

Magnetic properties of silicon crystals implanted with manganese

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Nowadays various technological approaches are proposed to increase Mn content in Si crystals. In this work we report the investigations of magnetic properties of silicon crystals grown by Czochralski method (CzSi:Mn) and by floating zone method (FzSi:Mn) implanted with Mn⁺ ions at substrate temperature $T_s \leq 340$ K (CzSi:Mn) or $T_s = 610$ K (FzSi:Mn). The SIMS analysis showed the presence of Mn atoms in the implanted Si crystals with projected range $R_p = 140 \pm 50$ nm, distribution width 100-200 nm and peak concentration of 10^{20} - 10^{21} cm⁻³. After implantation all the samples were annealed in a broad temperature range, $T_A = 500$ - 1400 K, under hydrostatic pressure, $HP = 1 \cdot 10^4$ bar in Ar atmosphere.

In this work we investigated the influence of parameters T_s , T_A and HP on the magnetic properties of Si:Mn crystals. The field and temperature dependence of magnetization

was measured in the temperature range $T = 5$ - 300 K in magnetic field up to 1000 Oe using superconducting SQUID magnetometer. The magnetic properties of Si:Mn were further studied by electron paramagnetic resonance (EPR) in the temperature range $T = 4.2$ - 300 K. Based on the magnetic properties we can divide these samples in two groups. To the first group we refer the samples characterized by the presence of ferromagnetic phase with weak temperature dependence of magnetization at temperatures up to 300 K what indicates high ferromagnetic Curie temperature (above 400 K) in these materials. The temperature dependence

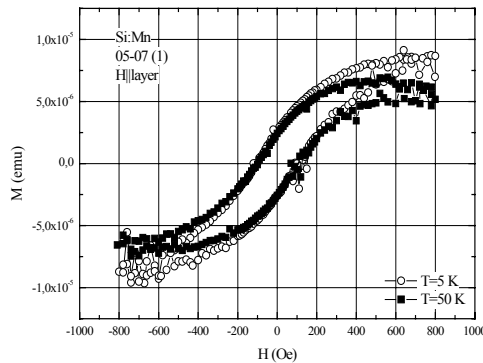


Fig. 1. Ferromagnetic hysteresis loops in Si crystals implanted with Mn.

of magnetization for the samples from the second group can be described as a sum of a Curie-Weiss paramagnetic contribution and a temperature independent ferromagnetic contribution. In Fig. 1. the temperature evolution of ferromagnetic hysteresis loop characteristic for the second group is presented. We established the implantation and annealing conditions for which the FzSi:Mn crystals exhibit ferromagnetic properties. For the CzSi:Mn crystals we were not able to determine such conditions. The key technological parameters determining the magnetic properties of Si crystals implanted with Mn are T_s and T_A .

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