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STRUCTURAL AND MAGNETIC PROPERTIES OF Si SINGLE CRYSTALS IMPLANTED WITH Mn

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Ferromagnetic ordering in silicon implanted with Mn^+ ions is of wide interest recently. This ordering is related to the structure of Mn-enriched near-surface layer in the implanted material (see, *e.g.*, Refs. [1-4]). Silicon-based diluted magnetic semiconductors would be the preferred spintronic materials due to existing technology used in Si-based microelectronics and wide availability of high quality Si single crystals. The aim of present work is to study an influence of the ferromagnetic phase Mn_4Si_7 created during annealing on ferromagnetic properties of Si:Mn.

Si(001) samples were implanted with 160 keV Mn^+ ions, to a dose, $D = 1\times10^{16}$ cm^{-2}. Si:Mn samples were processed for t_A = 1-10 h at up to T_A = 1070 K (HT) under ambient or enhanced hydrostatic pressures (HP), up to p_A = 1.1 GPa (see Table 1). To investigate the phase composition of thin polycrystalline layers created at processing, X-ray measurements were performed using coplanar 2θ scans in the glancing incidence geometry at W1 beamline of HASYLAB at DESY. The sample was fixed with the angle between monochromatic X-ray beam (wavelength λ = 1.54056 Å) and the sample surface equal to 1°. The detector moved parallel to the diffraction plane. Magnetic properties were studied by superconducting quantum interference device (SQUID) magnetometry using a Quantum Design MPMS XL. Two types of measurements, magnetization (*M*) vs. temperature (*T*) and *M* vs. field (*H*) were performed. The *M*(*T*) curves were obtained using zero-field-cooling/field-cooling (ZFC/FC) protocol at the constant field of 100 Oe.

Si:Mn sample	T_A [K]	t_A [h]	p_A [Pa]
1	920	10	1.1×10^9
2	720	10	1.1×10^9
3	1070	5	1×10^5
4	610	1	1×10^5

Table 1. Annealing conditions of Si:Mn samples.

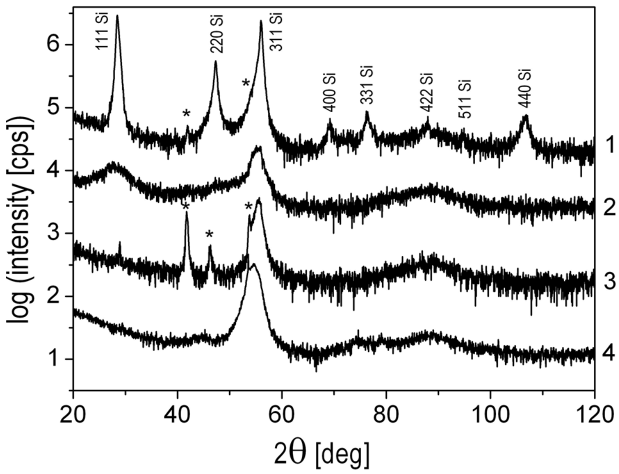

Figure 1. Coplanar 2θ scans measured using glancing incidence geometry for Si:Mn 1-4 samples (see Table 1). Diffraction peaks coming from Mn_4Si_7 phase are indicated by stars.

As shown in Fig. 1, the X-ray diffraction peaks from the ferromagnetic Mn_4Si_7 phase were detected mainly for the samples 1 and 3. The *M*(*H*) curves were recorded at 4 K, 150 K and 300 K (Fig. 2). Magnetic field was applied parallel to the sample surface for the both experimental procedures. Experimental curves have been modeled using the Preisach approach of magnetic response described by T. Song *et al*. [5].

Experimental magnetic curves, *M*(*H*) and *M*(*T*), possess diamagnetic background at the temperature range of 4–300 K caused by silicon host crystal. The diamagnetic background was approximated by a straight line for both experimental protocols and has been extracted from the original data in order to investigate magnetic response of pure magnetic component of SiMn. From these experiments, we can conclude that after annealing at temperature range of 570–1070 K under atmospheric pressure no significant magnetic response was observed in Si crystals implanted with Mn. However, HT-HP annealing affects in generation of magnetic particles (domains, clusters) with relatively high spontaneous magnetization of $(3–4)\times10^{-16}$ emu/particle and absolute concentration of $(5.8–8.3)\times10^{8}$ particles/mg. Surprisingly, average spontaneous magnetization and density of magnetic particles values decrease with the increasing of temperature during *HT-HP* annealing.

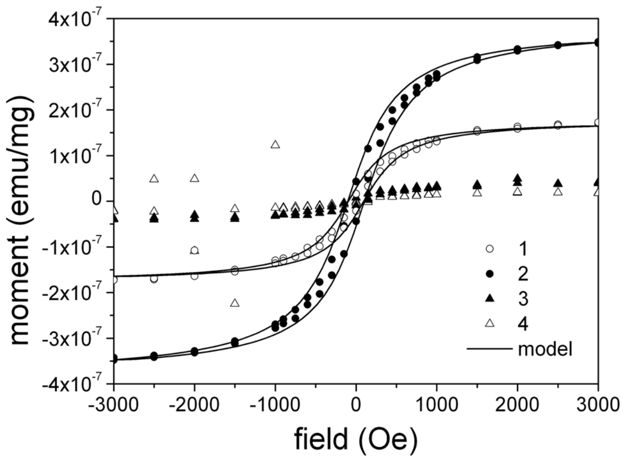

Figure 2. *M*(*H*) curves measured at 300 K for Si:Mn 1–4 samples (see Table 1).

From our experiments it follows that magnetic properties of samples are not directly related to formation of the Mn_4Si_7 phase. Probably some other defects created during processing are responsible for observed magnetic properties of samples.

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