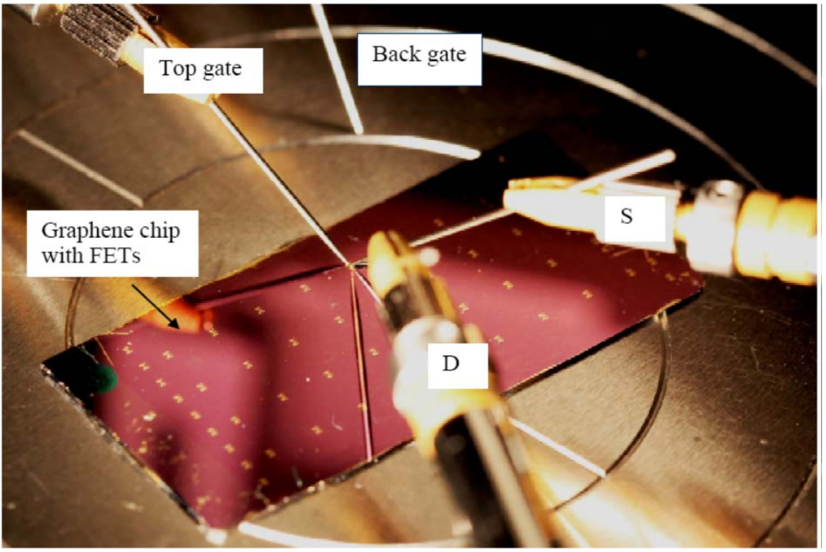


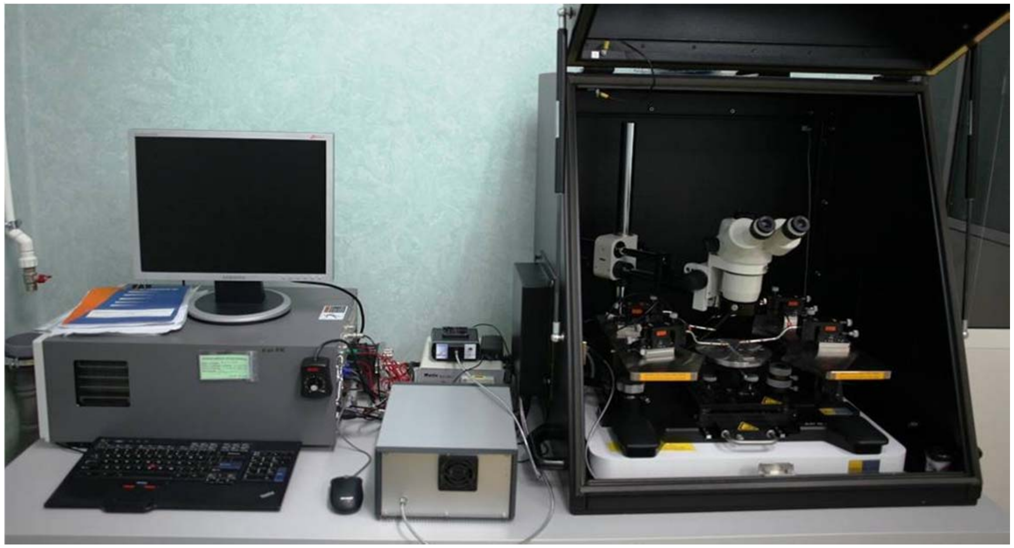
Device fabrication

Gate metallization and lift-off
5nm Cr/ 40nm Au

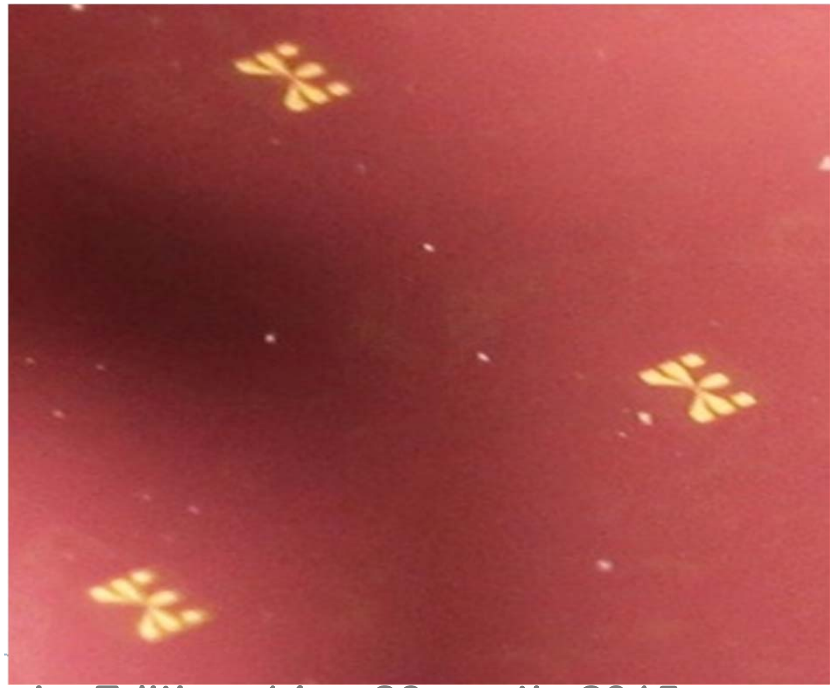


Electrical Measurements



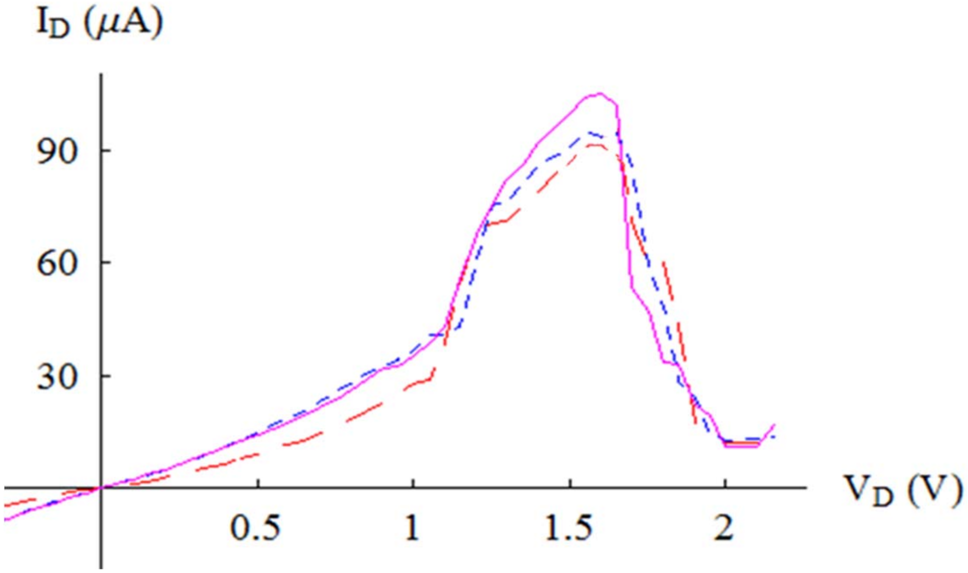


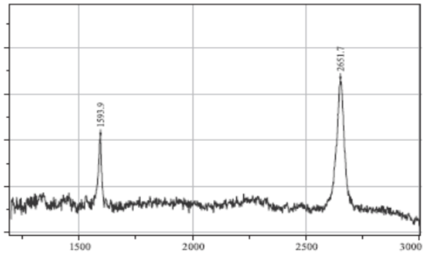
Semiconductor Characterization System - 4200-SCS/C/Keithley with Wafer Probing Station –Easyprobe EP6/ Suss MicroTec

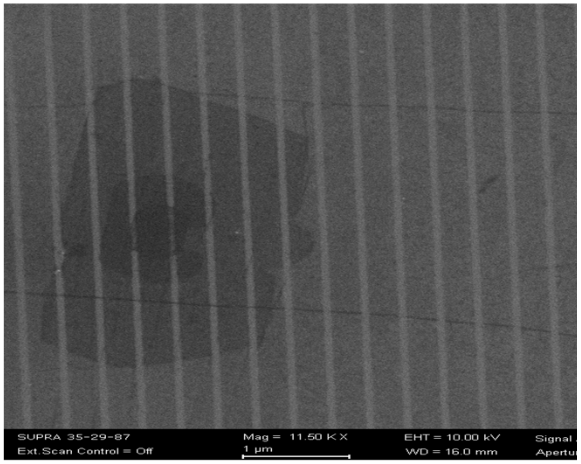


Electrical Measurements

Defect-free areas, strong NDR behaviour



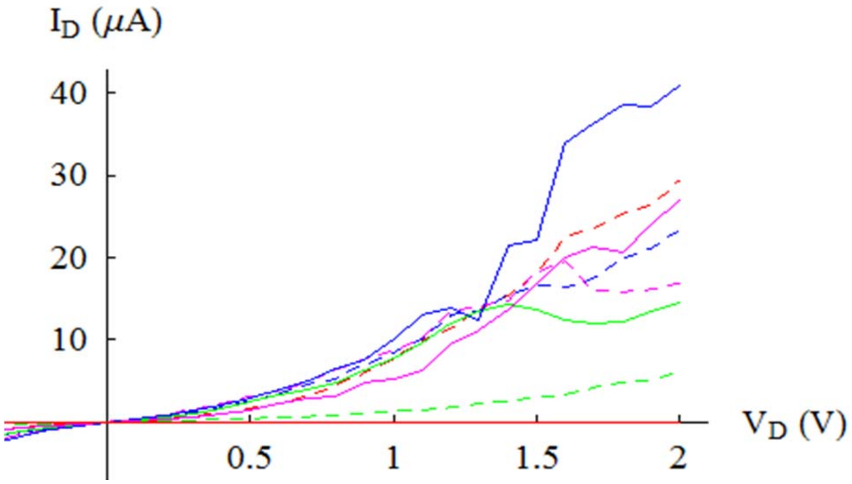




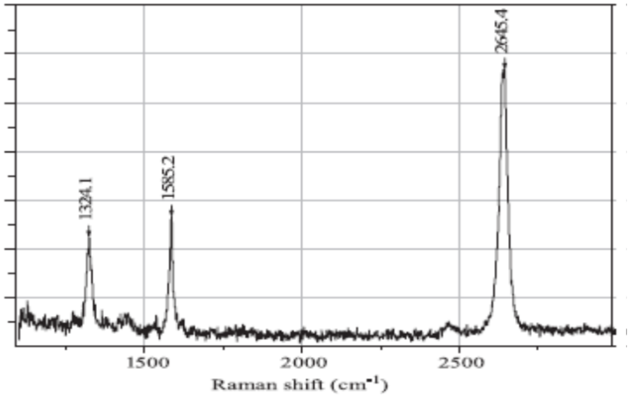
NDR behavior of the graphene FET with oblique gate at VTG = 0.5 V (dashed red line), 1 V (dotted blue line), and 1.5 V (solid red line).

PVR ratio is tuned by the gate voltage. For a top-gate voltage of 1.5 V, the maximum drain current attains 105 µA at a drain voltage of 1.6 V and decreases to about 12 µA at VD = 2 V. The PVR for this top-gate voltage value is about 8.75. For the top-gate voltage of 0.5V maximum and minimum ID values are about 90 µA and 12 µA, respectively, the corresponding PVR being 7.5.

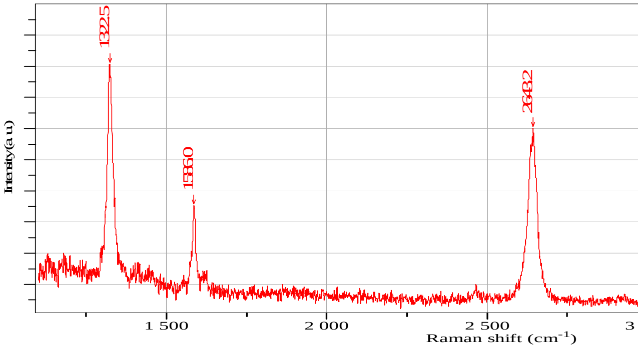
Electrical Measurements

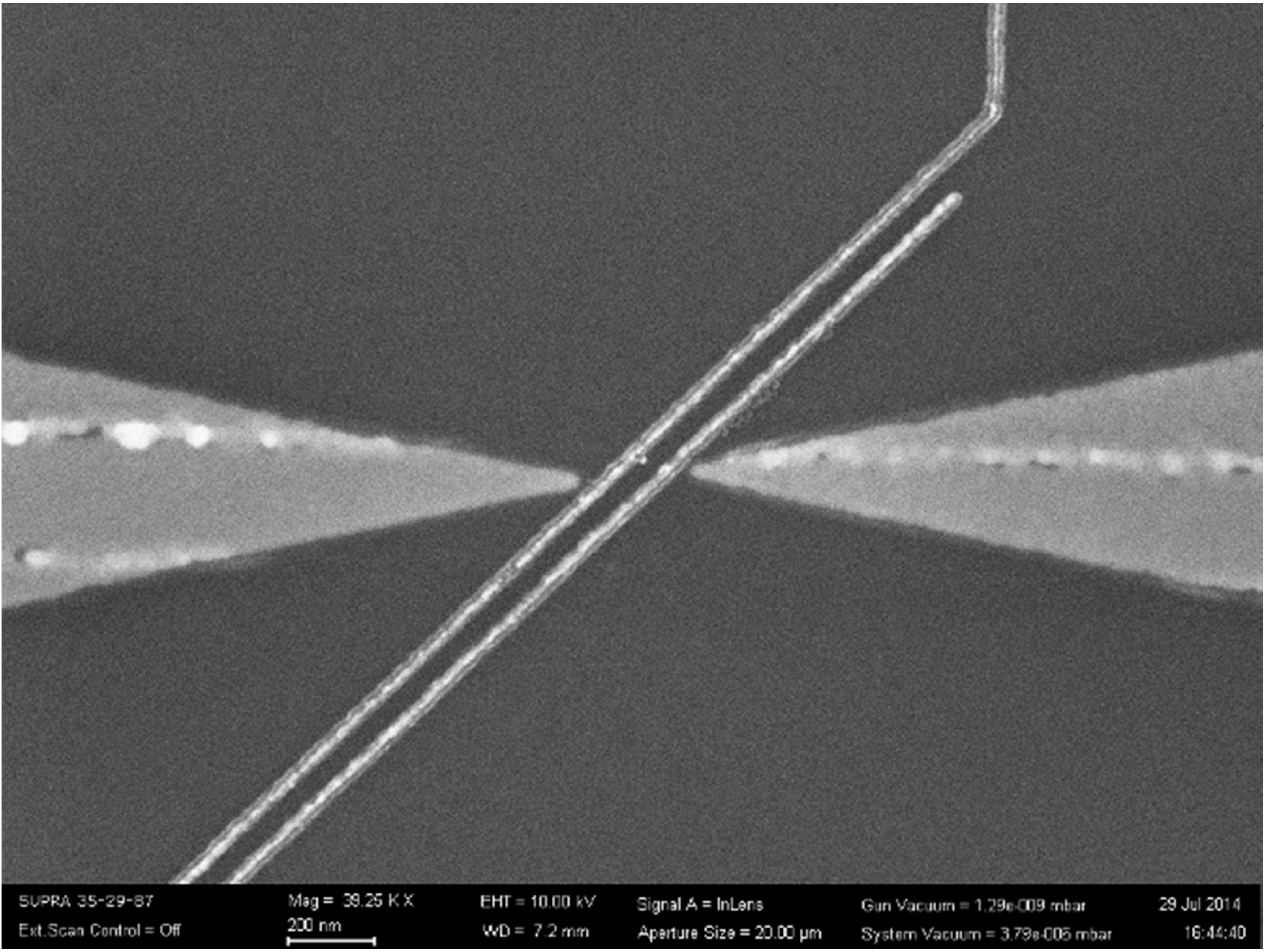


Areas with defects - No NDR,but strong and tunable nonlinear I-V dependence



Drain current–drain voltage dependences of the graphene FET at various top-gate and back-gate voltages: VTG = −2 V (solid black line), VTG = −1 V (dotted magenta line), VTG = 0 V (dotted red line), VTG = 1 V (dotted blue line), VTG = 2 V (solid blue line), VTG = 2 V and VBG = 40 V (solid magenta line), VTG = 2 V and VBG = 50 V (dotted black line), and VTG = 2 V and VBG = 60 V (solid red line)




SUPRA 35-29-87
Ext.Scan Control = Off
Mag = 39.25 K X
200 nm
EHT = 10.00 kV
WD = 7.2 mm
Signal A = InLens
Aperture Size = 20.00 µm
Gun Vacuum = 1.29e-009 mbar
System Vacuum = 3.79e-005 mbar
29 Jul 2014
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