Dipartimento di Fisica
Università di Torino

Sezione di Torino
Istituto Nazionale di Fisica Nucleare

Centro inter-dipartimentale "NIS"
Università di Torino

2nd Workshop

"Diamond & New Technologies"

Technological applications of artificial diamond

Tuesday 16th September 2014
Aula Avogadro, Istituto di Fisica
Via P. Giuria 1, Torino

Program

Morning session: Diamond for biosensing
Chairman: V. Carabelli, *University of Torino*

$9^{00} - 9^{30}$	Diamond for bio-sensing: The "DiNaMo" project at INFN-To	F. Picollo, *INFN Torino*
$9^{30} - 10^{00}$	Biosensing neuronal signaling: a challenge for diamond-based lab-on-chip	E. Carbone, *University of Torino*
$10^{00} - 10^{30}$	Advances in diamond electrodes	A. Pasquarelli, *Ulm University*
$10^{30} - 11^{00}$	*Coffee break* (*sponsored by* Diamtec GmbH)	
$11^{00} - 11^{30}$	Single-crystal-diamond based biosensors	E. Bernardi, *University of Torino*
$11^{30} - 12^{00}$	Single crystal diamond mechanical resonators with Q-factors over 35,000 in air	B. Fairchild, *RMIT - Melbourne*
$12^{00} - 12^{30}$	Nanodiamonds as probes for biomedical imaging	A. Boni, *IIT@NEST - Pisa*
$12^{30} - 12^{45}$	IIa Technologies - A new source for CVD diamond	D. Detlef, *Diamtec GmbH - Pforzheim*
$12^{45} - 14^{00}$	*Lunch*	

Afternoon session: Diamond for photonics
Chairman: M. Genovese, *INRiM - Torino*

$14^{00} - 14^{30}$	Diamond for photonics: The "FIRB" and "ADiNTech" projects at UniTo	P. Olivero, *University of Torino*
$14^{30} - 15^{00}$	Templated Arrays and hybrid materials: new ways with nano diamonds	A. Greentree, *ARC Centre of Excellence of Biophotonics, RMIT - Melbourne*
$15^{00} - 15^{30}$	Engineering colour centres in diamond: barriers and possibilities	D. Jamieson, *University of Melbourne*
$15^{30} - 16^{00}$	Creation and charge state control of optical centres in diamond	S. Pezzagna, *University of Leipzig*
$16^{00} - 16^{30}$	*Coffee break*	
$16^{30} - 17^{00}$	NV center : a local and vectorial probe for strain in diamond nanostructures	E. Dupont-Ferrier, *Néel Inst. - Grenoble*
$17^{00} - 17^{30}$	Sub-diffraction imaging of colour-centres in diamond	I. P. Degiovanni, *INRiM - Torino*
$17^{30} - 18^{00}$	Electrical stimulation of color centers in diamond with sub-superficial graphitic electrodes	J. Forneris, *University of Torino*
$18^{00} - 18^{15}$	Closing remarks	E. Vittone, *University of Torino*

Diamond for bio-sensing: The “DiNaMo” project at INFN-To

Federico Picollo

INFN – National Institute of Nuclear Physics, Section of Torino

Ion beam lithography is a versatile tool, useful to exploit diamond properties, since allows the realization of 3-dimensional graphitic micro structures in this material. In order to improve this technique the DINAMO project (grant for young scientist funded by INFN) started. This project is focused on the development of a nanofabrication process where MeV Deep Ion Beam Lithography (DIBL) is integrated with advanced nano-fabrication processes such as Focused Ion Beam (FIB) Micromachining. In this contribution the results obtained in the first year of activity will be summarized.

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Biosensing neuronal signaling: a challenge for diamond-based lab on-chip

Emilio Carbone

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Neuronal signals regulate the input-output relationships of the many neuronal networks forming the brain. These “coded signals” are electrochemical in nature and originate from a sequence of molecular events generated by integral membrane proteins (ion channels, receptors and transporters). Ion channels and membrane receptors generate action potentials (APs) of various shapes, regulate the release of neurotransmitter from presynaptic terminals (synaptic transmission) and thus control the function of complex neuronal networks. The accurate resolution of neuronal signals in single neurons or neuronal networks *in vitro* and *in-vivo* is a key objective to identify the molecular basis of brain functioning and the molecular targets of neurodegenerative diseases. While presently exists a large number of commercially available micro-electrode arrays (MEAs) able to detect APs with low-spatial resolution, there is an increasing demand to monitor simultaneously AP-shapes and neurotransmitter release at low- and high-spatial resolution. Among the many new biomaterials available, nano-diamonds are potentially able to bridge the gap.

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Advances in diamond electrodes

Alberto Pasquarelli

Institute of Electron Devices and Circuits, Ulm University

In the last two years a new technology for the growth of nanocrystalline diamond films on transparent substrates has been developed. The material allows the fabrication of microelectrode arrays which combine the well known electrochemical properties of diamond with an unprecedented transparency. We also investigated the energy profile at the surface of NCD-films with oxygen and amino surface termination, to understand the charge transfer mechanisms in the presence of covalently bound electro-active functionalizing groups. The results of this study look promising for biosensing and photovoltaic applications.

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Single-crystal-diamond based biosensors

Ettore Bernardi

Physics Department, University of Torino

The investigation of the mechanisms involved in the adrenaline secretion is crucial in neuroscience research in order to achieve a better understanding of the signal transmission among neurons, but commonly used biosensors have limited biocompatibility, robustness and transparency. Our research is focused on the realization of biosensors fabricated by means of high energy ion lithography of high-purity monocrystalline CVD diamond samples that may overcame the above mentioned restrictions. Suitably aligned metal masks and variable-thickness contact masks were employed to define “highly damaged regions”, i.e. converted from sp^3 diamond bonds to sp^2 graphitic-like bonds, with emerging end-points with micrometric resolution. This fabrication process provides sub-superficial highly conductive graphitic micro-channels, embedded in a highly insulating and chemically inert diamond matrix, that can act as multiple bio-sensing electrodes for cellular *in vitro* recordings, both in single cell or multi-cell setups.

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Single crystal diamond mechanical resonators with Q-factors over 35,000 in air

Barbara Fairchild

MicroNano Research Facility, RMIT University, Melbourne

Cantilever-based sensing is becoming increasingly important for tasks such as the detection of small forces, biological and chemical sensing, and quantum mechatronics. The sensitivity of a cantilever increases as the resonance frequency and Q increases, and hence there is a push for ever higher frequency cantilevers. Diamond has the highest Young's modulus of any material, and is therefore promising for such applications. We report on the fabrication of micron scale single crystal diamond mechanical resonators with Q>35,000 in air.

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Nanodiamonds as probes for biomedical imaging

Adriano Boni

Italian Institute of Technology - National Enterprise for nanoScience and nanoTechnology (IIT@NEST)

Nanometre-sized fluorescent emitters are needed as probes for fluorescence imaging with minimal perturbation in applications ranging from materials science to probing protein interactions in living cells. Dye molecules have a very high brightness per unit volume or mass, but are usually not photostable at room temperature. Fluorescing centres in diamond are very attractive in this respect because of the rigidity of the diamond lattice and its wide bandgap, which cause a localization of 'optical' electrons within one to two interatomic distances from the defect. In this talk the applications of nanodiamonds as probes for biomedical imaging will be discussed, with a focus on optical and nuclear magnetic resonance techniques.

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Diamond for photonics: The “FIRB” and “ADiNTech” projects at UniTo

Paolo Olivero

Physics Department, University of Torino

Two projects are currently ongoing at the Physics Department of the University of Torino on diamond science and technology, i.e. the “Development of microfabrication techniques in diamond for applications in bio-sensing and photonics” project (2011-2015) supported by the Italian Ministry for Teaching, University and Research (MIUR) within the “FIRB – Future in Research 2010” scheme, and the “Advanced Diamond-based Nano-technologies - A.Di.N-Tech.” (2013-2015) project supported by the University of Torino in the framework of the “University Research Projects - Junior PI Grants” scheme. The projects aim at developing in close synergy new architectures in artificial diamond for applications in photonics (single-photon emitters, quantum cryptography) and bio-sensing (cellular sensors, microfluidics). In this contribution a synthetic progress report on the status of both projects will be given.

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Templated Arrays and hybrid materials: new ways with nano diamonds

Andrew D. Greentree

Australian Research Council Centre of Excellence for Nanoscale BioPhotonics, RMIT University

The exquisite properties of nanodiamonds are creating opportunities for novel ensors, including luminescent markers and environmental probes. They can also act as single photon sources for tasks such as quantum information processing. However we have significant issues around the practical use of nano diamonds for such tasks. Absolute yields for the fraction of nano diamonds containing particular colour centres are unknown, and so optimisation of growth conditions is problematic. Also, the integration of nano diamonds with external optical systems is difficult and laborious. Here I will discuss two projects that we have been involved with that seek to address these problems. The first is the development of templated arrays of nano diamonds, which offer the opportunity to determine absolute yield for rare colour centres. The second is work on diamond in fibre approaches to nano diamond integration using tellurite glass.

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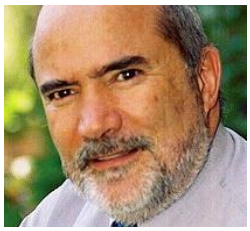
Engineering colour centres in diamond: barriers and possibilities

David Jamieson

Microanalytical Research Centre, University of Melbourne



The deterministic construction of colour centres in diamond remains an elusive goal. Yet this goal must be achieved if a monolithic diamond-based device is to be constructed that exploits the promising quantum mechanical attributes of colour centres in diamond such as the negatively charge nitrogen-vacancy centre. With the advent of high purity synthetic electronic-grade diamond, devices fabricated in this material measured by ion beam induced charge have revealed a charge collection efficiency for MeV ion impact approaching 100% even for impacts remote from the surface electrodes with a bias field of 30 V/mm. Devices fabricated from this material are also relatively immune from trapped charge induced polarization that can degrade the charge collection process. This suggests the carrier mobility and lifetime are high enough to allow charge transport over long distances more characteristic of silicon that has been reported to date in diamond. This presentation looks at the remaining barriers to exploit these excellent properties for the deterministic fabrication of colour centre arrays for large scale integration.

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Creation and charge state control of optical centres in diamond

Sébastien Pezzagna

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For many applications based on nitrogen-vacancy (NV) centres in diamond, such as magnetometry or quantum information processing (QIP), the control or stabilisation of the charge state of the NV centres is nowadays a critical issue. Depending on the local environment of the NV centres, different charge states are known to occur: NV^-, NV° and possibly NV^+ and NV^{2-}. However, only the NV^- form and its associated electron spin, which can be optically polarised and read out at room temperature, are valuable tools for magnetometry and QIP. Recently, the charge state control of shallow NV centres has been demonstrated by different techniques: chemically, electrically and optically. In this work, we show the passive control of the charge state of NV centres by co-doping with either phosphorous (for n-type doping and stabilisation of NV^-) or boron atoms (for p-type doping and stabilisation of NV°). Moreover, the control can be extended to other optical centres, as demonstrated also with the silicon vacancy (SiV) centres.

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NV center : a local and vectorial probe for strain in diamond nanostructures

Eva Dupont-Ferrier

Néel Institute, CNRS Grenoble

Unique mechanical properties of single crystal diamond make it an ideal material to build sensitive cantilever-based sensors. Recent progress in fabrication technology now allows for diamond resonators with high quality factors to be built. We use Nitrogen Vacancy (NV) centers in diamond to map the cantilever strain, as NV center properties are sensitive to strain. In particular, measuring ESR spectra of the four possible orientations of NV centers embedded in the resonators allows for in situ vectorial mapping of the strain present in the diamond resonators.

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Sub-diffraction imaging of colour-centres in diamond

I. . P. Degiovanni

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We present an experiment exploiting the photon anti-bunching behaviour of single photon emitters to enhance the resolution of optical fluorescence microscopy of single colour centres in diamond. Optical microscopy images of colour centres in bulk diamond grown exploiting Chemical Vapour Deposition (CVD) techniques were acquired on a pixel-by-pixel basis using a laser scanning confocal microscope. Together with the direct measurement of the numbers of detected photon, we show that by acquiring higher-order autocorrelation function ($g^{(n)}$) - exploiting, e.g., a detector tree or, equivalently, an higher order Hanbury-Brown-Twiss interferometer - resolution enhancement is achieved. Results show an increase in lateral resolution in agreement with theory that predicts a narrowing of the point spread function proportional to the square root of the highest order of the autocorrelation function measured.

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Electrical stimulation of color centers in diamond with sub-superficial graphitic electrodes

J. Forneris

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In this contribution, the effectiveness of MeV ion beam writing for the electrical excitation of color centers in diamond is explored. Differently from photoluminescence, electroluminescence requires an electrical current flowing through the diamond sub-gap states for the excitation of the colour centres. With this purpose, buried graphitic electrodes with a spacing of 10 µm were fabricated in the bulk of detector-grade CVD single-crystal diamond samples. The electroluminescence imaging was combined with a photoluminescence mapping of the sample using a confocal microscopy setup in order to provide a characterization of the light-emission features of the devices under test. The spectral analysis of electroluminescence evidenced a bright emission from native neutrally-charged nitrogen-vacancy centers (NV^0) and from He-related defects (λZPL = 536.3 nm, λZPL = 560.5 nm) associated with the ion implantation process. The fabrication of buried electrodes on high-purity samples was also exploited to address the stimulation of single-photon emission from isolated NV^0 centers.

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