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Surface modification of YIG by magnet array

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ABSTRACT

In this work, magnetostatic surface spin waves (MSSW) were propagated along the single crystal YIG ($Y_3Fe_5O_{12}$) film grown on GGG substrate. In order to obtain magnonic crystals, unlike the conventional methods, the surface of YIG films were magnetically modulated by magnet array in one and two-dimensions. The surface modulated YIG films formed sharp band gaps at approximately 6.55 GHz and 6.58 GHz at 1600 Oe magnetic field for one and two-dimensional magnonic crystals, respectively. It was found that a very small magnetic field change leads a large change in the peak value of band gap frequency.

1. Introduction

In recent years, considerable development of novel micro and nano sized materials with tuneable magnetic properties, making them promising candidates for the development of microwave information processing devices. Recently, many microwave information processing devices based on polycrystalline magnetic metals and alloys have been studied [1]. The very large intrinsic spin wave damping in such materials brings some technical problems such as spin wave excitation and reception and large damping does not allow propagation to be observed over distances more than a few tens of micrometres [2]. Among the various materials, yttrium iron garnet $Y_3Fe_5O_{12}$ (YIG) seems more appropriate material for microwave signal processing devices due to the very low spin wave damping.

Recently, the researchers have shifted to the area of magnetic field controlled devices in which magnetostatic spin waves (MSW) are used to store, carry and process information and this new research field is growing exponentially. MSW have been known since 1961 [3] but, they began to be used in the field of high-frequency microwave signal processing devices technology much later, mainly in connection with the discovery of YIG films. The YIG films based on MSW have been researched for decades because of their wide range of applications in the microwave, communication and magnetic detection areas such as delay lines, oscillators, filters, resonators, pulse separators, multi channel and compressive receivers, core devices in many microwave generators and analyzers, phase shifters and tuners in phased array radar systems and magnetic field sensors [4–6]. The main reason of attraction of YIG films is that the low magnetic loss, narrow ferromagnetic resonance line width, moderate value of saturation magnetization ($4\pi M_0 = 1750$ G) and low coercivity which are favourable for microwave devices [4]. In addition, low damping in YIG films allows spin-wave propagation to be observed over centimetre distances [5]. The production of high quality YIG thin film as spin-wave waveguides opened up new possibilities for the study of spin waves and spin waves dynamics. It has been discovered that the propagation of spin waves in a non-uniform magnetic media, which is called as magnonic crystal, is more interesting than uniform waveguides [7]. Magnonic crystals are a new class of materials which have a periodically modulated magnetic property where collective spin excitation (spin wave) can propagate. Magnonic crystals can exhibit wide magnonic band gaps in the spin wave dispersion. A periodic modulation of magnetic sample can create an artificial magnetic band structure with allowed and forbidden frequency regions as observed in the photonic crystals which are optical counterparts of magnonic crystals.

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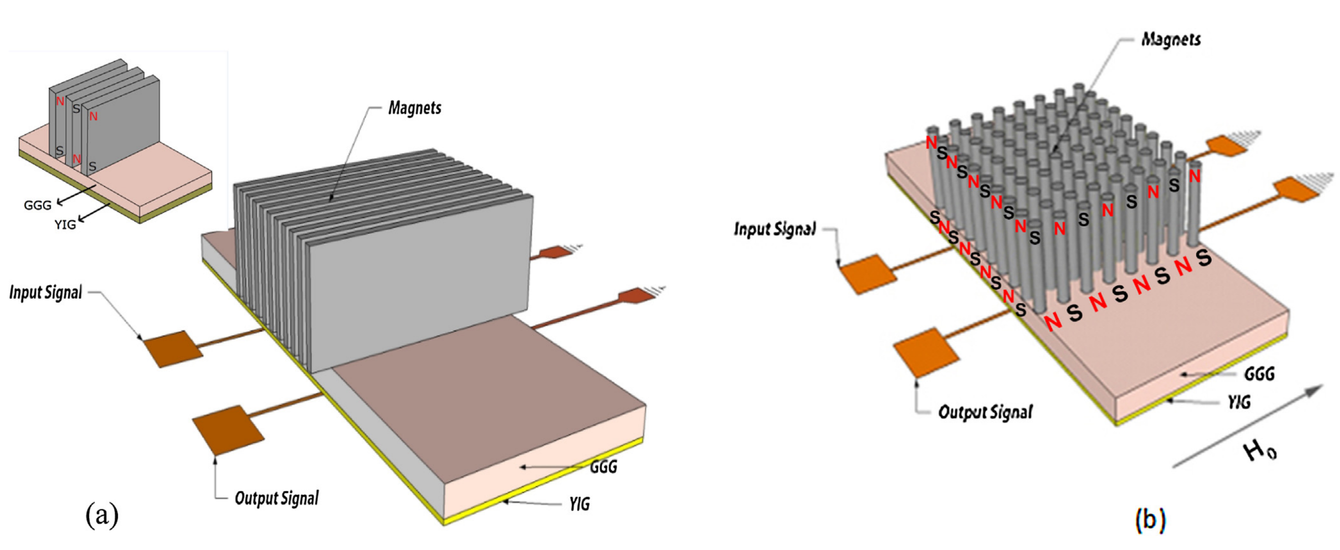

Fig. 1. The schematic illustration of magnonic crystals modulated by magnet array in (a) one-dimension, inset shows poles, and (b) two-dimension. Magnetic poles are displayed with S and N.

In the literature, many different methods of creating magnetic inhomogeneities in a spin-wave waveguide have been demonstrated [8–13]. Geometric structuring of a waveguide is the simplest method to fabricate a magnonic crystal such as arrays of macroscopic metallic stripes or dots, etched grooves or pits, periodic variation of the internal magnetic field and saturation magnetization were among the means for creating periodic magnetic structures [8–10]. However, above mentioned surface modification methods are irreversible and do not allow any adjustment or real time control. Another more general method is to alter the effective external magnetic bias in a localized region. This can be achieved via the magnetic field from a direct-current-carrying wire, placed in contact with the surface of a YIG waveguide [11–13]. The main disadvantages with this design are that, only one-dimensional magnonic crystals can be created and the large scale of the required applied current (0.25–1.25 A) make these types of magnonic crystals difficult for the practical use. Unlike other previous methods, Voronenko et al. [14] have employed a different method to create spatially periodic variation of magnetic field in a YIG waveguide by using utilized a high-coercivity magnetic tape recorded with a sinusoidal signal.

In this study, instead of previously reported magnetically surface modification methods, surface of YIG waveguide was modulated by magnet array in one and two dimensions. For both surface modulations, transmission characteristics were investigated in detail.

2. Experimental

Fig. 1 shows the schematic illustration of the one- and two-dimensional magnonic crystals composed of a rectangular shape with 5 mm wide, 20 mm long and 5 μm thick YIG single crystal film. As can be seen in Fig. 1 the film surface was modulated in two different ways. Fig. 1(a) shows the one-dimensional surface modulation made by magnet array. NdFeB (N50N) magnet was used to create magnet array, the remanence magnetization is about 14.5 kG, coercivity is 10.5 kOe and maximum energy product (BH_{max}) is 51 MGOe. The magnet thickness is 250 μm and distance between two magnets is 270 μm. Total 10 magnets were placed on the YIG film in one-dimension. The magnets are not in contact with film surface. The distance between magnets and film surface is about 0.8 mm. Fig. 1(b) shows the two-dimensional surface modulation made by magnet array. The magnet diameter is 300 μm and distance between two magnets is 300 μm. Total 10 × 8 magnet bars were placed on the YIG film in two-dimensions. It was easy to form one dimensional magnet array, first the poles of magnets were found and then magnets were positioned as shown in Fig. 1a. In the positioning process a paper in the magnet size was placed between the magnets manually, later this array was taped to hold all magnets together. Finally, the magnets were position as shown in Fig. 1a. For two dimensional magnet arrays, we have used a home-made micro drilling system, which can make holes with diameter 100 μm or higher with a 1 μm resolution. The system is controlled by a computer and desired hole-array can be made automatically. Then the rod shape magnet were placed in these holes and then glued.

Two micro strip antennas with 50 μm widths were placed symmetrically on to the both ends of the periodic array to excite and detect MSWs. The distance between antennas was 8 mm. A network analyzer connected to the input and output antenna was used to measure the spin wave transmission curves. External magnetic field applied by an electromagnet along the sample width direction.

3. Results and discussion

Fig. 2(a) and (b) shows the surface magnetic field profile for one and two-dimensional magnonic crystals, respectively. The surface magnetic field profiles for one and two-dimensional magnonic crystals were determined from solutions of magnetostatic Maxwell equations by using finite element method (FEM). The surface profiles were simulated using magnetic fields, no current interface in AC/DC module of COMSOL multiphysic software. The magnet array were plotted in three dimensions and placed in a limited domain. The calculations were carried out by choosing the domain boundaries as magnetic insulator. In this way, magnonic crystals which have periodical surface magnetic field modulation were obtained by using magnets in one and two-dimensions.

Three distinct classes of MSW can be excited and propagate in a thin magnetic waveguide depending on the angle between the wave propagation direction and the external magnetic field orientation [5] called as Forward Volume Magnetostatic Spin Waves (FVMSW), Backward Volume Magnetostatic Waves (BVMSW) and Magnetostatic Surface Spin Waves (MSSW). Unlike the FVMSW and BVMSW, MSSW is localized on the surface of the film in where they propagate. The earlier studies have showed that MSSW is more