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Effects of High-Energy Proton-Beam Irradiation on the Magnetic Properties of ZnO Nanorods

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1. Introduction

ZnO is a wide-band-gap semiconductor with many technological applications, including catalysis, gas sensing, and the fabrication of spintronics and microelectronic devices [1-3]. The geometric, electronic, and defect surface structures play a role in many applications of ZnO [1,2].

After many efforts to understand the key to triggering ferromagnetism in ZnO, defect-induced magnetism acquires a general consensus among the researchers. However, there are still many problem for the application due to its unstable magnetism state and too small magnetization values [1,2].

Here we investigate magnetic properties of ZnO nanorods after high-energy proton-beam irradiation. Electron spin resonance (ESR) measurement on temperature was made to identify intrinsic or extrinsic defects as well as to observe magnetic ordering after irradiation. Understanding the effects of proton beam irradiation on magnetic behavior may help to shed light on the mechanism responsible for the magnetic ordering in this material.

2. Methods

Znic acetate, $(CH_3COO)_2Zn{\cdot}2H_2O$, supplied by Aldrich, was used for the sample synthesis. The ZnO polycrystalline sample was prepared by sol-gel method from a water soluble zinc acetate precursor following previous works [3], the dried mixture being calcined for 8 h at 773 K. The obtained nanocrystalline powders were pressed into pellet disks of ~1.2 mm thickness and 10 mm diameter for proton beam irradiation. The ZnO nanorods were irradiated by 20-MeV proton beam under a fluence of 10^{12} cm^{-2} at Korea Multi-purpose Accelerator Complex (KOMAC). The trajectory profile as a function of depth was obtained using SRIM (stopping and range of ions in matter) simulation. ESR measurements were made in the temperature range of 5 K to 300 K by using a X-band ESR spectrometer. The magnetic susceptibility of ZnO nanorods before and after irradiation was recorded by using a superconducting quantum interference device (SQUID) magnetometer.

3. Results and discussion

3.1 SRIM simulation

The SRIM simulation for the trajectory profile along the target depth for 20 MeV H^+ ions in ZnO shows an ununiform distribution of the protons (Fig. 1). The simulation result shows that most of H^+ ions are implanted into the bottom of the disks [1]. It was calculated that ~7 % of irradiated H^+ ions are transmitted out of sample by simulation.

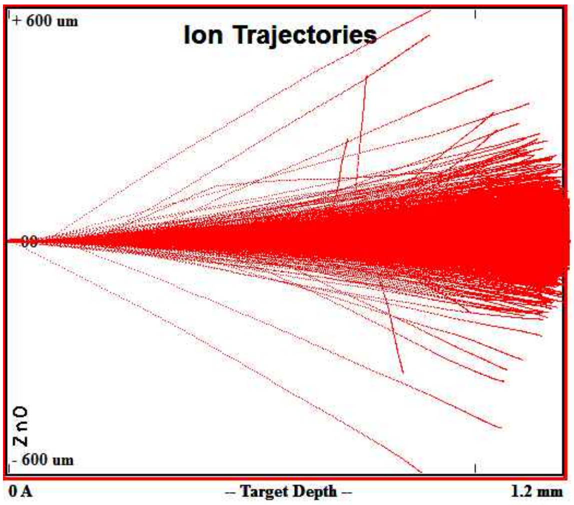

Fig. 1. SRIM simulation of projectory profile of incident H^+ ions along target depth in ZnO nanorods.

3.2 ESR spectra

Figure 2 shows ESR spectra for the samples before and after irradiation at room temperature. The spectra show two ESR resonance lines at g=2.003 and g=1.96 in both samples. It is reported that the signals at g=1.96 and g=2.003 arise from the hydrogen donor and oxygen vacancy with a single trapped electron, respectively [4,5]. Before irradiation emergence of signal of g=1.96 is attributed to intentionally doped hydrogen in the sample during synthesis [3]. The resonance frequencies and linewidths before and after irradiation remain to be unchanged, indicating no effects by irradiation. The spectrum after irradiation, however, shows a broad resonance line unlike the one before irradiation. The broad resonance line may arise from the fields made by magnetic ordering in the sample.

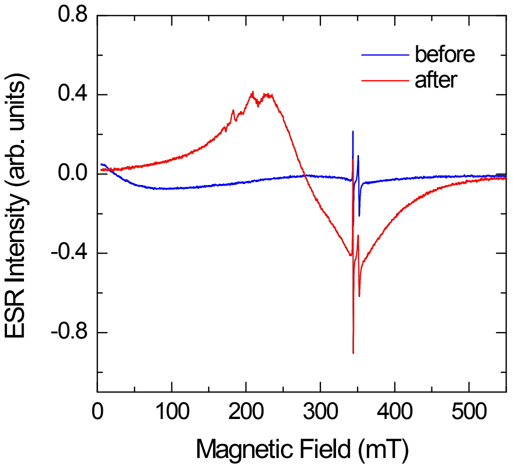

Fig. 2. ESR spectra for ZnO nanorods before and after irradiation with a fluence of 10^{12} cm^{-2} recorded at room temperature. Two narrow resonance lines of g=2.003 and g=1.96 correspond to those of lower and higher fields, respectively.

Figure 3 shows broad ESR line intensity as a function of temperature for the sample after irradiation. The ESR intensities obtained by fits with a Lorentzian line correspond to the magnetic susceptibilities. The behavior obtained evidences that there is a magnetic ordering in the sample. With decreasing temperature the resonance frequencies shift to the lower field, indicating ferromagnetic ordering in this temperature range.

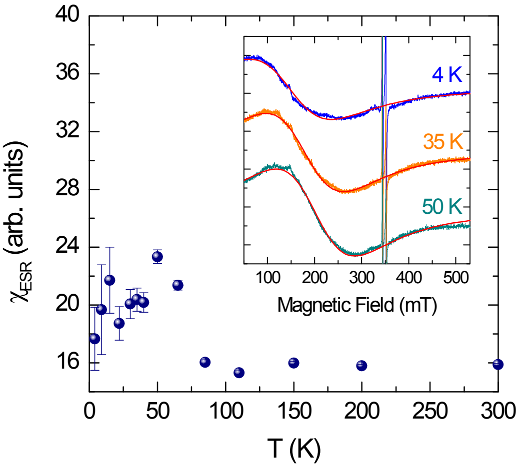

Fig. 3. Broad ESR line intensity for the sample after irradiation as a function of temperature. Inset shows the spectra at various temperatures as well as solid lines obtained by fits with a Lorentzian line.

3.3 SQUID data

In Fig. 4, the magnetic moment at 300 K of the samples before and after irradiation. Clear ferromagnetic hysteresis loops are observed at 300 K [1,2,6]. After irradiation the coercive field, H_C, increases from ~40 Oe to ~90 Oe compared to that before irradiation (see inset of Fig. 4). Meanwhile, the strength of ferromagnetic component is found to be suppressed in the sample after irradiation.

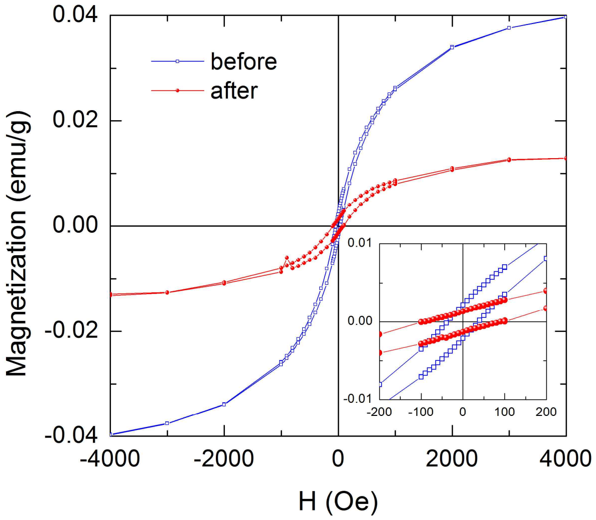

Fig. 4. Hysteresis loops for the sample before and after irradiation measured at 300 K. The diamagnetic linear backgrounds were subtracted from the measured signal in both samples. Inset shows the magnified portion of the hysteresis loops near origin.

4. Conclusions

We have investigated proton-beam irradiation effects on the magnetic properties of ZnO nanorods. After irradiation a broad ESR line is observed, indicating emergence of ferromagnetic ordering up to room temperature. In M-H curve, stronger coercive field is observed after irradiation.

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