2015 Joint International Symposium on Applications of Ferroelectrics-International Symposium on Integrated Functionalities and Piezoresponse Force Microscopy, 24-27 May 2015, Singapore
Tutorial for ISIF

Science and Technology of Multifunctional Oxide and Ultrananocrystalline Diamond (UNCD) Films and Applications to a New Generation of Multifunctional High-Tech and Medical Devices

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TUTORIAL ABSTRACT

New paradigms in the research and development of novel multifunctional oxide and nanocarbon thin films are providing the bases for new physics, new materials science and chemistry, and their impact in a new generation of multifunctional devices for micro/nano-electronics and biomedical devices. This tutorial will focus on discussing the science, technology, and engineering of multifunctional oxide and nanocarbon thin films and applications to a new generation of multifunctional micro and nano-devices, as described below:

1. **Science and technology of complex oxide thin films and application to key technologies:**

- Novel TiO_2/Al_2O_3 superlattices, exhibiting giant dielectric constant (up to k=1000), low leakage current (10^{-7}-10^{-9} A/cm^2) and low losses ($\leq$ tang d=0.04), based on new physics underlined by the Maxwell-Wagner relaxation mechanism, which enables a new generation of microchip embedded capacitors for microchips implantable in the human body, the next generation of gates for nanoscale CMOS devices, and super-capacitors for energy storage systems
- Novel $BiFeO_3/SrTiO_3/ BiFeO_3$ nanolaminates (BSB-NL) have recently been shown to exhibit two orders of magnitude lower leakage current than stochiometric BFO layers, i.e., from 10^{-5} A/cm^2 to 10^{-7} A/cm^2. The BSB-NL also shows very high piezoelectric response, which is ~ 5 times higher than that of the pure BFO with the same thickness. The strained state of the BFO layers concurrently with the chemical and crystallographic state of the interfaces between the BFO and STO layers contribute to the very high values of piezoresponse and very low leakage current observed in the BSB-NLs. BSB-NL are being integrated with the ultrananoacrystalline diamond (UNCD) films described below to develop a new generation of implantable biosensors and piezoelectrically actuated MEMS drug delivery devices.

2. **Science and technology of novel ultrananocrystalline diamond (UNCD) films and integration for fabrication of a new generation of industrial components and multifunctional and biomedical devices:**

UNCD films developed and patented by Auciello et al. are synthesized by novel microwave plasma chemical vapor deposition (MPCVD) and hot filament chemical vapor deposition (HFCVD) techniques using an Ar-rich/CH_4 chemistry that produces films with 2-5 nm grains, thus the name UNCD to distinguish them from nanocrystalline diamond films with 10-100 nm grains. The UNCD films exhibit a unique combination of outstanding mechanical, trtibological, electrical, thermal, and biological properties. In relation to the materials science of UNCD films, this tutorial will describe the synthesis of UNCD films and characterization of all the properties described above. Then, a detailed discussion of all applications developed until now will be presented.

First, industrial components and devices currently commercialized by Advanced Diamond Technologies (a company co-founded by Auciello and colleagues in 2003), will be described, namely:

a) UNCD-coated mechanical pump seals for the petrochemical, pharmaceutical and car industries (**shipping to market**);

b) UNCD-coated bearings for mixers for the pharmaceutical industry (**shipping to Merck-Millipore market**);

c) New UNCD electrodes for water purification systems based on electrolysis process, which outperform all other electrodes in the market today **(shipping to market**)

d) UNCD-AFM tips for science and nanofabrication (**shipping to market**)

e) RF-MEMS switches monolithically integrated with CMOS driving devices for next generation of radars and mobile communication devices (prototype system demonstrated)

f) NEMS switch-based logic

Second, a new generation of biomedical devices based on the UNCD coating technology and integrated with piezoelectric thin films for some MEMS devices, all being developed for commercialization by Original Biomedical Implants (Company co-founded by Auciello and Gurman (MD) in 2013) will be described, namely:

a) Bioinert UNCD coating for encapsulation of microchips implantable in the human body (an example to be described relates to a microchip implantable on the eye retina to restore sight to people blinded by retina photoreceptors degeneration)

b) UNCD coating for devices to drain eye liquid for treatment of glaucoma (advanced studies on animals performed)

c) UNCD-coated magnets located outside the eye to produce magnetic fields to attract super-paramagnetic nanoparticles injected in the eye to push detached retina (animal studies and first clinical trials performed)

d) UNCD bio-inert coating for artificial heart valves (prototype demonstrated)

e) UNCD-coated dental implants (advanced animal studies performed)

f) New Li-ion batteries (LIBs) with UNCD-coated anodes and other components enabling a new generation of LIBs with $\geq$ 10x longer life and smaller dimensions than current LIBs for pacemakers and defibrillators, and also applications to cell phones and other electronic devices (prototype LIB demonstrated)

g) UNCD surface used as a unique platform for growing stem cells and induce differentiation into other cells of the human body for medical treatments based on nanotechnology.