Production of Mn_xGa magnetic nanoparticles for permanent magnets

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Large-scale applications of permanent magnets require high-temperature stability in many applications such as electric vehicles and wind turbines. The current state of the art for high performance magnets is NdFeB magnets. However, the supply chain for rare earth-based materials has known risks. Consequently, there is a market opportunity to develop alternative magnet technology that is not based on rare earths.

Mn-Ga compounds have attracted much attention in recent years as alternative materials to the rare earth permanent magnets. Mn-Ga alloys are among the few non-rare earth compounds which possess large magnetocrystalline anisotropy. Recently, much research has focused on improving the magnetic properties of the Mn-Ga system. However, hard magnetic phases are metastable and producing this magnet as a single phase has proven difficult. The complexity of the phase diagram (Fig. 1) illustrates that the synthesis of this metastable phase is difficult at normal conditions.

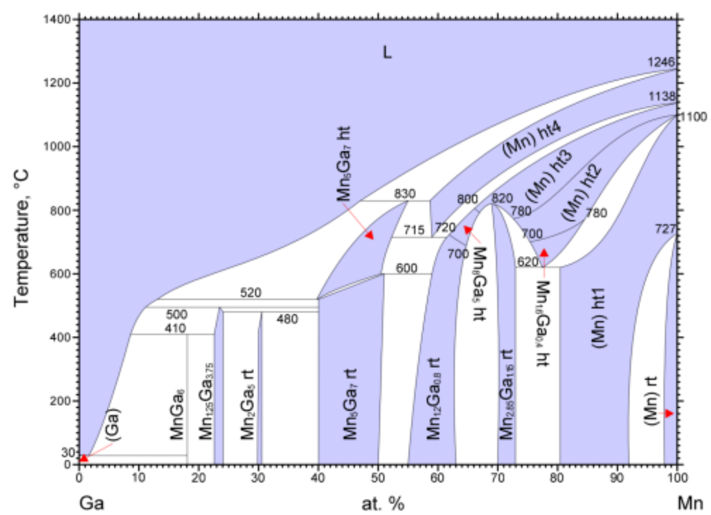

Fig. 1 Phase diagram for MnGa system

Mn-Ga alloys have different crystal structures and magnetic properties that depend on the Mn:Ga stoichiometry. Among all the compositions of Mn-Ga systems, MnxGa (x=2-3) are attractive due to the high magnetic properties which can be obtained. The two common phases of MnxGa alloys are the hexagonal (D019) and the tetragonal (D022) phases. The hexagonal phase is easily obtained by arc-melting while the D022 phase is obtained after annealing. At room temperature, the hexagonal phase shows antiferromagnetic order with a small magnetic moments, while the tetragonal D022 phase is ferrimagnetic or ferromagnetic, depending on the composition of the MnxGa crystal.

Nanofoundry proposes to develop a MnxGa (x=2-3) rare earth free magnetic material comprising a pure D022 phase. Research indicates potential magnetization (MS) of 50 emu/g and coercivity (HC) of 4 kOe for the Mn2Ga phase. A higher coercivity of 1T and small magnetization of 20 emu/g (Fig.1) should be obtained for the Mn3Ga phase. This will be achieved using arc-melting synthesis and a post-annealing process to produce the required hard magnetic phase structure D022.

There are few options for producing nanoscale MnXGa materials. The chemical process has not proven practical. In most permanent magnet alloys, small size powders are usually obtained by ball milling. However, such processes result in a large particle size distribution—in the range of microns. In the proposed work, we will investigate the possibility of obtain small grain size powders by using supercritical conditioning of the powder after the ball milling process. The process is illustrated in Fig. 3 below.

We further propose development of this class of materials with different compositions and magnetic phases on large scale using physical/chemical combined process techniques (Arc Melting, ball milling and supercritical conditions of liquids). We will use an Arc melting synthesis process to produce the initial phase, followed by a post-annealing process. We will use ball milling and supercritical conditioning to tune size distribution and magnetic properties.

The advantages of the process described here are that the resulting particles assume high magnetic anisotropy of $1x10^7$ erg/cm^3, the materials (Mn and Ga) are relatively abundant and therefore low cost, and the manufacturing process itself is sustainable, safe, and low cost.

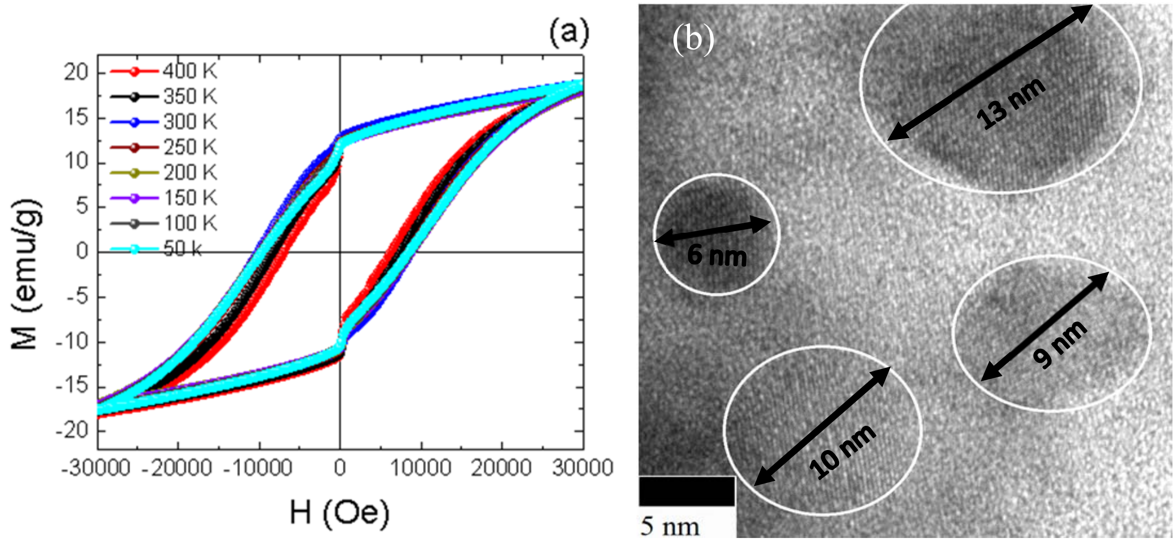

Fig. 2. Some Results for Mn3Ga particles: (a) Magnetization dependence on field at different temperature. (b) HRTEM image for the formed typical Mn3Ga particles.

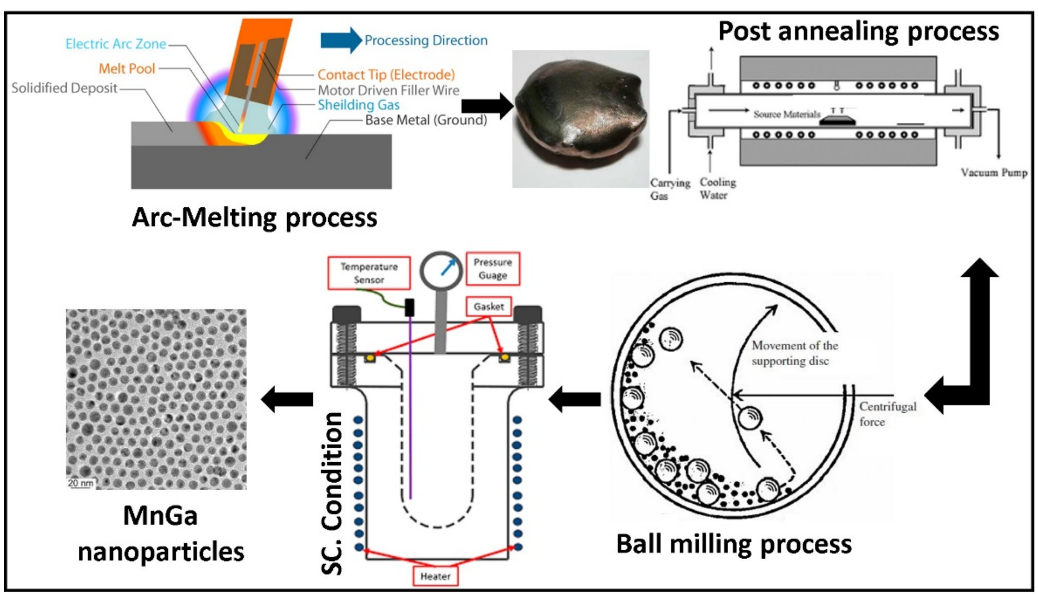

Figure 3: proposed process for materials production

1. Ahmed A. El-Gendy et al. Nanostructured Do22-Mn3Ga with high coercivity. J. phys. D: appl. Phys. 48(12), 125001, 2015.