POSTERS

Electrical and optical properties of LSMO/ Monolayer MoS_2 photodiodes

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Two dimensional (2D) transition metal dichalcogenides (TMDs) and artificial van der Waals heterostructures made from these materials have been experimentally and theoretically investigated as promising candidates for novel photovoltaic and optoelectronic devices due to their excellent optical and electrical properties[1,2]. Very recently, many experimental efforts have been made on the fabrication and study of 2D-2D heterostructures,like for example MoS_2-WS_2 and graphene-MoS_2[3,4] and 2D-3D heterostructures, such as graphene-Si. Nevertheless, the interaction between two dimensional material and transition metal complex oxides has not been largely investigated so far. In this work, we investigate heterostructures made of 3D lanthanum strontium manganite oxide (LSMO) and 2D monolayer MoS_2 and report their photodiode behavior.

Here, we report the photodiode behavior in LSMO (p type)/monolayer MoS_2 (n type) heterostructures fabricated by deterministic transfer of mechanically exfoliated flake and transfered to LSMO[5]. Under illumination, an obvious photocurrent (and photovoltage) is generated by the photovoltaic effect. The photocurrent and photoresponsivity are dependent both on the incident light wavelength and power density. The device displays short-circuit currents up to 0.4 nA and open-circuit voltages up to 400 mV. Measuring as a function of incident optical power density, we find that the open-circuit voltage and short-circuit current depend linearly and logarithmically, respectively, on power density, confirming an ideal photodiode behavior.

In conclusion, we have investigated the electrical and optoelectronic properties of LSMO/monolayer MoS_2 heterostructures. Our work may benefit to the integration of two-dimensional materials with metal complex oxides. This might contribute to developments in the area of van der Waals heterostructures and it will provide novel applications in electronics and optoelectronics.

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FABRICATION OF HYBRID SYSTEMS: SUSPENDED GRAPHENE / SUPERCONDUCTOR

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Motivated by the growing interest in topological superconductors, in this work we are developing a suspended graphene / superconductor hybrid system. In these systems, being in contact with a superconducting material. (Nb), graphene acquires superconducting properties due to the proximity effect [1].

Our hybrid systems consist on a graphene flake suspended over a superconducting bridge. The graphene flakes (figure 1A) have been obtained by mechanical exfoliation and characterized by Raman spectroscopy. The superconducting bridge is fabricated using electron beam lithography, optical lithography and DC magnetron sputtering. To improve the electrical contact between the superconducting Niobium bridge and the graphene flake, we have deposited a capping layer of Palladium [2]. Atomic force microscopy and scanning electron microscopy are used in order to choose the more suitable nanofabrication process. Preliminary electrical characterization is shown (figure 1B).

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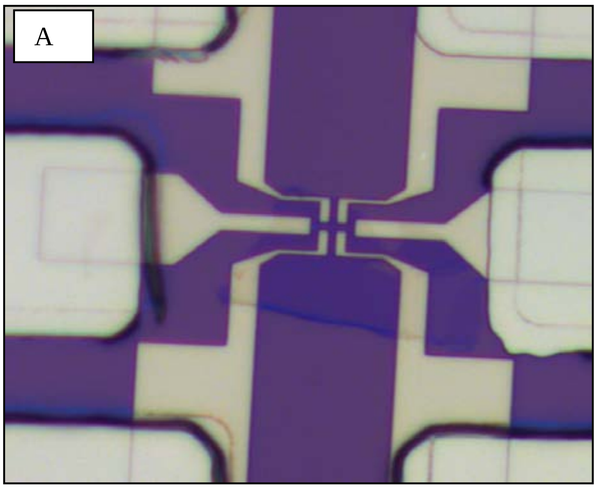
Figures



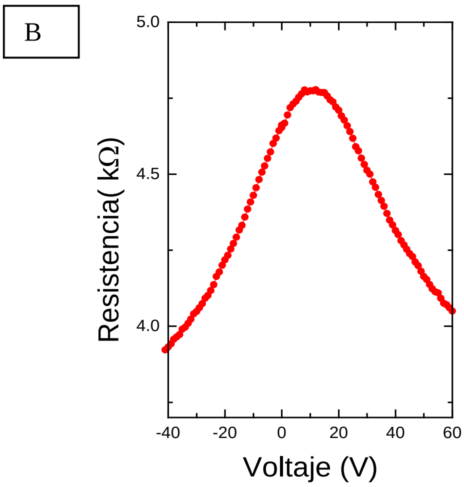


Figure 1. A) Optical image of a graphene flake on PDMS. B) Resistance vs gate voltage of a suspended graphene flake over the bridge at room temperature.

Fabrication of Lumped Element Kinetic Inductance Detectors for millimeter and sub-millimeter Astronomy

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Space instrumentation is a crucial aspect for advances in Astrophysics and Cosmology. The new space missions and ground-based telescopes require a new generation of detectors for achieving the needed sensibilities. In our work, we fabricated and characterized Lumped Element Kinetic Inductance Detectors, LEKIDs, designed for millimeter and sub-millimeter radiation sensing [1]. The LEKIDs are superconducting microresonators, with slightly different resonant frequencies, all coupled to a common feedline. The incidence of the incoming radiation breaks Cooper pairs in the superconductor, thus modifying the superconducting kinetic inductance and resistance of the resonators. This in turn changes the resonance properties, providing the detection mechanism of the sensors.

The kinetic inductance of the detectors, and hence their sensitivities, scales inversely proportional to the film thickness. Also, the geometrical configuration of the the geometrical configuration of the inductive meander lines(width, thickness and distance) provides the impedance seen by the incoming radiation which influences the optical coupling. These facts limit the devices design and fabrication developments are needed. Several demonstrators for space and earth-based observations have been fabricated, see Figure 1. Fabrication process includes DC magnetron sputtering with confocal configuration, laser and electron beam lithography and etching techniques. Preliminary cryogenic characterization demonstrates the optical sensitivity of our devices.

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Figure

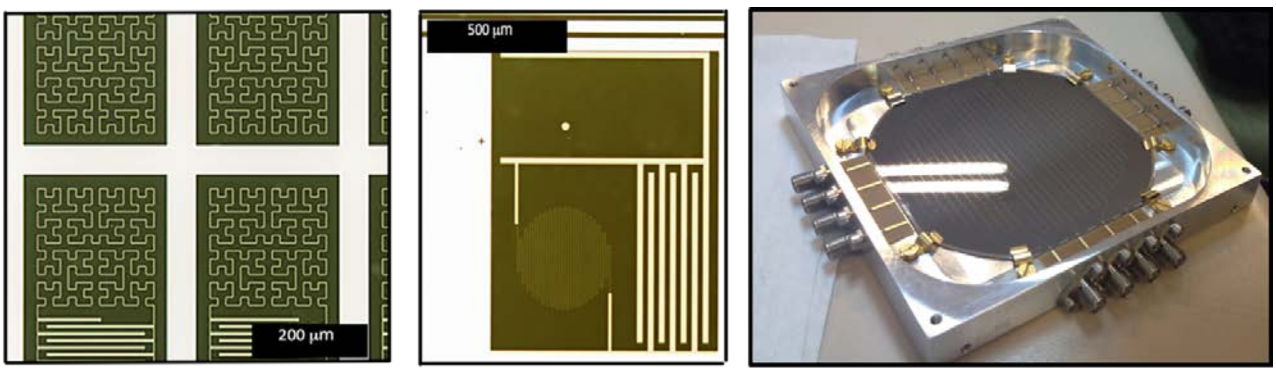

Figure 1: Some examples of the nanofabricated devices. The third picture is a NIKA2 1mm Array, fabricated by the typical NIKA process [2].

Graphene-based devices for bio-sensing platforms

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Biosensing systems became ubiquitous in recent years in medical and biomedical research, spanning a large range of health applications, from prognosis and/or diagnosis of diseases, to personalized medicine. The possibility of increased integration and miniaturization, often in microfluidic platforms, for mass production at economic cost, with enhanced performance (specificity, sensitivity and fast response) will pave the way for yet another boost in the use of biosensors in clinical practice and in point-of-care/point-of-use diagnosis and therapy.

The 2D carbon honeycomb lattice in graphene provides a surface of extreme sensitivity to electric fields and charges, thus suggesting its use for molecular detection based on electronic transducing. However, graphene high sensitivity and chemical stability comes at the cost of a poor analyte selectivity. Therefore, the fabrication of biosensors based on graphene interfaces requires surface functionalization. In this work, we immobilize probe molecules on CVD graphene surfaces for specific biorecognition of two important analyte types – antigens (proteins) and DNA. Two types of devices were fabricated: electrolyte-gated field-effect transistors (FETs), with a receded, integrated gate architecture (Fig.1A) and electrochemical microelectrode arrays (Fig.1B). The electrical signal in case of the graphene FETs is the shift in the Dirac point of the transfer curves, as a function of analyte concentration. Electrochemical detection is based on Electrochemical Impedance Spectroscopy and Cyclic Voltammetry measurements using 2 mM $Fe(CN)6^{3-/4-}$ redox probes. The devices were fabricated in the clean-room at the 200 mm wafer scale using standard photolithography technology [1].

A graphene immuno-FET is developed by immobilization of antibodies to specifically detect the biomarkers related with the hemorrhagic transformation of ischemic stroke. The probe immobilization is achieved via a pyrene-derivative linker, attached to the graphene surface via π-π interaction of the pyrene group and providing, at the other end of the molecule, a succinimidyl ester group that reacts with a primary amine from the protein antibody. The device was able to detect the biomarker (MMP-9) in concentrations down to 0.01 ng/mL, in a range up to 10 ng/mL. Compared with existing MMP-9 immunoassays our immuno-FET has similar or higher sensitivity and, because it is based on a much simpler label-free protocol than conventional methods, has a much shorter time to diagnostic [2].

The nucleic acid sensor is developed by immobilization of single-stranded DNA (25 nucleotides long) on the pyrene derivative-functionalized graphene transistor channel. Hybridization with complementary DNA (cDNA) was detected down to 1 aM, with a saturation attained at 100 fM and sensitivity to single nucleotide polymorphism (SNP). Graphene electrochemical sensors functionalized with the same DNA sequence (but without the linker) were successful in detection of cDNA in the range 5 pM to 50 nM with SNP sensitivity.

These results open the possibility for fabrication of sensors, using standard clean-room technology, with high sensitivity and low cost, that may be used in health, environment and food industries.

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Figures

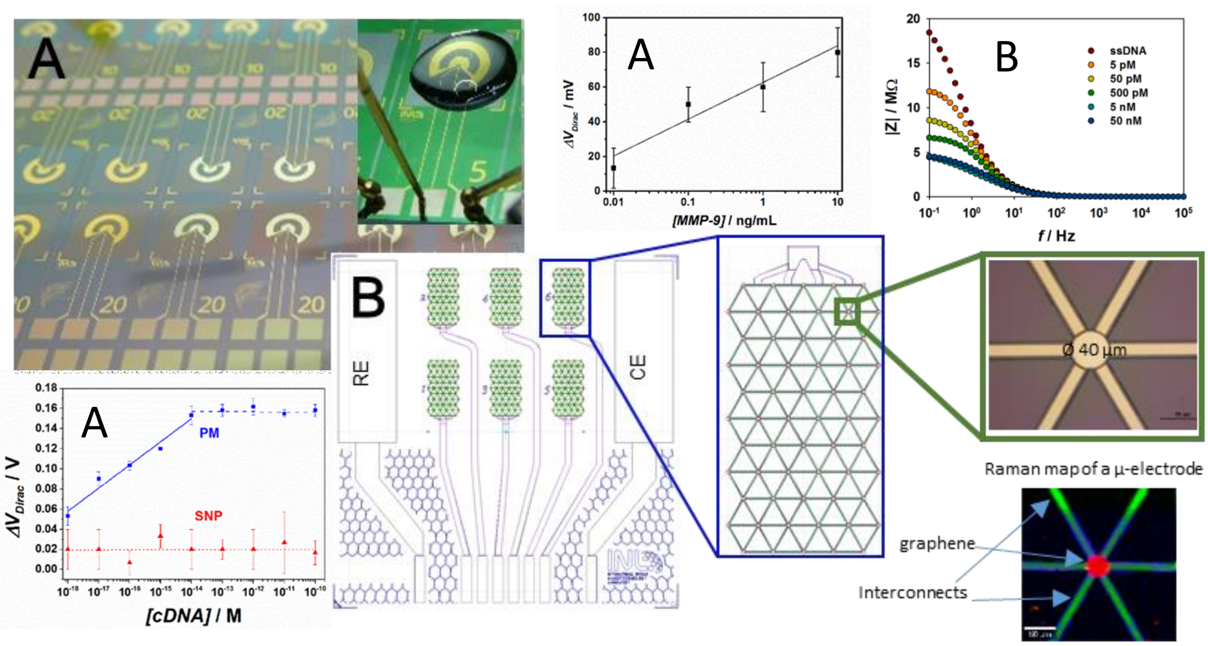

Figure 1:
Two types of devices were fabricated at the 200 mm wafer scale – A: Functionalized electrolyte-gated graphene FETs fabricated at 200 mm wafer scale were used to detect the protein biomarker MMP-9 and c-DNA, with attomolar detection limit and SNP sensitivity. B: Graphene on Au microelectrode arrays were used to detect DNA by EIS, with pM sensitivity.

Sub-Terahertz detection and imaging using Strained silicon FET

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The development of novel materials, concepts and device designs for the generation and detection of terahertz radiation using semiconductors [1] has recently fuelled the research of room temperature THz sensors. Plasma waves based transistors (PWT) with submicron gate length are under extensive investigations [2-4]. We investigated room temperature detection by using Strained Silicon Modulation field effect transistor. Experimental results show a good level of response to terahertz radiation at 300 GHz and 150 GHz (Fig.1). Competitive performance parameters were obtained (NEP and responsivity) in comparison with other detectors.

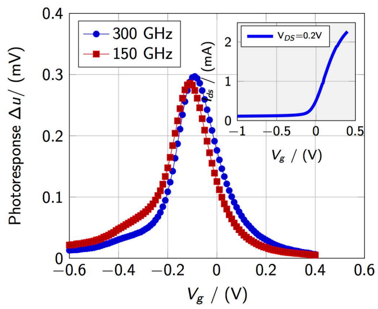

Fig1: Photoresponse vs. gate voltage under excitation of 150 GHz (red square) and 300 GHz (blue dotted) for Device with Lg=500nm. Inset shows the corresponding transfer characteristics

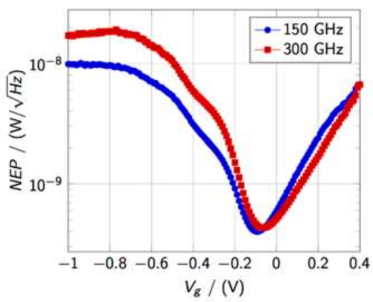

Fig.2: Noise equivalent power as a function of the gate voltage of Device with Lg=500nm and under different THz excitations: 150 GHz (blue dotted), 3000 GHz (red square), T=300K.

Enhancement of the photoresponse signal by imposing a dc drain-to-source current (I_{ds}) was observed experimentally and terahertz imaging features was demonstrated. A 2D numerical study was performed using Synopsys TCAD [5] to understand the response found in THz measurements. Simulation results show a non-resonant response in agreement with measurements showing a significant impact of the I_{ds} applied on the THz response. The bias current induces a large asymmetry degree in the boundary conditions of the plasma waves and, accordingly, a significant enhancement of the detector responsivity is observed [6].

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Graphene characterization by THz-TDS spectroscopy

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Graphene is a revolutionary material with excellent properties making it one of the most promising materials for the development of new transistors, sensor or transparent devices [1-2]. It shows higher mobility at room temperature [3] which makes it an excellent candidate for THz-FETs devices [4]. There are several ways to produce graphene [5]. Graphene exfoliation is the best way to produce high quality graphene but it is inviable to produce it on an industrial scale. CVD graphene is an alternative towards production of high quality graphene for electronic applications at the industrial scale. Due to the difficulty of obtain high quality graphene samples, it is essential the use of non-contact characterization techniques for identification of the flakes and for mapping of the geometrical conductivity [6].

Terahertz Time Domain Spectroscopy (THz/TDS) is a new technique for material characterization in the Terahertz range. Terahertz (THz) radiation has several advantages: It's a non-invasive and non-ionizing radiation, many materials have unique fingerprints in the THz range, and it is possible to obtain images with relative good resolution. THz-TDS is a non-contact technique making it a promising technique for material characterization (conductivity, mobility, permittivity…) [7].

We report on room temperature THz-TDS characterization of graphene flakes obtained by CVD and exfoliated methods. Two band absorptions were found in both samples at approx. 0.5 THz and 1 THz (Figures 1 - 2). There is a good agreement between both results. Peaks are good defined, and cannot be identified as water absorption peaks.

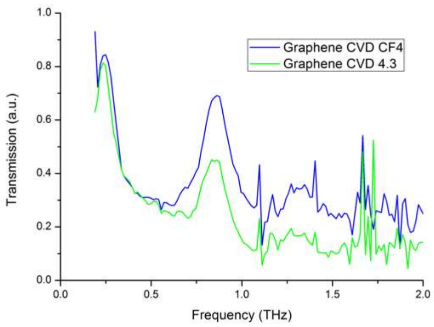

Fig 1. Transmission signal vs. frequency for different samples of Graphene CVD

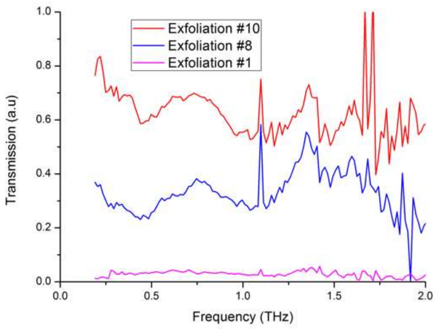

Fig 2. Transmission signal vs. frequency in exfoliated graphene.

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Raman Characterization of Graphene Oxide based heterostructures

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Graphene Oxide (GO) has recently become an attractive building block for fabricating graphene-based functional materials, this is because it possesses unique set of properties arising from oxygen functional groups that are introduced during chemical oxidation of the starting materials. GO is usually synthesized by oxidation of graphite or carbon nanofibers [1] by means of the Staudenmaier or the Hummers methods and it is often reduced by chemical agents [2] or thermal annealing [3] to restore the carbon lattice and to remove the structural defects and distortions.

Raman spectroscopy is an appropriate technique to study graphene based materials because the grade of defects, the crystallite size and the number of layers can be obtain from the first and the second order spectra. The Raman spectrum of GO presents two interbands in the region of 1000-1800 cm^{-1} related with crystallinity and edge defects [3]. In a previous work we have demonstrated that the position and intensity of these bands depend on the oxidation degree of GO and can be used to study the evolution of GO chemical structures during thermal annealing process. It is well stablished the effect of the substrate in the electronic properties of graphene. In order to prevent this effect an insulating material between the substrate and the flake of graphene must be used. Hexagonal boron nitride (hBN) is an isomorph of graphite composed of alternating B and N atoms in a honeycomb lattice. Because of its band structure, this compound is an insulating and relatively inert and makes it an excellent candidate to perform such as devices.

In this work, we present the fabrication and the Raman characterization of vertically stacked hBN-GO-hBN. The method to produce it is similar to that employed for graphene [4]. However, the main differences between the fabrication procedures are that the mechanical exfoliation of GO is carried out in presence of water and the flakes were deposited on a surface of PDMS instead of Si-SiO_2. The water induces the exfoliation of GO and prevents the cleavage of the flakes while PDMS favors the transference process. In order to remove the oxygen groups and to restore the carbon lattice of the GO, the heterostructure has been annealed from 100 to 1200 ºC.

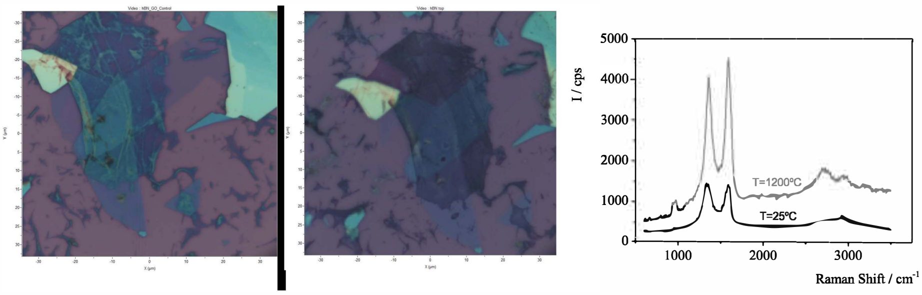

Figure 1. Optical Images of Graphene Oxide Heterostructure at room temperature (LEFT) and annealed at 1200 ºC (MIDDLE). Raman spectra of different heterostructures (RIGHT).

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