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Oxide Based Dilute Magnetic Semiconductor- A Brief Review

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ABSTRACT

Dilute magnetic semiconductors (DMS) play an important role in interdisciplinary materials science. Out of this oxygen based DMS this system has been the subject of intense research for Enhancement of magnetic property as well as the Curie temperature. In this system the charge and spin degrees of freedom are accommodated into single matter and their interplay is expected to explore novel physics and new devices. Rare earth oxides have become a interesting field of study for their interesting properties as well as their versatile applications in different fields. Recently the various physical properties, viz., optical (absorption spectra, IR spectra, Raman spectra), magnetic, thermal and hyperfine properties of rare earth oxides have been reported. The various 3d transition metal ion (e.g., Fe, Ni, Co etc) which has also high value of magnetic moment, has been doped in different rare earth oxides, in recent years and it is reported that there is an enhancement in the magnetization. Doping of 3-d metal ion in different rare earth oxide and other semiconducting oxide system can be interesting for the enhancement of magnetization. From the viewpoint of DMS, there may be strong ferromagnetic exchange coupling between localized spins due to carrier induced ferromagnetism and double exchange interaction when localized spin is introduced in the oxide semiconductor.

Keyword : Rare earth, Dilute magnetic semiconductor, Nanoparticle, Ferromagnetism

I. INTRODUCTION

The investigations on the magnetic properties of different substances results to the discovery of many interesting phenomenon viz. diamagnetism, paramagnetism, ferromagnetism etc. The different magnetic properties of materials motivated people to understand the nature of interaction of the constituent particles. In this connection different materials were grown in different form viz. single crystal, nanocrystalline etc. Over the past few decades, the microelectronics industry has made tremendous progress, with its basic unit. The smallest electronic component of such progress is the transistor, which was developed in the late 1940s by scientists at Bell labs. Over time, the metal oxide semiconductor field effect transistor (MOSFET) evolved as the most widely used transistor structure. The Moore`s law [1], proposed in 1965, tells that the number of transistors built on a wafer would double every in two years. Therefore the scaling would be the key factor to improve the performance and profitability in the microelectronic industry. The scaling to this dimension becomes a problem to as it need very thin gate oxide layers, that could be leaky and require constant refreshing. This would call for unacceptably high-power consumption, which could act as an impediment to further scaling down. Therefore newer approaches have explored for further miniaturization of microelectronics.In this direction one such approach was to incorporate spin of the charged carrier in addition to their charge in the device.It has some other advantages also. The magnetic material can remember its spin state without any refresh and this memory is non-volatile. Relatively low energy is required to manipulate the orientation of the spin of the carrier which will develop the low power spintronic device. Since the concentrations of magnetic ion in these semiconductor materials are low, they are called dilute magnetic semiconductor/ spintronic materials. Metal-based spintronics already has several applications such as hard disk drives and read-write heads. However, new functionalities can be derived from semiconductor spintronic devices.

II. DMS/SPINTRONIC SYSTEM

The key elements of spintronics are injection, manipulation, transfer and detection of spin-polarized carriers across a semiconductor device. A ferromagnetic source material is required to produce such spin-polarized carriers. Ferromagnetic materials have an unequal density of states (DOS) of spin-up and spin-down states at the Fermi level. In recent years, considerable work has been devoted to the study of diluted magnetic semiconductors (DMS) [2-12] These semiconductors are doped with ions that have a net spin. The interaction among these spins leads to a ferromagnetic state at low temperatures. These types of materials have a lattice structure similar to that of the undoped semiconductor, at least for the diluted magnetic case. This similarity provides an honest lattice match between the doped and undoped cases, allowing them to be a potential material for the preparation of devices. The field of DMS received a considerable boost when a few years ago Ohno doped Mn ions into GaAs, and found Curie temperature above 100 K [13]. This is not yet sufficient for applications, but progress in this area is rapid and room temperature ferromagnetism could be achieved even with considerable dilution [14-16]. The properties of electrons in the solid state (mass, charge and spin) lay the foundation of the information technology we use today. Integrated circuits and high-frequency devices made from semiconductors, used for information science and communications, have had great success using the charge of electrons in semiconductors. Mass storage of data indispensable for information technology is administered by magnetic recording (hard disks, magnetic tapes, magneto-optical disks) using spin of electrons in ferromagnetic materials. It is then quite natural to ask whether both the charge and spin of electrons can be utilized to increase the performance of the devices. We may then be ready to use the potential of mass storage and processing of data at an equivalent time. Alternatively, we may be able to inject spin- polarized current in to semiconductors to control the spin state of carriers, which may allow us to carry out (quantum bit) operations required for quantum computing. However, there are good reasons why this has not yet been realized. The semiconductors used for devices and integrated circuits, such as silicon (Si) and gallium arsenide (Ga As), do not contain magnetic ions and are nonmagnetic, and their magnetic Lande-g factors are generally rather small. In order for there to be a useful difference in energy between the two possible electron spin orientations, the magnetic fields that that might need to be applied are too high for everyday use. Moreover, the crystal structures of magnetic materials are usually quite different from that of the semiconductors utilized in electronics, which makes both materials incompatible with one another. DMS systems, is a very emerging field of present day research. In this system the charge and spin degrees of freedom are accommodated into single matter. In this field main emphasis would be given on the preparation of some new DMS/spintronic systems with high application potential as their number with high quality is still very poor.

III. REVIEW OF SOME WORKS ON RARE EARTH OXIDE BASED DMS/SPINTRONICS

The oxide based diluted magnetic semiconductor materials has potential use in the development of spintronic devices, Room temperature ferromagnetism (RTFM) has frequently been reported in transition-metal (TM) doped semiconducting [17- 20] or insulating [21-23] oxides, known as dilute magnetic oxides (DMO).

L. C. J. Pereira et.al.[5] found that Co-doped TiO_2 exhibit ferromagnetic behavior well above room temperature (RT) for low Co doping concentrations (Tc >650 K). The synthesis of both anatase and rutile Co: TiO_2 FM films were achieved using a wide variety of techniques. Magnetic moments of such films ranging from 0.16μ_B/Co to values as high as 2.3μ_B/Co have been reported. On the other hand Jianping Xu, et. al. investigated the structural, optical, and magnetic properties of Polycrystalline anatase $Ti_{1-x}Co_xO_2$ (x=0–0.06) films synthesized by sol-gel spin coating. They reported that at 300 K, the saturated magnetization is around 1.8 μB/Co, and it is independent of the concentration of Co.

Room temperature ferromagnetism in pure CeO_2, has been observed by R K Singhal et al [20] when the sample is heated in vacuum. They confirmed that the ferromagnetism observed in CeO_2 originates due to the oxygen vacancies (Vo). The exchange interaction between the magnetic ions takes place via oxygen vacancies. Wen et al [24] obtained magnetization of 0.47 emu g−1 in 2.1 at% Co doped CeO_2. The same behavior was found in Ni-doped CeO_2, with a magnetization of 0.012 emu g−1 for 4 at% Ni [25]. In these reports, the ferromagnetic behavior was interpreted as exchange of F centres, in which a combination of V_O and a small magnetic concentration of dopant ions were involved. Being a well-known catalyst, CeO_2 easily forms stable oxygen vacancies (V_o) without changing its fluorite structure [26] hence it is very interesting to investigate the role of V_O in mediating ferromagnetism.

RTFM has been reported in certain transition metal doped rare earth oxides. Specifically it was found that when a small amount of Cobalt is doped in high-k CeO2, the material exhibits high temperature ferromagnetism [22]. Later on ferromagnetism was also found in Ni and Fe doped CeO_2 [27-28]. Paul Slusser, Dhananjay Kumar, and Ashutosh Tiwari investigated [29] the magnetic behavior of Cu doped CeO_2 film deposited by pulsed laser deposition technique. They reported that the Magnetic coercivity increases from 40 G to 60 G when temperature decreases from room temperature to 10 while magnetization at 10 K is ~ 1.1 μ_B/Cu atom and shows a small and almost linear drop with increase in the temperature. The RTFM is also found in iron doped in cerium oxide nanoparticles synthesized by chemical process [30]. The sample was annealed at and above 740^{0}C. The discovery of ferromagnetism at room temperature in nanoparticles of pure and Co doped CeO_2 has also been reported by Qi-Ye Wen, et.al. [24]. For the preparation of solid oxide fuel cells (SOFCs) Samarium-doped CeO_2 [31] is a leading electrolyte material which requires a high sintering temperature (1400–1600 ^{0}C). By synthesizing reactive powders via carbonate precipitation, fully dense CeO2 ceramics doped with 0–20 at.% of samarium have been fabricated in this work via pressure less sintering at a significantly lowered temperature of 1000 ^{0}C. The resultant ceramics show ultrafine grain sizes of ~ 0.15–0.75 lm, depending upon the dopant concentration. Sintering studies indicated that samarium doping retards both densification and grain growth but increases the speed of the two in the intermediate stage of sintering. Subsequent investigations on the grain growth in the fully densified ceramics also showed the suppressing effects of dopant, which tend to saturate at 10 at. % of samarium. The energy of activation for grain growth increased from ~186 to ~ 254 kJ/mol by increasing the samarium concentration from 5 to 20 at. %.

The study on magnetic properties of insulating $Sm_{1.9}Co_{0.1}O_3$ films grown on a $SrTiO_3$ substrate is also available in the literature [32]. A pulsed laser deposition technique was utilized to grow the films under varied oxygen pressure. The films were characterized using several techniques, like x-ray diffraction, high resolution transmission electron microscopy, and magnetic property measurements. Films prepared at lower oxygen pressures were found to be monoclinic, whereas the films prepared at high oxygen pressures were cubic. Both film phases exhibited super paramagnetic-like responses, with the monoclinic films showing a very high coercive field at low temperatures. Careful microstructural analysis showed no secondary phases or compositional variation that would account for the observed magnetic response. The magnetic behavior of Co doped Sm_2O_3 film is well explained on the basis of widely accepted bound polaron theory for insulating ferromagnets. In this model, exchange mediating defects form magnetically active regions that behave like super paramagnetic clusters; however, unlike in super paramagnetic systems, the size of magnetically active regions is not static but changes dynamically with temperature.

Miyazaki et al. reported [33] the fabrication of single-crystalline La-doped EuO thin films with a Curie temperature (T_C) of about 200 K, This was the highest among rare-earth compounds without transition metals. From first-principle band calculation and x-ray diffraction profile, the observed increase in T_C cannot be explained only by the rise in hybridization intensity arising from lattice contraction and the increase in up-spin electrons of the Eu 5d state due to the electron doping. They explained that hybridization between the Eu 4f and donor states and/or Ruderman–Kittel–Kasuya–Yoshida interaction mediated by the doped La 5d state is a possible origin of the increase in T_C.

IV. CONCLUSION

Oxide based DMS is a rapidly growing field, out of these rare earth oxide based DMS drew much attention due to their magnetic, dielectric and optical behavior. Preparation and Characterization of many new materials have been reported but for further development in this field an exhaustive experimental study, clear theoretical explanation and fabrication of high quality sample is required. As these materials have high dielectric constant, wide band gap also respond to external magnetic field, they may be a promising candidate for the future application. Material design and synthesis of rare earth oxide based DMS with high T_C would make these materials more attractive as far as practical application is concerned.

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