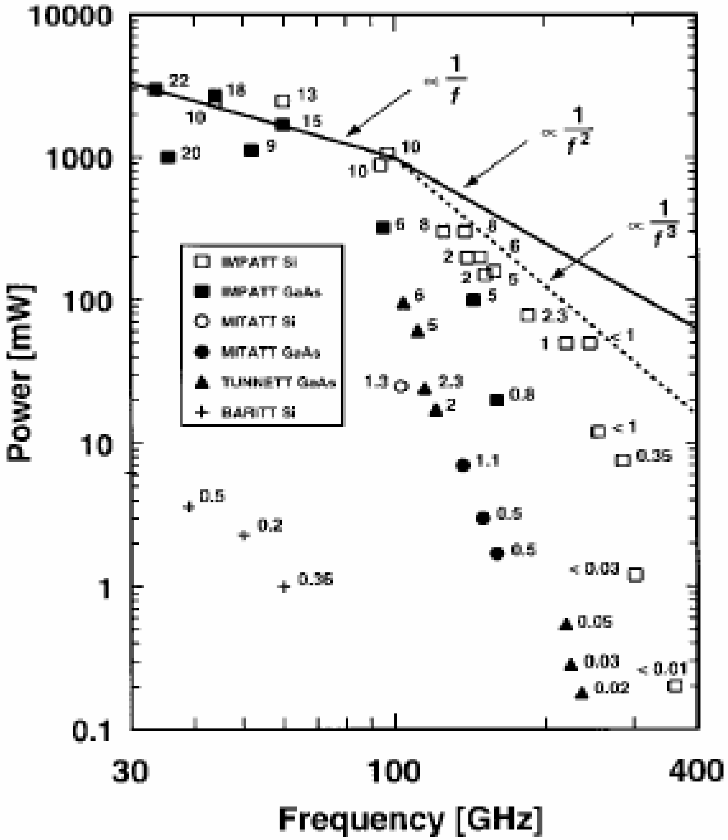
Seminarul National de nanostiinta si nanotehnologie

Tunable nanodevices based on carbon nanotubes and graphene.

M. Dragoman[1], D. Dragoman[2], D. Neculoiu[1], G. Konstantinidis[3], G. Deligiorgis[3], A.Cismaru[1], R.Plana[4]

[1]National Institute for Research and Development in Microtechnology (IMT), P.O. Box 38-160, 023573 Bucharest, Romania
[2]Univ. Bucharest, Physics Dept., P.O. Box MG-11, 077125 Bucharest, Romania
[3] Foundation for Research & Technology Hellas (FORTH) P.O. BOX 1527, Vassilika Vuton, Heraklion 711 10, Crete, Hellas
[4]LAAS CNRS, 7 Avenue du Colonel Roche, 31077 Toulouse Cedex 4, France

Seminarul National de nanostiinta si nanotehnologie



PROPERTIES OF IMPORTANT SEMICONDUCTORS FOR RF POWER GENERATION

	Si	GaAs	InP	6H-SiC (4H-SiC)	GaN	Diamond
Band Gap (eV) (@ 300 K)	1.12	1.42	1.34	3.06 (3.26)	3.39	5.5
Electron mobility (@ 300 K, cm^2/Vs) $\perp$ c-axis $\parallel$ c-axis	1400	8500	4600	400 (850) 80 (1020)	900	2200

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 46, NO. 6, JUNE 1998

Two-Terminal Millimeter-Wave Sources

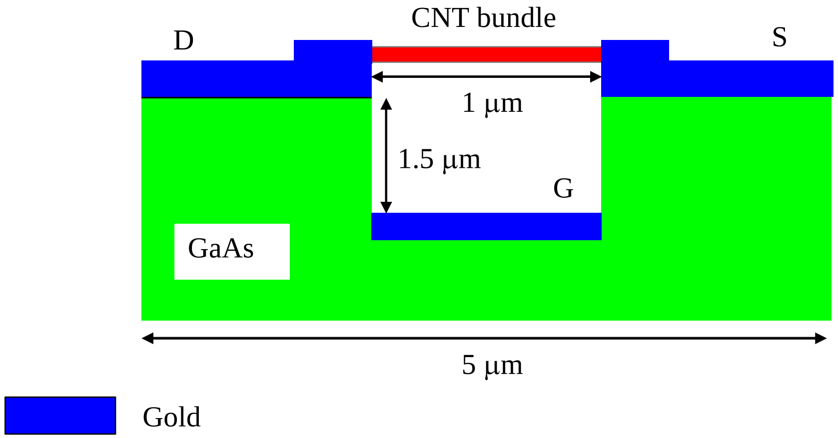
Heribert Eisele and George I. Haddad, *Life Fellow, IEEE*

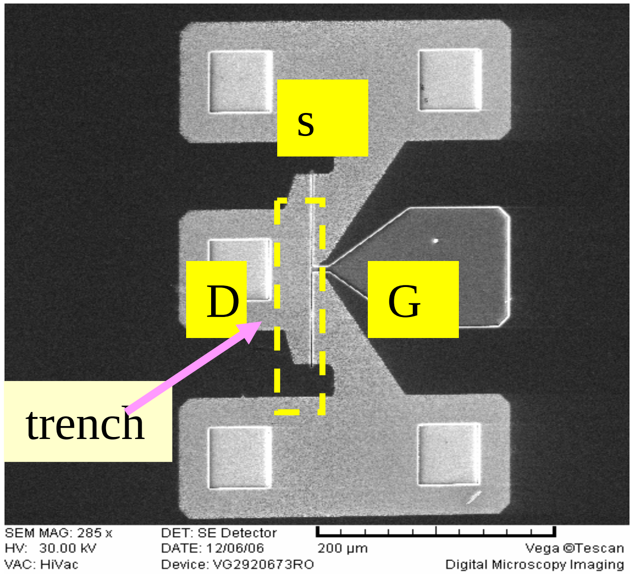
Seminarul National de nanostiinta si nanotehnologie

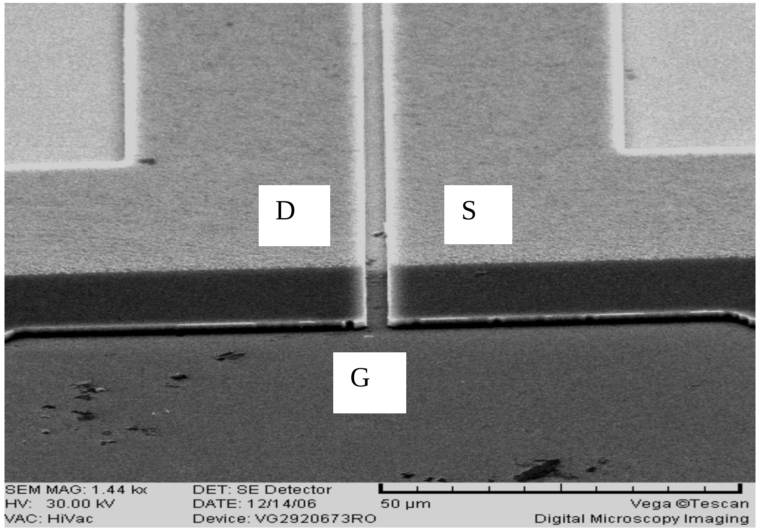
Carbon nanotube and graphene physical properties

Parameter	*Value and units*	*Observations*
Length of the unit vector	**2.49 Å**	**1.44 Å is the carbon bond length**
Current density	**$>10^9$ A/cm^2**	**-1000 times larger than the current density in copper - Measured in MWCNTs**
Thermal conductivity	**6600 W/mK**	**More thermally conductive than most crystals**
Young modulus	**1 TPa**	**Many orders of magnitude stronger than the steel**
Mobility	**10000-50000 cm^{2}V^{-1}s^{-1}**	**Simulations indicate mobilities beyond 100 000 cm^{2}V^{-1}s^{-1}/graphene 200 000 cm^{2}V^{-1}s^{-1}**
Mean free path (ballistic transport)	**300-700 nm semiconducting CNT 1000-3000 nm metallic CNT**	**- Measured at room temperature - At least three time larger than the best semiconducting heterostructures**
Conductance in ballistic transport		
Luttinger parameter *g*	**0.22**	**The electrons are strongly correlated in CNTs**
Orbital magnetic moment	**0.7 meVT^{-1} (d = 2.6 nm) 1.5 meVT^{-1} (d = 5 nm)**	**The orbital magnetic moment depends on the tube diameter**

SUSPENDED CNT FET DEVICE







APPLIED PHYSICS LETTERS 93, 043117 (2008)

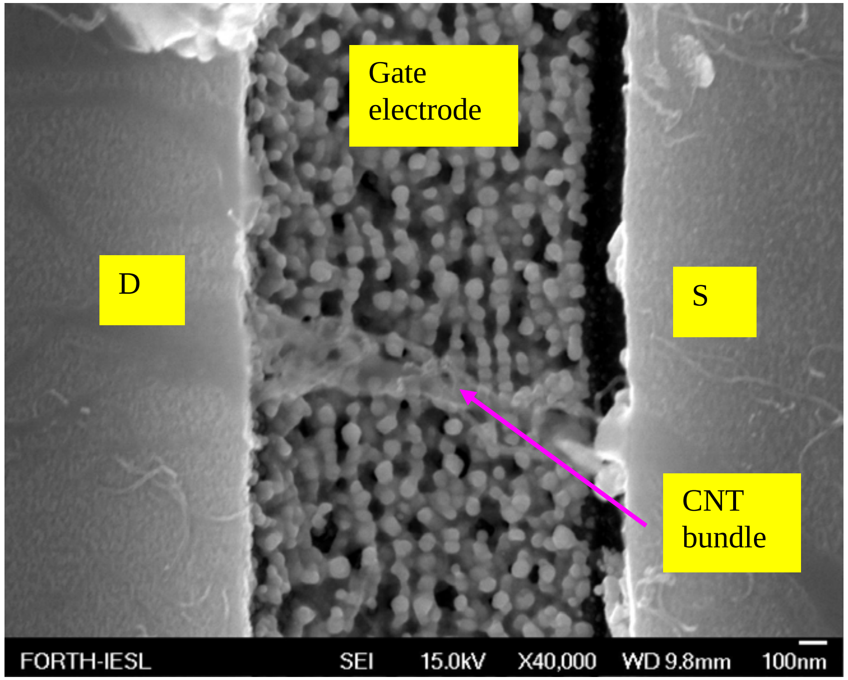
Multiple negative resistances in trenched structures bridged with carbon nanotubes

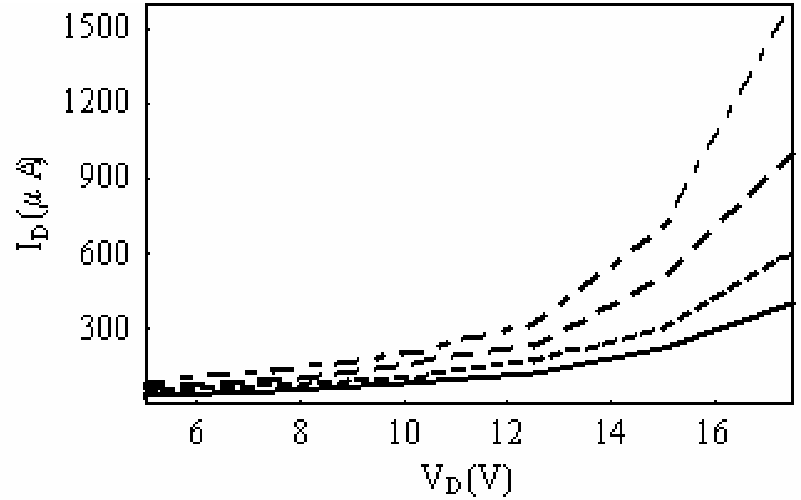
M. Dragoman,[1,a)] G. Konstantinidis,[2] A. Kostopoulos,[2] D. Dragoman,[3] D. Neculoiu,[4] R. Buiculescu,[5] R. Plana,[6] F. Coccetti,[6] and H. Hartnagel[7]

[1]*National Research and Development Institute in Microtechnology, Str. Erou Iancu Nicolae 32B, 077190 Bucharest, Romania*
[2]*FORTH-IESL-MRG, PO Box 1527, Heraklion, Crete 71110, Greece*
[3]*Physics Department, University of Bucharest, P.O. Box MG-11, 077125 Bucharest, Romania*
[4]*Electronics Department, Politehnica University of Bucharest, 1-3 Iuliu Maniu Av., 061071 Bucharest, Romania*
[5]*Department of Chemistry, University of Crete, Vassilika Vouton, Heraklion, Crete 71003, Greece*
[6]*LAAS CNRS, 7 Avenue du Colonel Roche, 31077 Toulouse Cedex 4, France*
[7]*Institut für Hochfrequenz Technik, Technische Universität Darmstadt, Merckstrasse 25, 64283 Darmstadt, Germany*

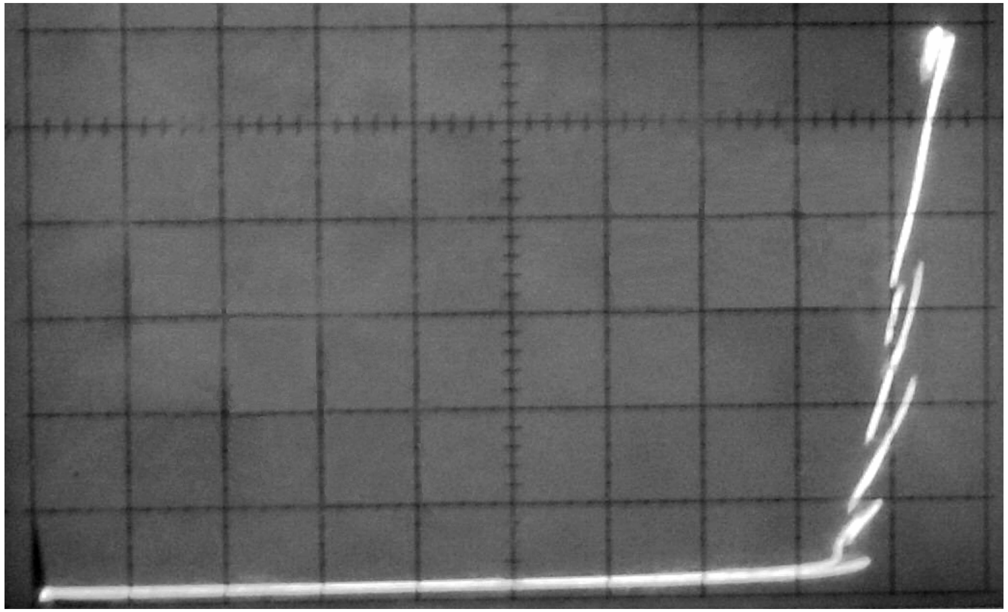
(Received 3 April 2008; accepted 2 July 2008; published online 30 July 2008)

Seminarul National de nanostiinta si nanotehnologie

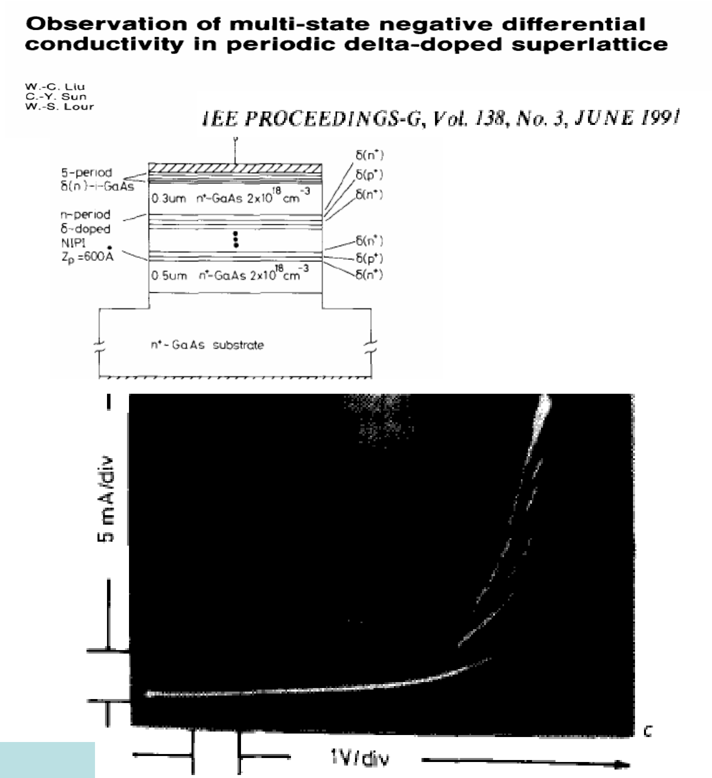




The I_D–V_D dependence on the gate voltage for V_G = 0 (solid line), 4 V (dotted line), 8 V (dashed line), and 12 V (dashed-dotted line).

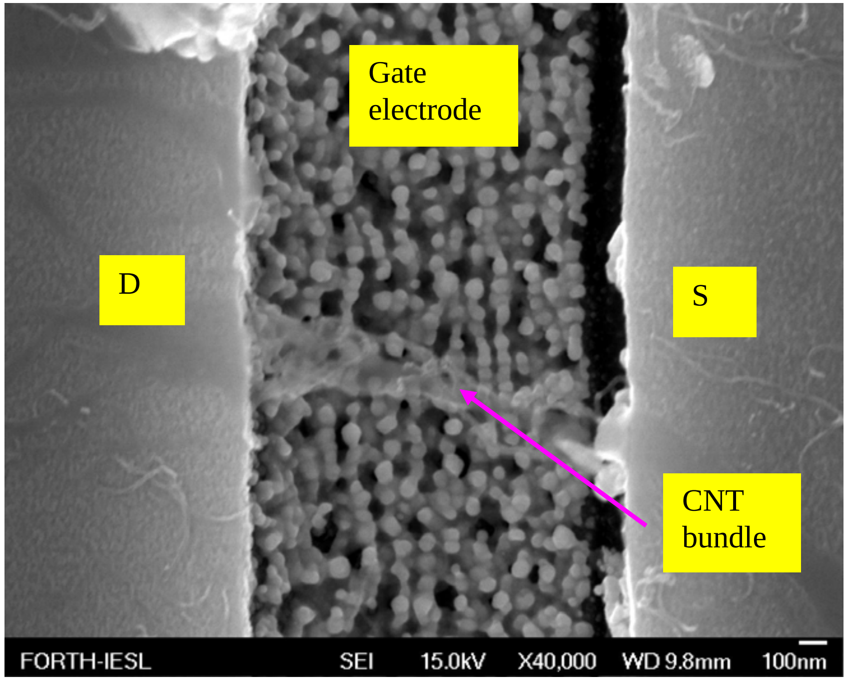


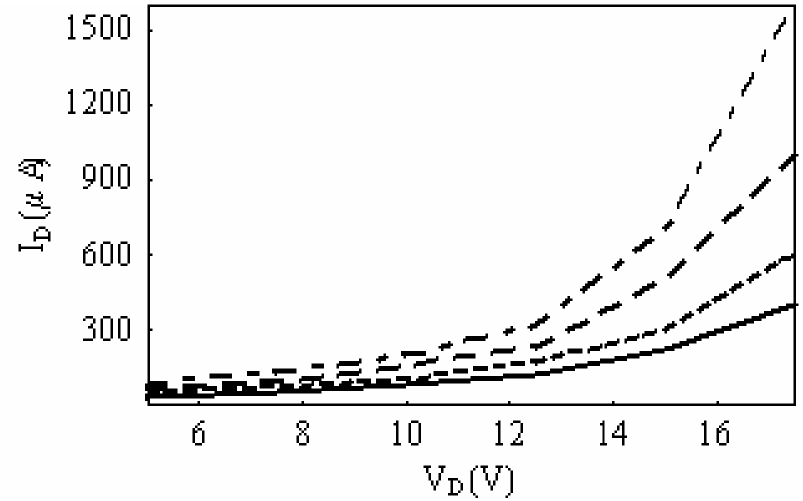
Multiple negative resitances at V_G= 14 V,vertical :500 μA/div, horizontal 2V/div



The jumps in the I_D–V_D characteristics are most probably due to charge accumulation followed by potential lowering at the potential step discontinuities between different CNTs in the bundle. A similar mechanism has been evidenced in . After overcoming the potential barrier at the electrode–CNT interface, which is responsible for the initial low-current region, the electrons in the CNT that is in direct contact with the electrode must overcome a potential barrier in order to penetrate in an adjacent CNT in the bundle (the potential barrier between adjacent CNTs is about 50 meV in height and 4 Å in width . Charge accumulation at this potential barrier and the subsequent potential lowering, i.e. the jump in the I_D–V_D curve, signifies that electron transport occurs through another conduction channel/CNT each time such a jump is observed.

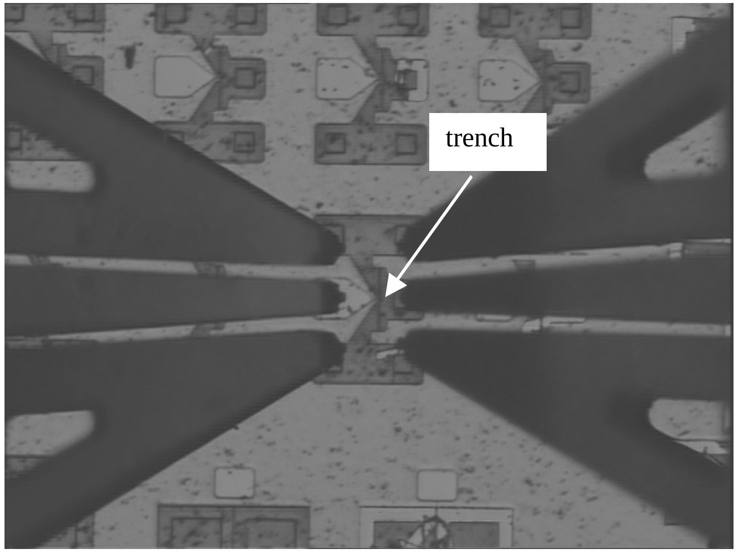
Seminarul National de nanostiinta si nanotehnologie

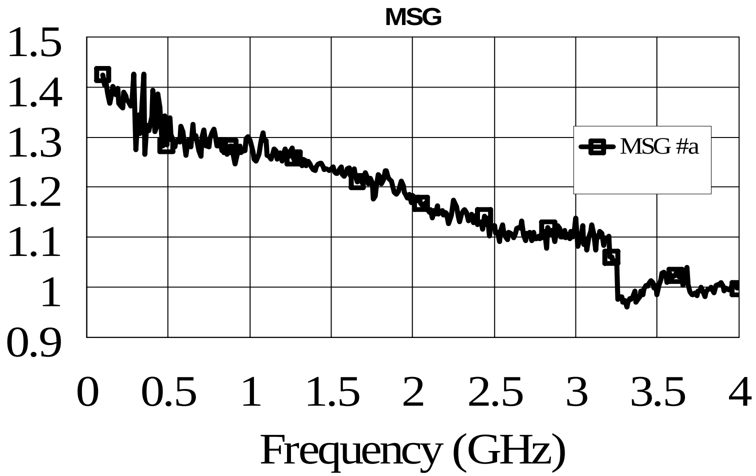




The I_D–V_D dependence on the gate voltage for V_G = 0 (solid line), 4 V (dotted line), 8 V (dashed line), and 12 V (dashed-dotted line).

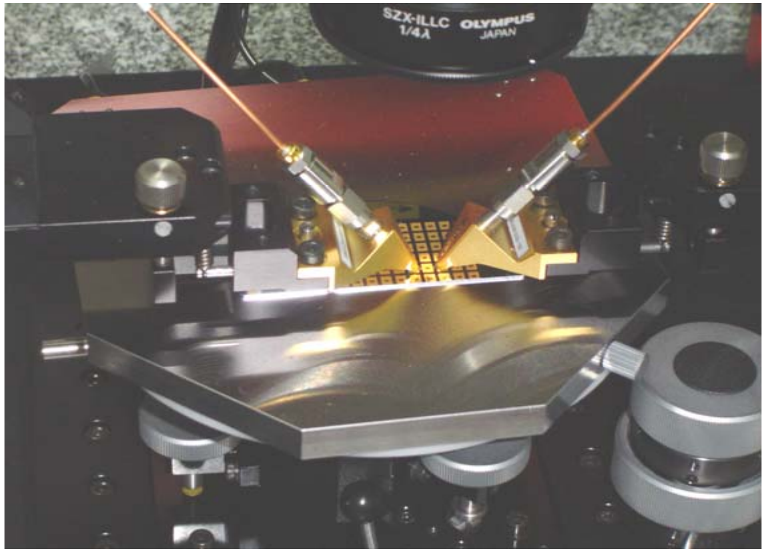
Seminarul National de nanostiinta si nanotehnologie



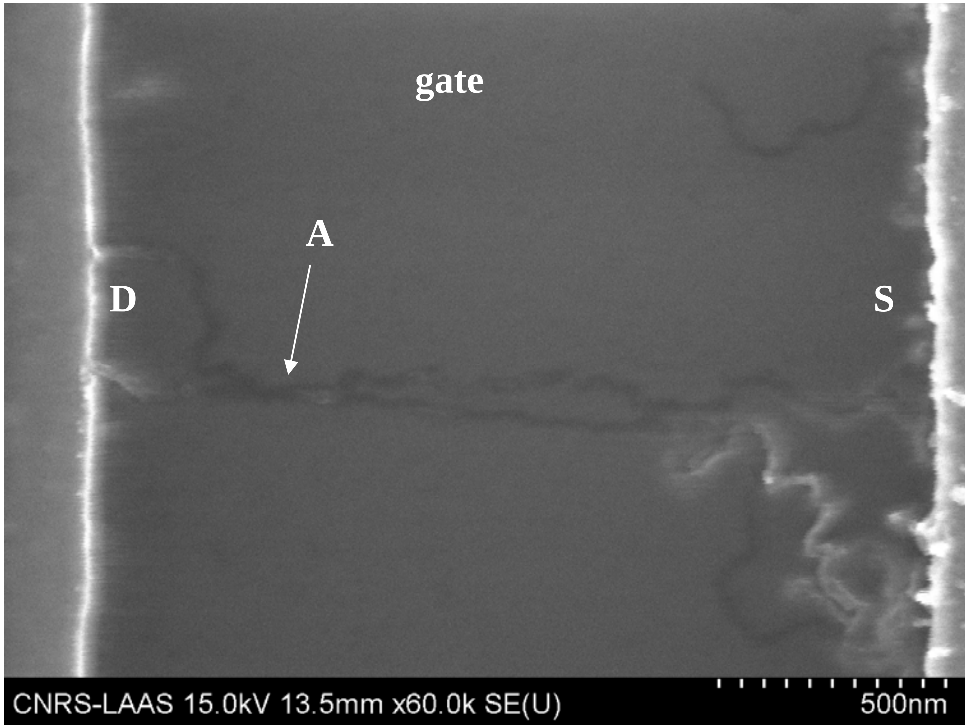


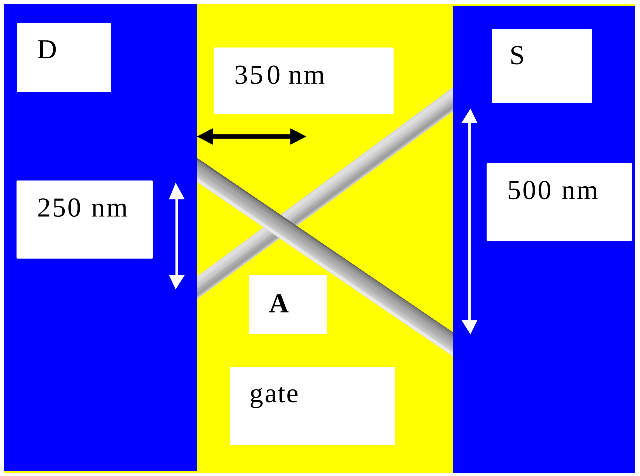
maximum stable gain

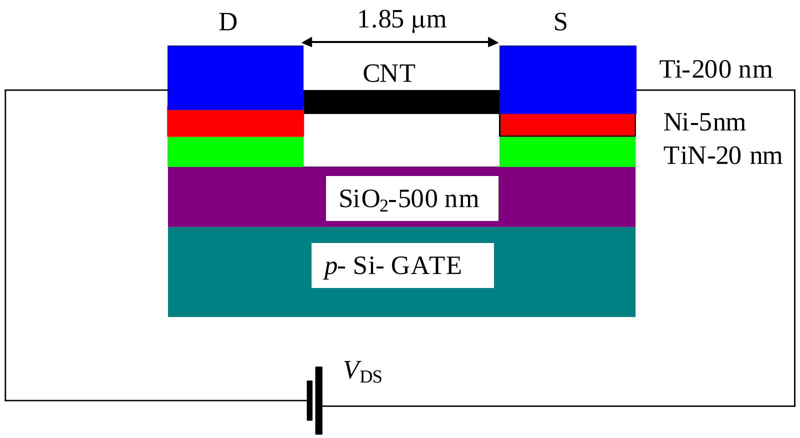
G[dB]= 10*Log(|S21|/|S12|)



CROSSED CARBON NANOTUBES



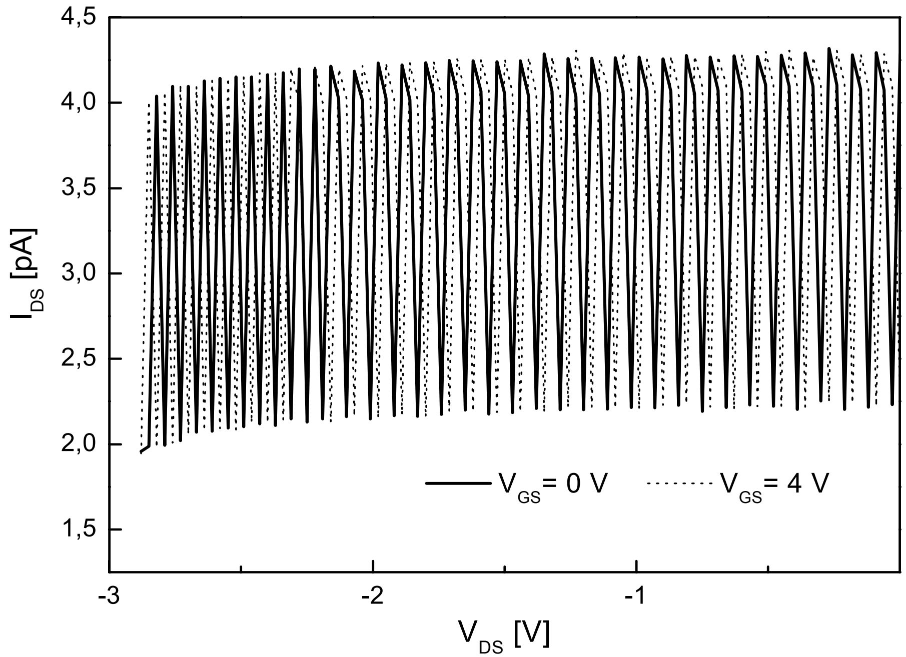


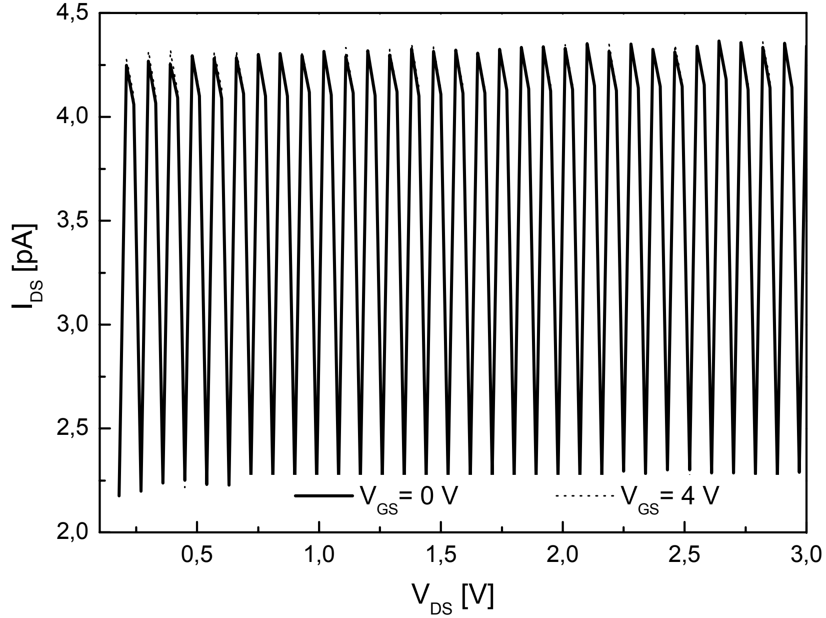


Grown by J.-H. Ting,

National Nano Device Laboratories , Taiwan

Seminarul National de nanostiinta si nanotehnologie

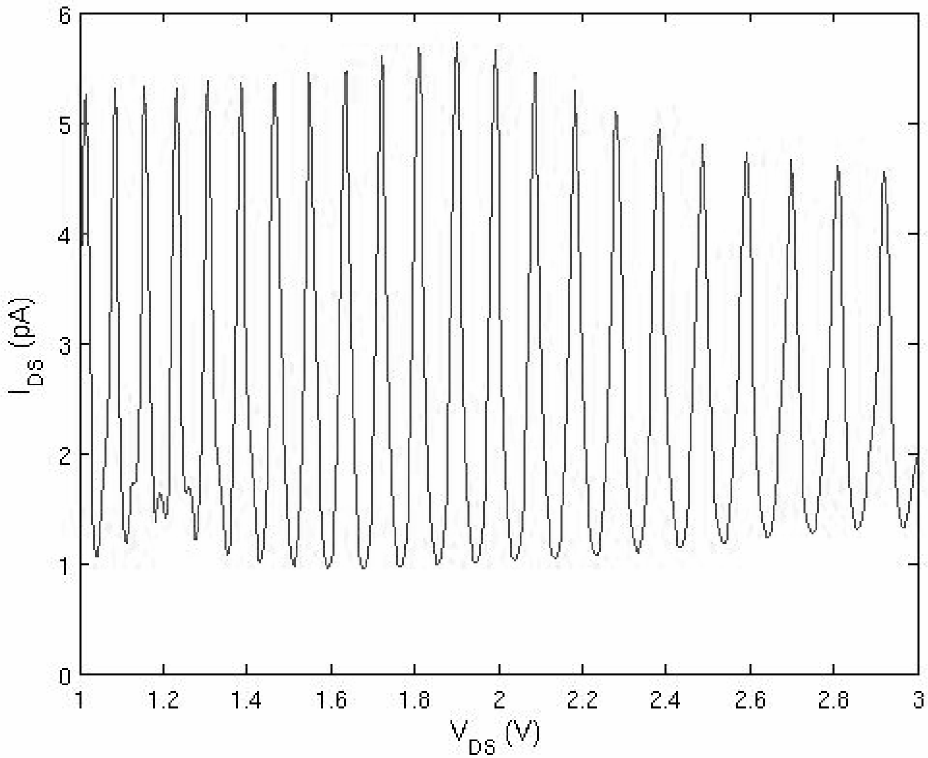




Drain current versus (a) negative and (b) positive drain voltage values, in the presence and absence of a gate voltage at room temperature.

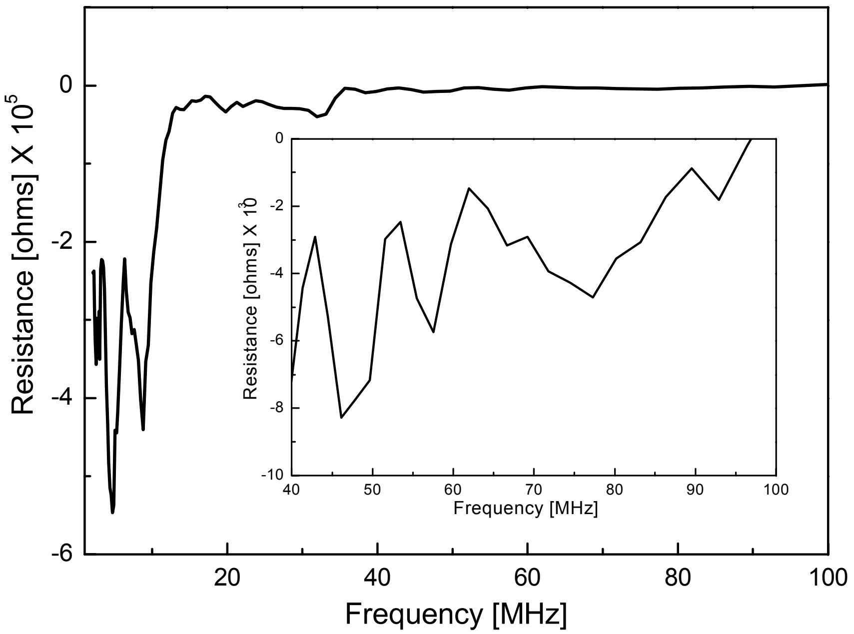
To be published J. Appl. Phys. 2009

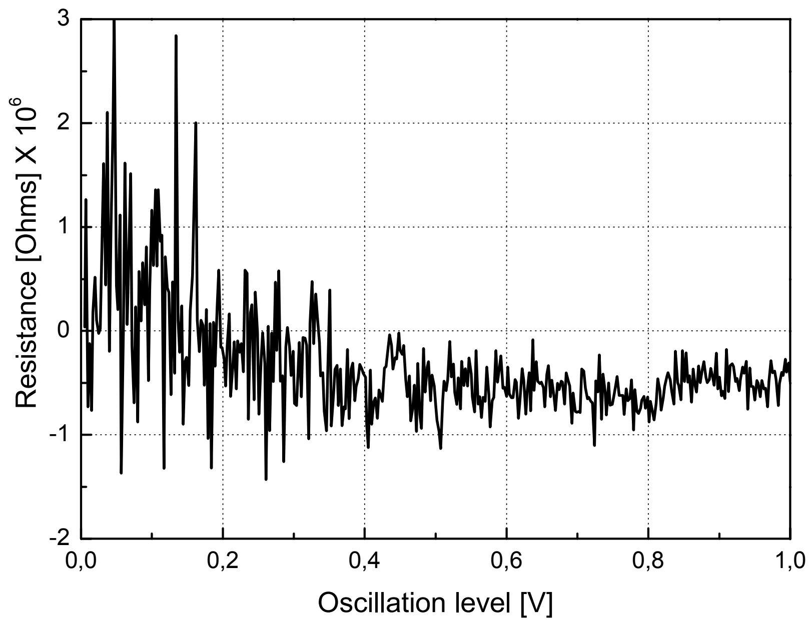
Seminarul National de nanostiinta si nanotehnologie



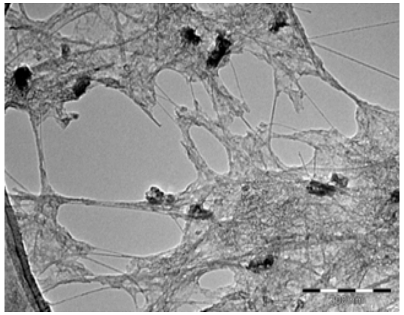
the crossed CNT device is modelled by considering that each CNT is formed from two coupled quantum wells. The first quantum well extends from the left contact up to the crossing point while the second is formed between the crossing point and the right side contact. In wide quantum wells, as is the situation in our case, there are numerous resonances/maxima in the quantum transmission, which generate oscillations in the drain current if the there is a sufficiently high contrast between the effective electron masses in the quantum well and the surrounding barriers This is not our case, however, because there are no oscillations in the drain current–drain voltage characteristic in suspended non-crossed CNTs (these experiments are not shown here) fabricated in the same time, in the same conditions and located elsewhere on the wafer. Hence, the observed current oscillations in the crossed-CNT situation are due to the coupling between the two quantum wells.

Seminarul National de nanostiinta si nanotehnologie

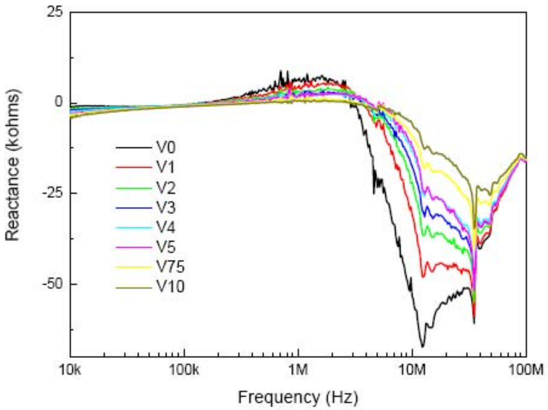


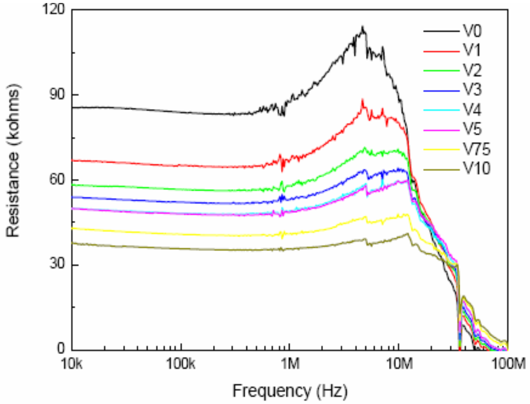


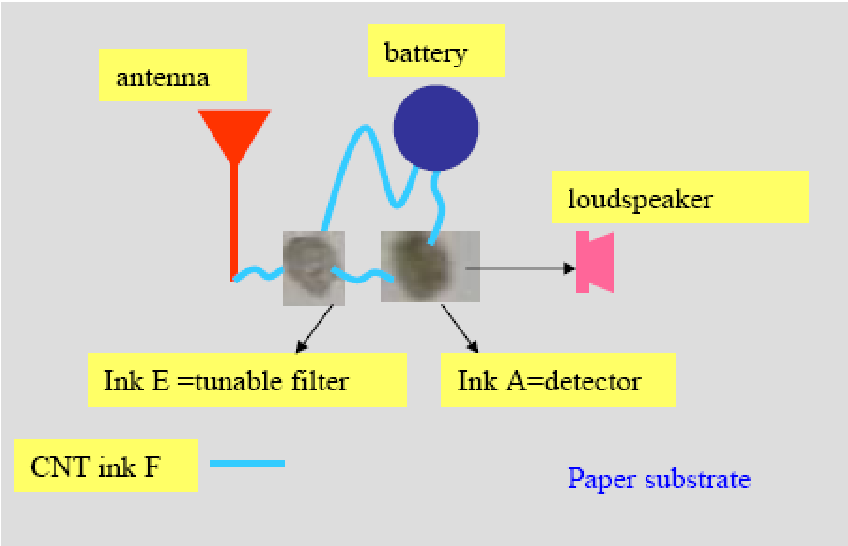
CNT ink devices on paper substrate



CNT ink prepared by Prof. E. Flahaut, Univ. Paul Sabatier, Toulouse

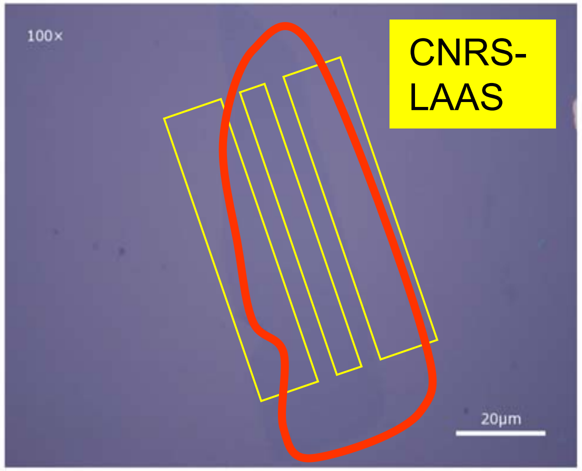


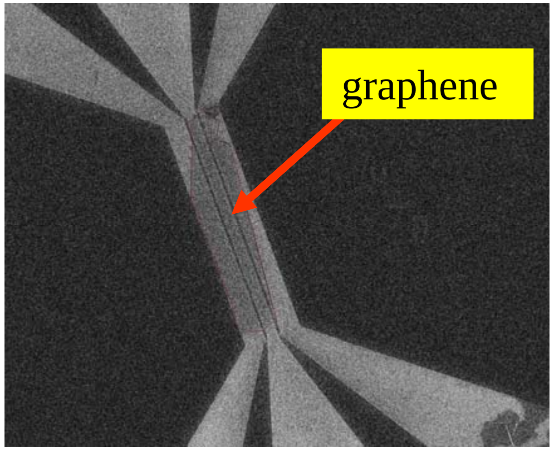




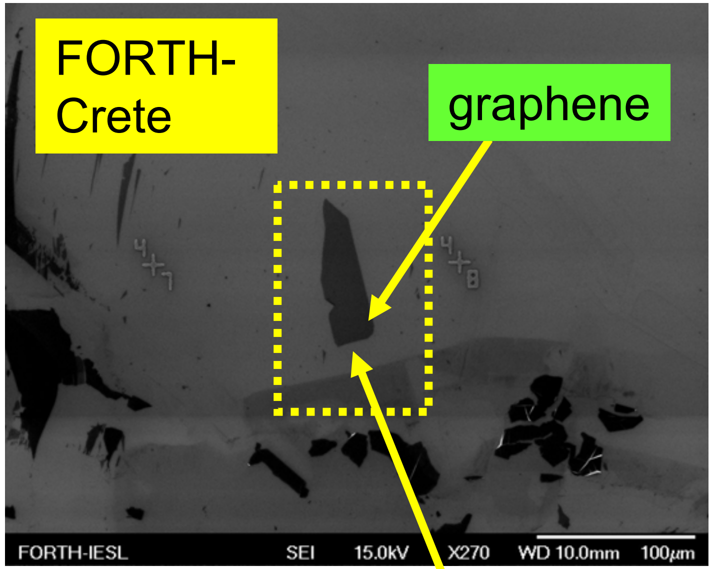
The radio on paper concept; CNT inks of various concentrations are used to implement various functions which are usually done by R, L, C components and copper.

Seminarul National de nanostiinta si nanotehnologie



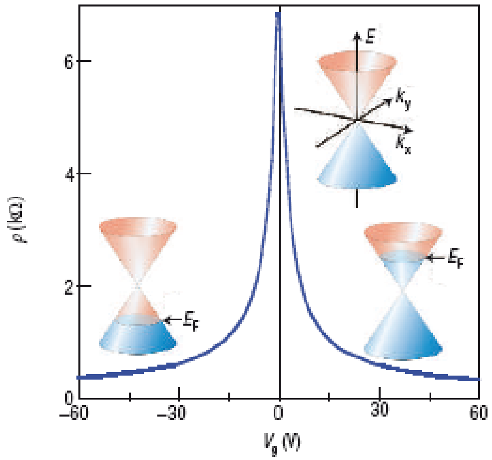


GRAPHENE



Graphene produced by Graphene Industries

sample 2229

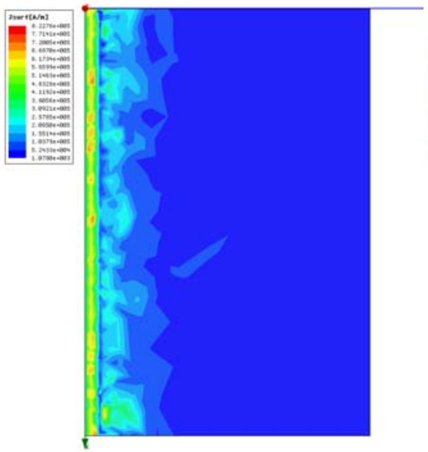


A. K. GEIM AND K. S. NOVOSELOV

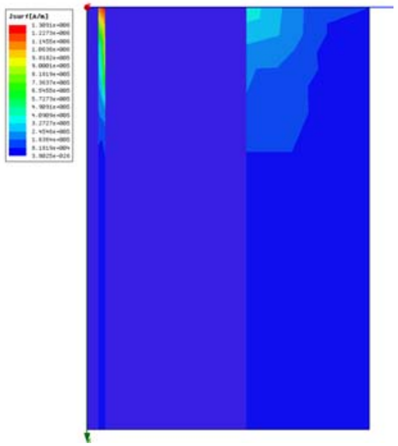
nature materials | VOL 6 | MARCH 2007

A PMMA bi-layer was spin coated on the sample and baked in oven at 150 ºC. A JEOL 7000F SEM equipped with a RAITH Elphy quantum attachment was used to directly pattern the PMMA layer with an electron beam. The sample was developed in MIBK:IPA 1:3 and was subsequently introduced in a Temescal e-gun evaporation chamber where 2 nm Ti/300 nm Au electrodes were deposited. The lift-off process was completed using acetone to remove the PMMA. Since graphene is not visible when coated with the PMMA, the exact co-ordinates of the graphene piece were previously mapped with the SEM. **The distance between the electrodes is *L* = 1.7 mm and the width *W* of the graphene flake across the electrodes is more than 80 mm.**

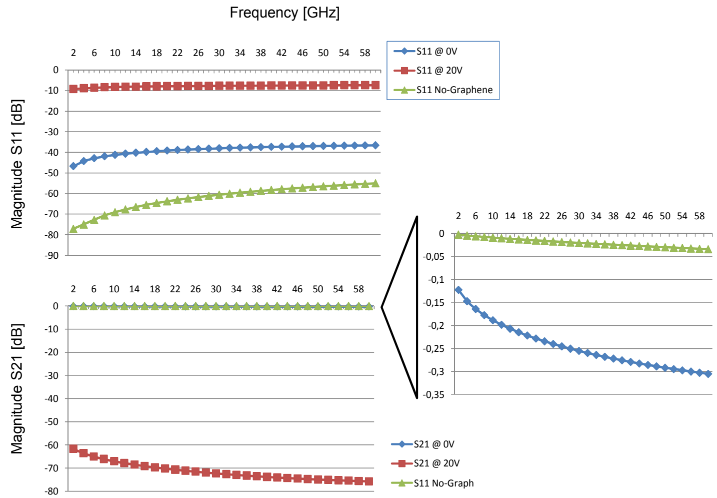
Seminarul National de nanostiinta si nanotehnologie

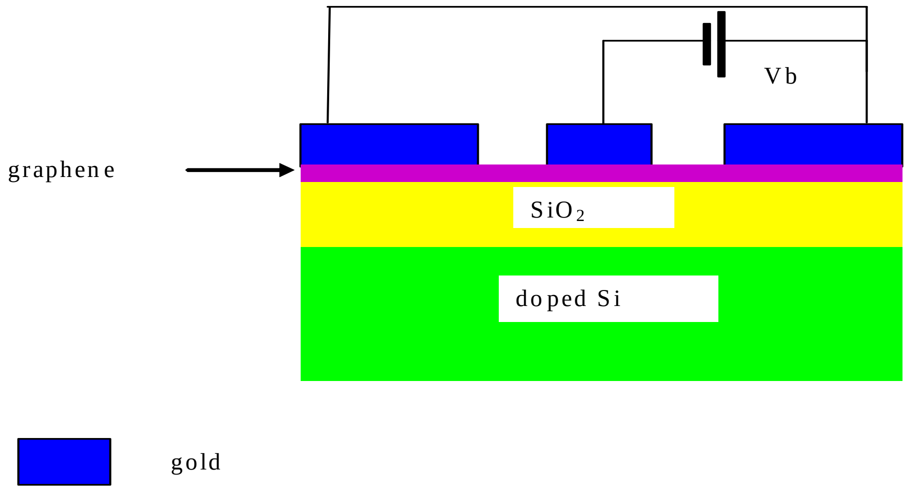


0.15 Ohm cm (0 V)



3E-5 Ohm cm (15 V)





JOURNAL OF APPLIED PHYSICS **105**, 054309 (2009)

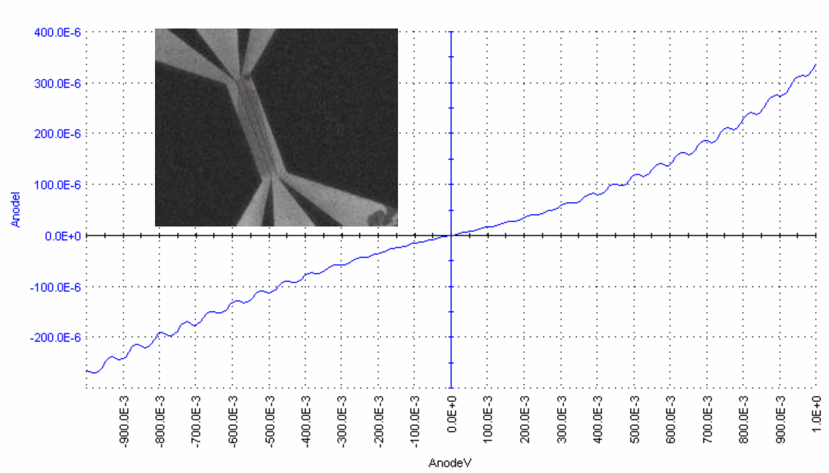
Microwave switches based on graphene

M. Dragoman,[1,a)] D. Dragoman,[2] F. Coccetti,[3] R. Plana,[3] and A. A. Muller[1]
[1]*National Institute for Research and Development in Microtechnology (IMT), P.O. Box 38-160, 023573 Bucharest, Romania*
[2]*Physics Department, University of Bucharest, P.O. Box MG-11, 077125 Bucharest, Romania*
[3]*LAAS, CNRS, 7 Avenue du Colonel Roche, 31077 Toulouse Cedex 4, France*

(Received 23 November 2008; accepted 1 January 2009; published online 11 March 2009)

$\theta = \tan(k_y / k_x)$

Seminarul National de nanostiinta si nanotehnologie



The origin of this effect is the carrier transport dependence on the two spatial components of the wave vector, dependence that becomes evident for wide contacts and affects the transmission of ballistic electrons, similar to the case of non-normal incidence. $\theta = \tan(k_y / k_x)$

$$I(V) = I_0[\exp(eV / nk_BT) - 1] f(V)$$

$$I_0 = S \frac{2emk_B^2T^2}{\hbar^3} \exp(-e\phi_B / k_BT) b$$

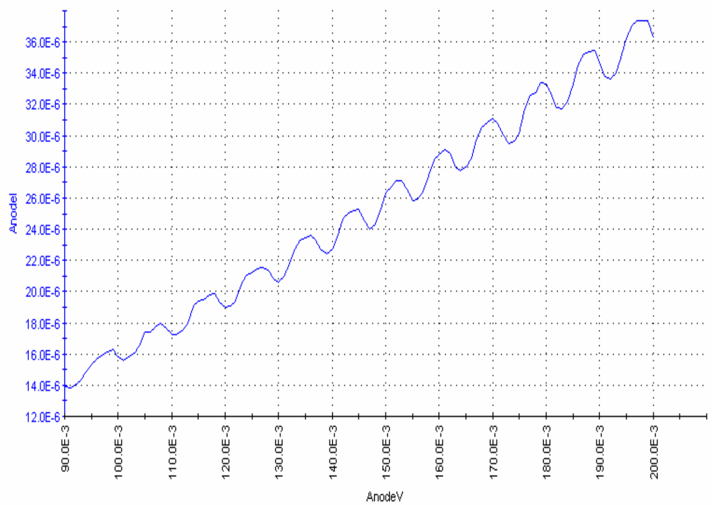
$$f(V) = \overline{T}(V)$$

I_0= 53 mA

n = 12

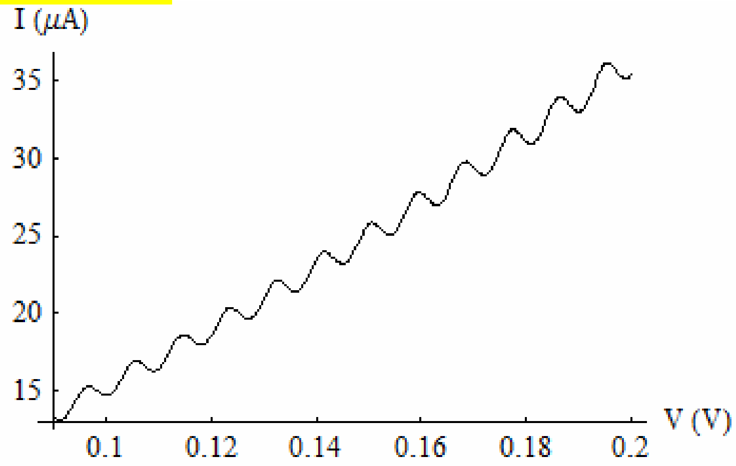
= 250 nm

D = 0.46 μm



the period of oscillations are determined uniquely by (it decreases with) *D*-, distance of ballistic transport whereas the depth of the oscillations is determined by (increases with) the Fermi wavenumber.

measured



simulated

Seminarul National de nanostiinta si nanotehnologie

Conclusion

These results which demonstrate a various of tunable effects in CNT and graphene based devices were obtained in one year in IMT-Bucharest in cooperation with FORTH-Crete and LAAS-CNRS Toulouse.

ACKNODLEGEMENTS

The author wish to thank many people helping him in the quest in the area of nanoelectronics, most of them being co-authors of many papers published in the last period of time. **My wife Daniela** has helped me with her deep knowledge in the area of quantum mechanics and solid state physics . **My colleagues from IMT Bucharest** and **dr. George Konstantinidis** from FORTH Heraklion, Greece, were behind almost any device reported in this paper especially due to their invaluable knowledge in the area of semiconductor technology. **Prof. Dan Dascalu** and **Prof. Robert Plana** are general managers and scientists with a very advanced vision about nanotechnology and they encouraged me always in my researches **to go further**. I also am indebt **Prof. Hans Hartnagel** who during many years has helped and guided me in the area of nanoelectronics.