Study of Feasible and Novel Nano-engineering Electronic Materials for Applications in Futuristic Devices and Research

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Abstract- Advances in the understanding of electronics have created revolution in all fields of its applications. May it be micro-electronics, micro-electromechanical systems, fluorescent-magnetic devices, nanobiodevices, terahertz devices or a vast field of nanotechnology, everywhere electronics has made a vital dent. Advancement of any engineering discipline is not possible without the development of materials. Hence continued researches full of vivid novelties are required in electronic materials technologies. Research demands that the development of newer materials, their characterization and appropriate applications be given topmost priority. With this aim, in this paper, scenarios of emerging trends have been focused to present the current and futuristic electronic and nano-electronic materials along with their feasibility

Keywords- Magnetic Tunnel Junction, Nanoferroelectrics, Nanomaterials, Porous Alumina Films, Pyro-Electric Thin Composite.

I. INTRODUCTION

The development in electronics engineering and electronic materials is currently towards creating the atomic and nano size devices from miniature size. It therefore envisages the synthesis and development of nanomaterials and of other materials in the form of thin films etc. In this respect, the pyroelectric composites and nano ferroelectrics are frontier materials. The search of advanced materials for conventional energy sources and renewable energy applications are also the emerging fields for research. Therefore the research for electrolytes, nanobattery, and electrochemically advantageous materials has been included in this paper.  Superconductivity is one of the most desired properties in electronic materials. For that, the efforts are being made to produce ultrathin-magnetic tunnel junctions(MTJ’s). The frontiers of research also include the development of conducting paper as these play vital role in electronic materials. Hence continued researches full of vivid novelties are required in electronic materials technologies. Research demands that the development of newer materials, their characterization and appropriate applications be given topmost priority. With this aim, in this paper, scenarios of emerging trends have been focused to present the current and futuristic electronic and nano-electronic materials along with their feasibility.

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II. NEW PYROELECTRIC THIN COMPOSITE FILMS

Pyroelectricity is a property of polar crystals characterized by the evolution of electric charge when exposed to heat. This property is utilized in various applications such as un-cooled thermal imaging, infrared-red light detectors, thermal switches, thermometers and gas sensors. The number of devices based on pyroelectric materials has increased during the last years due to their application in industries such as airplanes, cars and private home security control. Most of the knowledge today on pyroelectric materials is based on bulk-size single crystals. Pyroelectric polycrystalline thin films are also used in devices but require specific depositing conditions to obtain preferred crystallographic polar orientations [1]. Pyroelectric materials have lower detection sensitivity of infra-red light by few orders of magnitude compared to semiconductor crystals. Their main advantage is the ability to detect light in a wide wavelengths range, especially in the far infra-red, without any cooling requirements.

There is a high scientific and technological interest in developing new pyroelectric materials capable of better detection limit, higher lateral sensitivity and faster response time. One way of meeting these challenges, suggested by S.Berger and M.Nitzani [2], is to decrease the size and increase the surface density of the detecting crystals to obtain uniform electric response from each of the detecting crystals without any electric interaction between them. Berger et.al. presents a new thin composite film that consists of nanometer-sized pyroelectric rods grown inside alumina nano-pores. The rods are single crystals arranged in a uniform crystallographic orientation. Their surface density is of about 10¹¹/cm². The combination of small size, uniform crystallographic orientation and high surface density results in improved pyroelectric properties from theoretical and experimental view points.

II (A) SYNTHESIS OF MATERIALS

Thin porous alumina films (about 0.5 µm thick) are formed on the surface of pure aluminum foils (0.5 mm thick) by electrochemical anodization. Prior to anodization, the Al surface is electro-polished to a high degree of smoothness using an electrolyte solution of perchloric acid and ethanol (3:7 volume ratios) under a constant potential at 25°C. The anodization is done in an aqueous phosphoric solution (3 % vol.) under a constant current density at 25°C. The anodized samples are inserted into a super-saturated aqueous solution of TriGlycine Sulfate TGS-(NH₄C₂O)₃H₂SO₄. The insertion process is done at different temperatures in the range of 25-60°C. The liquid solution is cooled down slowly to enable nucleation and growth of single crystals in the pores. In some experiments a dc voltage is applied on the samples during cooling to enforce growth of single crystals with preferred polar crystallographic orientation. After
cooling, the samples are pulled out of the liquid solution. The crystals on the samples surfaces are removed by delicate wiping. Finally, the samples are dried in desiccators.

III. ELECTROCHEMICAL ENERGY SOURCES

Environmental issues and risks of oil shortage, lead to extensive research on new energy sources i.e. solar, wind, and geothermal renewable energies, that are alternatives to power stations based on oil, to produce electricity and, by cogeneration, heat. Whatever the interest of such energy sources, these must be associated in performing the electrochemical energy sources as batteries, in order to store the peak productions of electricity, or to electrolysers allowing pure hydrogen, useful for Proton Exchange Membrane Fuel Cells (PEMFC) to be produced. In most of the developed countries, researches are presently funded to succeed in adapting PEMFC to electric vehicle (EV) use. Both in lithium batteries and PEMFC, one of the main bottlenecks deal with the polymer electrolyte which must provide high performances, high lifespan and, above all, safety. In the frame of this paper J.Y. Sanchez et.al. emphasize the interest of using composite and nanocomposite polymer electrolytes.

III (A) NANOCOMPOSITE POLYMER ELECTROLYTES

Lithium polymer batteries (Li anode) improve the EV autonomy while limiting the battery weight and volume. While Li non-rechargeable batteries which associate liquid electrolyte to a porous polymeric separator are commercialized, their rechargeable version does not meet the requirements of EV in terms of both lifespan and safety. On the other hand the use of a polymer electrolyte free of added liquid solvent allows several hundred cycles of charge/discharge to be performed with a weak fading, meeting therefore the requirements for an EV application. Batscap company developed an EV i.e. Blue Car based on the lithium polymer battery. The elemental modulus of this battery whose total thickness is about 100 micrometers is shown in Fig.1.

![Fig.1 A lithium polymer battery of 100 µm thickness](image)

In such polymer electrolytes the polymer behaves both as a “viscous solvent” and as a separator preventing the battery of a short originating from a contact between the electrodes. The first function implies the salt dissolution, its dissociation, the ion solvation and their displacement. Polymers, polyethers and polyoxides are able to dissolve a wide variety of lithium salts and to interact with lithium cations. In addition to these functional properties, the host polymer, amorphous in the operating conditions of electrolytes, provide mechanical properties compatible with the use of thin films which allows the moderate conductivities (with respect to liquid electrolytes) to be compensated in terms of internal resistance. Up to recently, this objective was only achieved by cross-linking the polyether matrix.

It was early proposed to use nanofillers to improve the performances of polymer electrolytes i.e. through the addition of TiO₂, conductivity enhancement and sometimes, improvement of the polymer electrolyte interface with lithium anode. Jean-Yves Sanchez et.al. [3] approach was to improve remarkably the mechanical properties of polymer electrolytes while keeping a high conductivity level. Usual reinforcements by incorporation of woven or unwoven fibres as glass fibres are unsuited to the elaboration of thin films of some tens of micrometers. The authors selected to use highly crystalline cellulosic fibres originating from the mantle of a sea animal i.e. tunicin. These fibres which have a high form factor form a network by hydrogen bonding which occur at a percolation threshold of some %. The TEM photograph, of a dilute suspension of tunicin whiskers, presented in Fig.2, shows the high form factor of these fibres which have the shape of needles.

![Fig.2 TEM photograph of a dilute suspension of tunicin (a sea animal) whiskers.](image)

IV. NOVEL NANOSTRUCTURED MATERIALS FOR A VARIETY OF RENEWABLE ENERGY APPLICATIONS

Hydrogen can be generated by a variety of means including the electrolysis of water using electricity derived from wind power, photovoltaic or by thermo-chemical processing of biomass. Hydrogen can then be reacted with oxygen in fuel cells to generate electricity, combusted in an engine to generate mechanical energy, or simply burned to generate heat. In each of these cases, water is produced in a virtually pollution-free process. Unfortunately, before hydrogen can be employed in the transportation sector, numerous technical hurdles must still be overcome. Recent theoretical studies have shown that by complexing fullerenes with a transition metal (TM), H₂ dihydrogen ligands may be bound with binding energies appropriate for on-board vehicular storage. In an optimal structure, scandium has been predicted to complex with all of the twelve five-membered rings in a fullerene. The C₆₀[ScH₂(H₂)₄]₁₂ complex has a reversible hydrogen capacity of 7.0 wt.%.

Recently, Hot-wire chemical vapor deposition (HWCVD) has been employed as an economically scalable method for deposition of crystalline tungsten oxide nanorods and nanoparticles [4]. Under optimal synthesis conditions, only crystalline nanostructures with a smallest dimension of approximately 10-50 nm are observed with extensive transmission electron microscopy (TEM) analyses. The incorporation of these particles into porous films led to profound advancement in state-of-the–art electro chromic (EC) technologies. The development of durable inexpensive EC materials could make them suitable for large area window coatings and lead to decreased...
V. CRITICAL FIELDS IN LITHIUM NIOBATE NANO FERROELECTRICS

An important property like giant polarization with many other properties is commonly observed in ferroelectric materials, which have a wide area of applications. However, the most significant property is their ability to show non-volatile memory, which remains finite when the field is withdrawn. This is clearly noticed in the hysteresis curve of polarization (P) vs external electric field (E), which is non-linear.

The ferroelectric materials such as lithium niobate and lithium tantalate typically show this non-linear hysteresis behaviour, which can be explained by dynamical system analysis. The behaviour of these ferroelectrics is usually explained by domains and the domain wall movements. So, the spatial variation of the domain wall was studied previously by A.K.Bandyopadhyay et.al. [5] in order to see its effect on domain wall width in the context of Landau-Ginzburg functional. By treating it as an eigenvalue problem, the critical values of polarization (Pc) were estimated within the ‘zone of stability’ through a linear Jacobian transformation, which showed a possibility of a ‘giant memory’, and the corresponding limits of domain wall width were also found in the case of lithium tantalate and lithium niobate ferroelectric crystal.

VI. MODEL FOR MIGRATION-ASSISTED TUNNEL CONDUCTION IN ULTRA-THIN MAGNETIC TUNNEL JUNCTIONS

Magnetic tunnel junctions (MTJ’s) made of two ferromagnetic microelectrodes separated by a thin oxide barrier are key elements in modern spintronics. As thin barriers as 10 Å are now fabricated, providing resistance×area (R×A) as low as 1×10 µm². They can bear as high tunnel current densities as ~10⁴÷10⁶ A/cm², displaying sizeable electromigration processes, and dependent on relative polarization of electrodes. The physics behind such behavior is not yet well understood. Yu.G.Pogorelov et.al. [6] studied CoFeB/AIOx/CoFeB MTJ’s, fabricated by ion beam deposition with remote plasma oxidation of AIOx barrier. At shortest oxidation time, they have R×A ~ 4×12 µm² for area A from 1×1 to 3×8 µm, and high magneto-resistance ~15÷20% at room temperature. The resistance vs temperature R(T) varies from activated to metallic type from one sample to another (not correlated with the R×A values), and even in the same sample when passing from antiparallel (AP) to parallel (P) polarization of magnetic electrodes (Fig. 3). This indicates coexisting conduction mechanisms in these devices, perhaps due to formation of metallic patches of under oxidized Al and numerous structural defects within the barrier. Nevertheless, the averaged conductivity of these samples ~1Ω⁻¹cm⁻¹ is still much below the Mott threshold ~0.02e²/ha 200 Ω⁻¹cm⁻¹ for the bulk metal-insulator transition. Therefore the variation from negative to positive dR(T)/dT is most probably due to the competition between slowly decreasing R_ad(T) = [R_AP(T) + R_p(T)]/2 and faster decreasing magnetoresistance R_ad(T) - R_p(T) (inset in Fig. 3)

VII. NANOENGINEERING OF WOOD FIBRES FOR CONDUCTING PAPER

Paper manufacturing is one of the mainstays of the American economic infrastructure, and paper products influence almost every aspect of business and personal life. From currency to tissue, trees and paper influence our lives. Although, it is said that the electronic sector is taking over the paper industry, the present technology cannot meet the need for paper. Therefore, while there is no significant threat from the electronic sector on the paper industry, it is wise to look for new opportunities to develop new paper-based products with extra functionalities.

To fill the many market sector needs, a variety of processes have been developed and introduced for production of pulp, forming sheets, and coating paper after formed into sheets. The coating processes developed thus far include printability improvements, opacity improvements, smoothness, and strength to name a few. These coating processes have in common that they apply a coat to the substrate paper after formation of the sheet from the microfibers. In this work, K.Vanhamraam et. al [7] demonstrated enhancement in the electrical properties of paper using a systematic layer-by-layer (LbL) nanoassembly of polyelectrolyte thin films on cellulose microfibers prior to papermaking. LbL nanoassembly is a unique method based on sequential deposition of oppositely charged polyelectrolytes or nano-particles on surfaces of different shapes and sizes.

The authors have used an aqueous dispersion of poly (3, 4-thielenedioxythiophene)-poly (styrenesulfonate) (PEDOTPSS) conducting polymer as anionic polyelectrolyte, and poly (allylamine hydrochloride) (PAH) and poly(ethyleneimine) (PEI) as primary cationic polyelectrolytes. By creating alternating layers of these two polyelectrolytes on the surfaces of wood microfibers, authors have produced a nanocoating that enables the microfibers to exhibit moderate electrical conductivity. Subsequently, they have used these microfibers for the production of handsheets that have a measurable electrical conductivity.
REFERENCES


