CEMS STUDY OF TRANSPARENT SnO_2 FILMS DOPED WITH ^{57}Fe

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The origin of magnetic interactions in diluted magnetic semiconductors (DMS) is an interesting issue as a basic problem in magnetism and its possible application in spintronics [1-2]. We have reported different types of magnetic source in case of Fe doped SnO_2 powders, prepared by sol-gel method and post annealing [3], and also the phonon density of states (DOS) of rutile type structures of SnO_2 and TiO_2 [4]. The dilution and clustering of doping Fe species can be estimated by Mössbauer spectra and phonon DOS. We have clarified that the diluted Fe species probe the phonon DOS in SnO_2 more faithfully than in TiO_2. When a large magnetization was obtained for diluted Fe doped SnO_2, a magnetic relaxation with broad lines was observed in room temperature Mössbauer spectra. However, when the small magnetization was observed, no magnetic component was found in Mossbauer spectrum. In the latter case, the magnetization disappeared by annealing for long time [3]. It is clear that defects in DMS can also contribute to enhance the saturation magnetization.

On the other hand, thin films of $Sn_{1-x}{}^{57}Fe_xO_{2-\delta}$ have been implanted at room temperature with $1x10^{17}$ Fe ions/cm^2 and at 300^{o}C with $5x10^{16}$ and $1x10^{17}$ Fe ions/cm^2, with an implantation energy of 100 keV in each case [5]. The as-implanted samples at room temperature and post-annealed samples did not show any Kerr effect, but the sample implanted with $1x10^{17}$ Fe ions/cm^2 at substrate temperature of 300^{o}C showed Kerr effect although magnetic sextets were not so clearly observed in the ^{57}Fe conversion electron Mössbauer (CEM) spectra. Kerr effect disappeared after annealing. This suggests that the number of magnetic defects decreases by absorption of oxygen due to annealing in air atmosphere [5]. We have also showed that the bulk magnetization is enhanced by introducing Sb^{5+} in the Fe doped SnO_2 powder [6]. We have tried to prepare ^{57}Fe implanted SnO_2 films at the substrate temperature of 500^{o}C, which showed Kerr effect [7]. The Kerr effect did not disappear after annealing. We have characterized tin oxide doped with ^{57}Fe and some transition metals.

SnO_2 (Sb) films with thickness of 200 nm were prepared on quartz glass by DC sputtering, and implanted with 5×10^{16} ^{57}Fe ions/cm^2 at the substrate temperature of 500 °C in vacuum, using an energy of 100 keV. From TRIM calculations of implantation conditions of 5×10^{16} Fe ions/cm^2, the iron profile peak is expected to be located at about 40 nm depth with a maximum Fe concentration of 5 at. %. Some samples were step by step post-annealed at 400 °C, 500 °C, 600 °C, 700 °C, and 800 °C. Polar Kerr effect of these samples was measured with magnetic circular dichroism (MCD) mode.

We have fabricated gas flow counter for CEMS and XMS, respectively, and further have also developed a dual counter to get both CEM and XM spectra simultaneously [7]. As another application, a He gas proportional counter can be applied to depth selective CEMS (DCEMS) by detecting the different energy electrons emitted from the surface. Three CEM spectra were simultaneously observed on each sample from different depths by discriminating the resonance electrons with three energy regions (2–6.5 keV, 6.5–11 keV, and 11–20 keV) using homemade Mössbauer system and He + 5% CH_4 gas flow counter [8,9] . This method provides the rough depth profile of layers, which is named as DCEMS. In contrast to DCEMS, a conventional CEMS, which detects all electrons, is called an integrated CEMS (ICEMS). Doppler velocity was calibrated with standard α-Fe foil at room temperature and a γ source of ^{57}Co/Cr matrix was used.

The Fe doped SnO_2 films annealed at various temperatures have been characterized by DCEMS using a back-scattered type of gas flow counter in order to study especially the effect of post annealing. The SnO_2 films implanted with ^{57}Fe at room temperature were measured at 15 K. The review on CEMS study of implanted samples and some additional results will be presented.

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References

(1) J. M. D. Coey, M. Venkatesan, and C. B. Fitzgerald, Nat. Mater. 4, 173 (2005).

(2) A. Punnoose, J. Hays, A. Thurber, M. H. Engelhard, R.H. Kukkadapu, C. Wang, V. Shutthanandan, and S. Thevhuthasan S, Phys. Rev. B 72, 054402 (2005).

(3) K. Nomura, C. A. Barrero, J. Sakuma, and M. Takeda, Phys. Rev. B 75, 184411 (2007).

(4) A. I. Rykov, K. Nomura, J. Sakuma, C. Barrero, Y. Yoda, and T. Mitsui, Phys. Rev. B 77, 014302 (2008)

(5) K. Nomura and H. Reuther, Hyperfine Interact. 191, 159 (2009).

(6) K. Nomura, C. A. Barrero, K. Kuwano, Y. Yamada, T. Saito, and E. Kuzmann, Hyperfine Interact. 191, 25 (2009).

(7) K. Nomura, T. Okubo, and M. Nakazawa, Spectrochim. Acta B 59, 1259 (2004).

(8) K. Nomura, S. Iio, Y. Ujihira, and T. Terai, Industrial Applications of the Mössbauer Effect, Eds. M. Gracia, J. F. Marco, and F. Plazaola, AIP, CP 765, 108 (2005).

(9) K. Nomura, Z. Nemeth, and H. Reuther, ICAME09 proceeding, Journal of Physics: Conference Series (JPCS), 217(2010)012118.