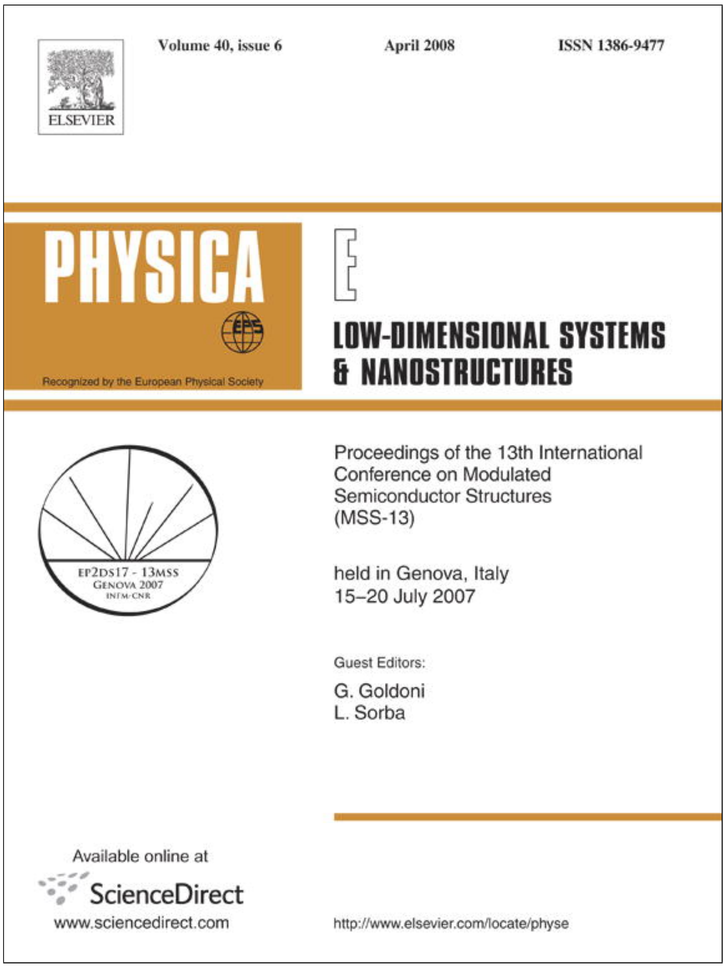

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# Magnetic properties of MnP nanowhiskers grown by MBE

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**Abstract**

MnP nanowhiskers have been grown by molecular beam epitaxy technique on the InP(1 0 0) surface. The measurements of the magnetization revealed that samples with MnP nanowhiskers exhibit ferromagnetic behavior up to room temperature. The investigation of temperature and angular dependences of ferromagnetic resonance has shown the existence of 90° anisotropy. The high values of coercive field and peak temperature obtained for the samples make it possible to consider such materials for potential applications in spintronic devices.


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*Keywords:* Nanowhiskers; Molecular beam epitaxy; Magnetic properties

## 1. Introduction

One-dimensional nanostructures have come to increasing attention due to wide variety of their properties [1,2]. Among them, nanowhiskers that can exhibit magnetic properties are worthy of notice because they can be potentially utilized for the investigation of fundamental magnetic properties of low-dimensional systems as well as for the fabrication of radically new spintronic devices.

Recently, various groups have reported on successful synthesis of different nanowhiskers which can show ferromagnetic properties [3–8]. One of the important parameters required on materials for the desirable functioning of the spintronic devices at room temperature range is a high ferromagnetic transition temperature. This demand can be met by MnP that apart from relatively high Curie temperature has a diversity of interesting properties [9]. MnP nanorods have been already synthesized via thermal decomposition of continuously delivered metal–phosphine complexes using a syringe pump [7].

Here, we report on the investigation of magnetic properties of the samples with self-assembled MnP nanowhiskers obtained by an alternative method which is based on using the molecular beam epitaxy (MBE).

## 2. Experimental

Nanowhiskers have been grown by MBE technique without any preliminary deposited metal catalyst on InP(1 0 0) substrates. In the growth procedure, conventional Knudsen cell was used for Mn evaporation. The temperature of cell was held at 650 °C. Tertiarybutylphosphine (TBP) was decomposed at 805 °C inside the cracking cell to obtain $P_2$ gas which was subsequently introduced to the main chamber at flow rates in the range from 2.0 to 2.3 sccm. Nanowhiskers were grown at 510 °C for 2 h.

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## 3. Results and discussion

As mentioned above, we do not use any catalyst for the growth of nanowhiskers. The so-called self-catalytic (or catalyst-free) method of the growth is of importance because it allows to avoid any contaminations of nanowhiskers from a metal catalyst. Scanning electron microscopy (SEM) has shown that nanowhiskers have diameters close to 150 nm, lengths up to 2 μm and seem to be oriented along crystallographic directions equivalent to ⟨0 1 1⟩ of the InP substrate (Fig. 1). The chemical composition of elements measured using energy-dispersive X-ray spectrometry has revealed that some of the nanowhiskers have more complicated structures containing, in addition to the MnP phase, an InP part despite the fact that our MBE apparatus does not contain any In supply source. It seems to be caused by the excess evaporation of In atoms from the InP substrate and their following absorption by MnP nanowhiskers that start to play a role of the catalyst.

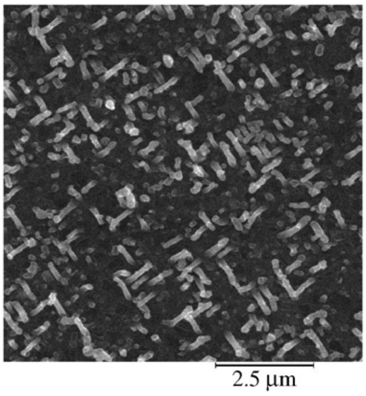


Fig. 1. SEM image of nanowhiskers.

The magnetic properties of the samples with nanowhiskers have been examined by measurements in a superconducting quantum interference device (SQUID). The temperature dependences of the magnetization demonstrate that the samples exhibit ferromagnetic properties up to room temperature (Fig. 2a). The common behavior of the magnetization curve is similar to that of bulk MnP. The Curie temperature of the samples is also found to be correlated with a value obtained in bulk MnP (~291 K). Besides, the samples have shown a high peak temperature, which was evaluated to be 260 K. The results of the measurements of the field dependences of magnetization shown in Fig. 2b demonstrate the presence of clearly resolved hysteresis loops up to 280 K. The value of coercive field ($H_c$), which persists up to 220 K, corresponds to 3000 Oe. Moreover, at low temperatures (see curve 3

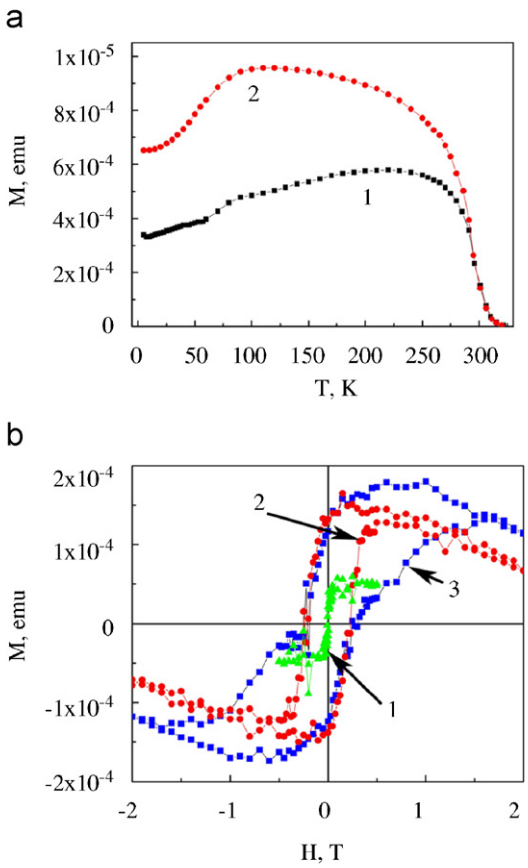


Fig. 2. (a) Temperature dependences of magnetization measured in an applied field of 100 Oe for the sample with MnP nanowhiskers after zero-field cooling (1) and field cooling (2). (b) Magnetic field dependences of magnetization measured at 295 K (1), 220 K (2) and 15 K (3).

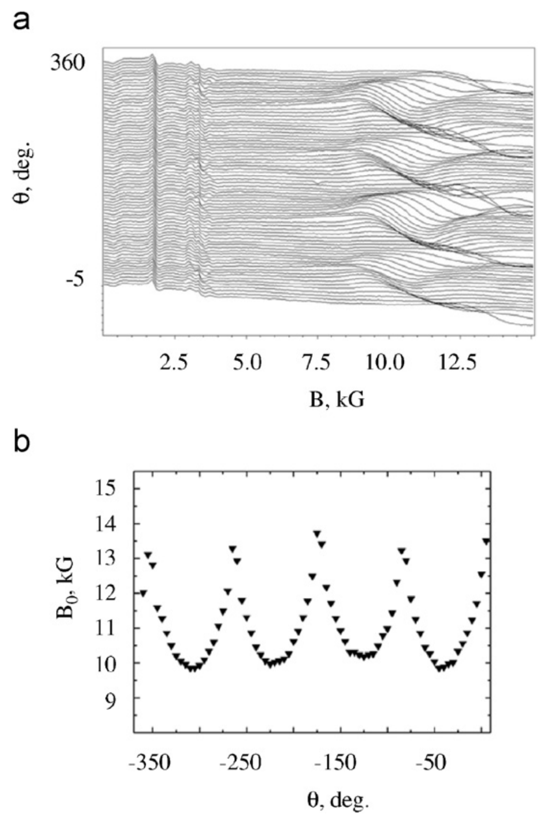


Fig. 3. Angular dependence of the FMR spectra at 250 K for the rotation of the magnetic field in the (0 1 1) plane of the InP substrate: (a) experimental spectra, (b) resonant field position as a function of the rotation angle $\theta$. $\theta = 0$ corresponds to the field normal to the (1 0 0) substrate surface.

in Fig. 2b) double-hysteresis-like loop was observed. The existence of additional coercive field equal to 7000 Oe is still unclear but can be a result of Mn doping of the InP matrix [10,11].

We have also registered the temperature and angular dependences of the ferromagnetic resonance (FMR) spectra in the X-band (9.38 GHz) in the temperature range from 120 to 420 K. The temperature dependence of the FMR signal intensity resembles that of the magnetization. An example of the angular dependence is given in Fig. 3. These data show a presence of 90° symmetry. The anisotropy decreases with increasing temperature and almost disappears at 310 K.

## Acknowledgments

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