Sizeable enhancement of anti-weak localization effect in In_2O_{3-x} thin film caused by H_2 gas mixing in N_2 gas atmosphere on heat treatment

Hiromi Kobori [a,1], Masaya Kawaguchi [b], Naoki Hatta [b], Tyuzi Ohyama [b]

[a] *Dep. of Phys., Fac. of Sci. and Engi., Konan Univ., Okamoto 8-9-1, Hyogo 658-8501, Japan*

[b] *Dep. of Phys., Grad. Sch. of Sci., Osaka Univ., Machikaneyama 1-16, Toyonaka, Osaka 560-0043, Japan*

Abstract

Through magneto-conductance (MC) measurements, we have observed sizeable enhancement of anti-weak localization (AWL) effect in In_2O_{3-X} thin film (60nm) caused by H_2 gas mixing (10%) in N_2 gas (90%) atmosphere on the heat treatment (HT). In case of the HT in pure N_2 gas, the AWL effect is recognized, but is very small. With respect to those experimental results, we conclude that interstitial indium atoms in In_2O_{3-x} are effectively generated and the AWL effect due to the spin-orbit (SO) interaction is come up.

Key words:
anti-weak localization; In_2O_{3-X} thin film; heat treatment; H_2 gas

1. Introduction and Experimental Procedures

Indium oxide (IO), In_2O_{3-x}, is generally an n-type semiconductor due to conduction electrons (CEs) provided from naturally generated oxygen vacancies (OVs). One OV in IO supplies two CEs. Consequently the concentration of CEs is dependent on that of OVs. With respect to the CE concentration above $1.5 \times 10^{18} cm^{-3}$, IO is considered to be in the metallic phase with the disordered system. In this work, we have employed thin films of IO (whose thickness is 60nm) produced by the magnetron-sputtering method on grass substrate. For those IO samples, the heat treatment (HT) has been carried out at 500°C and for 30min, in the atmosphere of N_2 or N_2 (90%) + H_2 (10%). It is found that the CE concentrations in the IO samples are almost independent on the temperature between 2.0K and 300K and $5 \times 10^{19} cm^{-3}$, $9 \times 10^{19} cm^{-3}$ and $1.2 \times 10^{20} cm^{-3}$, without the HT, with the HT in the atmosphere of N_2 and N_2 (90%) + H_2 (10%), respectively. Accordingly we note that all IO samples employed in this experiment are in the metallic phase. Generally speaking, the magneto-conductance (MC) of metallic thin films with the disordered system can be analyzed within the framework of the weak localization (WL) and anti-weak localization (AWL) theories. Main origin of the WL in the IO samples is believed to come from the scatterings of CEs by OVs. Previously, we reported on the magnetic-field induced two-to-three-dimensional-transition below 8T for the IO samples with the thickness of 10, 15, 45 and 60nm, through the experimental results obtained as functions of the temperature, the magnetic field, the azimuth of the magnetic field to the film surface, and the film thickness [1,2]. In this paper, we present experimental results concerning the effects of the HT for the IO samples in the atmosphere of N_2 or N_2 (90%) + H_2 (10%) on the electrical quantum transport related to the WL and the AWL.

[1] E-mail:kobori@konan-u.ac.jp

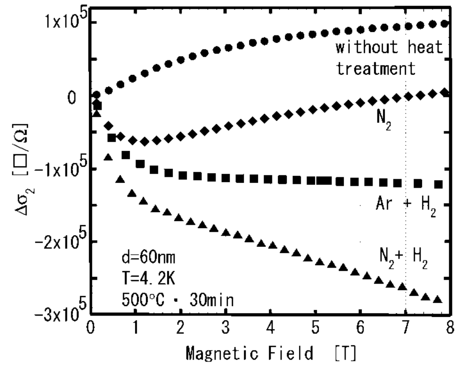

Fig. 1. The MC for the IO samples at 4.2K, without and with the HT.

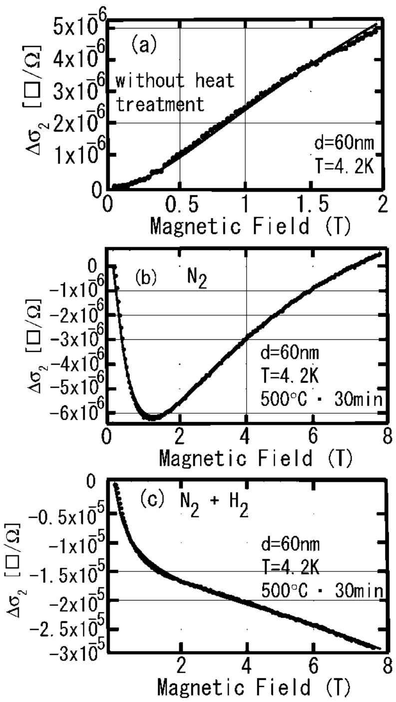

Fig. 2. Comparison between the experimental and theoretical results.

2. Results and Discussions

From the dependence of the electrical conductance on the temperature (<~30K), the magnetic field (<~2T) and the azimuth of the magnetic field to the film surface (0°~90°), we have found that CEs in the IO samples without and with the HT have the 2D nature. In this case, we note that the inelastic scattering length and the cyclotron diameter (36nm at 2T) are larger than the effective thickness that the CEs are really confined in the direction vertical to the sample surface (TCE). The TCE is regarded to be less than the sample thickness (60nm). Figure 1 shows the MC for the IO samples at 4.2K, without the HT, with the HT in the atmosphere of N_2 and N_2 (90%) + H_2 (10%), respectively, in the vertical configuration for the magnetic field direction and the sample surface. For comparison, we show the experimental results on the HT in the atmosphere of Ar (90%) + H_2 (10%). As seen in Fig.1, the MC for the IO samples without the HT exhibits only the WL effect, and not the AWL one. The AWL effect is most prominent for the IO samples with the HT in N_2 (90%) + H_2 (10%) gas. Here the temperature and time of the HT were 500°C and 30min. It is found that the HT in N_2 (90%) + H_2 (10%) gas brings forward the stronger AWL effect than that of Ar (90%) + H_2 (10%). Figure 2 shows the comparison between the experimental and theoretical results. We have employed the WL and AWL theories with respect to the 2D disordered electronic system given by Hikami-Larkin-Nagaoka [3,4]. The origin of the AWL effect is bound to the spin-orbit (SO) interaction due to interstitial indium atoms in the IO samples. We consider that the interstitial indium atoms are generated due to the removal of a fraction of oxygen atoms from the IO samples by the HT. In addition, we note that the electrical conductance of the IO samples with the HT drastically increases (up to ~4 times) compared to that without the HT, but the increase of the electron concentrations for them is only several ten percents. This indicates that the HT for the IO samples promotes the crystallization of a small amount of amorphous region in those sample. By means of the HT in the atmosphere containing H_2 gas, it is expected that the dangling bonds in the IO samples are terminated by hydrogen atoms. From the theoretical estimation by use of the fitting parameters, we have obtained that $L_\epsilon = 24.9$nm, $L_{SO} = 4.10 \times 10^4$nm and $\tau_\epsilon/\tau_{SO} = 0.02$ without the HT, $L_\epsilon = 65.6$nm, $L_{SO} = 25.0$nm and $\tau_\epsilon/\tau_{SO} = 1.62$ with the HT in N_2 gas, and $L_\epsilon = 138$nm, $L_{SO} = 10.2$nm and $\tau_\epsilon/\tau_{SO} = 3.67$ with the HT in N_2 (90%) + H_2 (10%) gas. Here L_ϵ and τ_ϵ are the inelastic-scattering-length and -time, and L_{SO} and τ_{SO} are the SO-scattering-length and -time, respectively. In the theoretical results, the spin-Zeeman effect is also included.

References

[1] N. Hatta, H. Kobori and T. Ohyama, Physica B, 298 (2000) 482.

[2] H. Kobori, M. Kawaguchi, N. Hatta, T. Ohyama and S. Ishida, Phys. Stat. Sol. (b)230 (2002) 277.

[3] S. Hikami, A. I. Larkin and Y. Nagaoka, Prog. Theo. Phys. 63 (1980) 707.

[4] Z. Ovadyahu, Phys. Rev. Lett. 52 (1984) 569.