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MAGNETIC AND ACOUSTIC EXCITATIONS IN CONFINED NICKEL NANOWIRES

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Abstract. The magnetic and vibrational excitations of periodic arrays of Ni nanowires, in 1μm-thick Al_2O_3 membranes on Al substrates, have been investigated by Brillouin scattering. Ni nanowires of 30 and 40 nm diameter and periodicity of 100 nm have been studied in a transverse magnetic field from 0-0.4 T. The *p-s* polarized spectra feature three peaks, with Brillouin frequencies below 20 GHz, and whose intensities are strongly dependent on the applied magnetic field and whose Stokes/anti-Stokes intensity ratios are unequal. These results indicate that the three peaks are magnetic in origin. A surface acoustic wave on the Ni-filled Al_2O_3 structures is also observed in *p-p* polarized spectra, with a phase velocity of about 3400 m/s for the 30nm-diameter nanowire sample.

1. INTRODUCTION

Nanoscale structures have attracted much interest recently owing to their potential use in high-density magnetic memories [1,2] and optical media [3]. The magnetic nanowire arrays in highly-ordered alumina templates [4,5] show promise as high-density storage materials. Therefore, investigation into their magnetic, optical and other properties is of fundamental interests.

Surface Brillouin scattering has been successfully applied to the study of magnetic excitations, as well as acoustic waves in both bulk and thin-film magnetic structures over the last two decades. For instance, the acoustic [6] and magnetic properties [7] of polycrystalline Ni as well as supported thin Ni films [8,9], have been studied by Brillouin scattering. However, the novel structure of the recently-developed Ni nanowires [4,5] is drastically different from bulk Ni or thin Ni films in that, the dimensionality of the system has been lowered. As has been shown previously for semiconductors, two-dimensional confinement in nanostructure introduces novel physical effects [10].

The present Brillouin study of periodic arrays of Ni nanowires, in 1μm-thick Al_2O_3 membranes on Al substrates, has interestingly revealed three bulk spin waves and one surface acoustic wave propagating on the surface of the sample.

2. EXPERIMENT

Hexagonally ordered porous alumina membranes have been prepared via a two-step anodization process on Al substrates [11,12]. Nickel was electrodeposited from aqueous electrolytes at the pore tips of the resulting high aspect-ratio porous alumina structure. Scanning electron micrographs of the resulting membranes revealed that they have a thickness of about 1 μm and a pore spacing of 100 nm, with respective pore diameters of 30 and 40 nm.

Brillouin spectra were recorded in the 180°-backscattering geometry using a JRS Scientific Instruments (3+3)-pass tandem Fabry-Perot interferometer and the 514.5 nm line of an argon-ion laser. The experiments were carried out in an air ambience at room temperature. A stream of pure, dry argon gas was directed at the irradiated spot on the sample to cool it and to keep the air away from it. The magnetic field $\boldsymbol{B}$ (0–0.4 T), generated by a computer-controlled GMW 3470 electromagnet, was applied perpendicular to the axes of the nanowires

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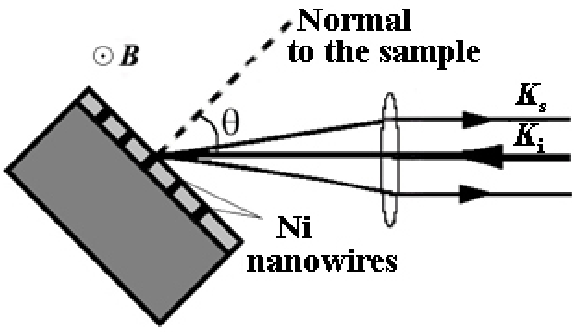

Fig. 1. Schematics of scattering geometry in the scattering plane. The magnetic field *B* was applied perpendicular to the axes of the nanowires and the scattering plane.

and the scattering plane (see Fig. 1). The incident light wave vector $\boldsymbol{k}_i$ made an angle θ with the sample surface normal and the backscattered light was collected from within a solid angle of 0.2 steradian around $-\boldsymbol{k}_i$. The incidence angle θ was varied between 30° and 75°. Wave vector conservation on the surface requires that the light interacts with surface acoustic phonons with a wave vector of magnitude $q = 2k_i \sin\theta$. Measurements were made in the *p-p* and *p-s* polarization configurations, with a typical data acquisition time of eight hours.

3. RESULTS AND DISCUSSIONS

Fig. 2 shows *p-s* polarized Brillouin spectra, recorded at incidence angle θ = 45°, of a 30nm- diameter Ni nanowire sample in applied magnetic fields of 0.04 and 0.40 T respectively. At magnetic fields below 0.04 T, three Brillouin peaks due to magnons were observed. The peaks in the Stokes spectrum are labeled as S_1, S_2 and S_3 while, the corresponding anti-Stokes ones, A_1, A_2 and A_3 respectively. With increasing magnetic field, the lowest-frequency peak (S_1) shifts up slightly in frequency while the center one (S_2) shifts down slightly in frequency. At $B \approx 0.3$ T, these two peaks merge into one broad and intense peak. On raising the magnetic field, the combined peak increases in frequency with increasing magnetic field. In contrast, the frequency of the highest-frequency weak peak (S_3) is almost independent of the applied field.

As the nanowire diameter (30 or 40 nm) is much shorter than the wavelength (≈ 360 nm) of the surface spin waves, the presence of Damon-Eshbach surface spin waves is not expected on the ends of the Ni nanowires. This is consistent with the fact that no one peak appears on only the Stokes (or anti-Stokes) side of the spectrum [13] (see Fig. 2). Thus the three Brillouin peaks observed are ascribed to bulk magnons.

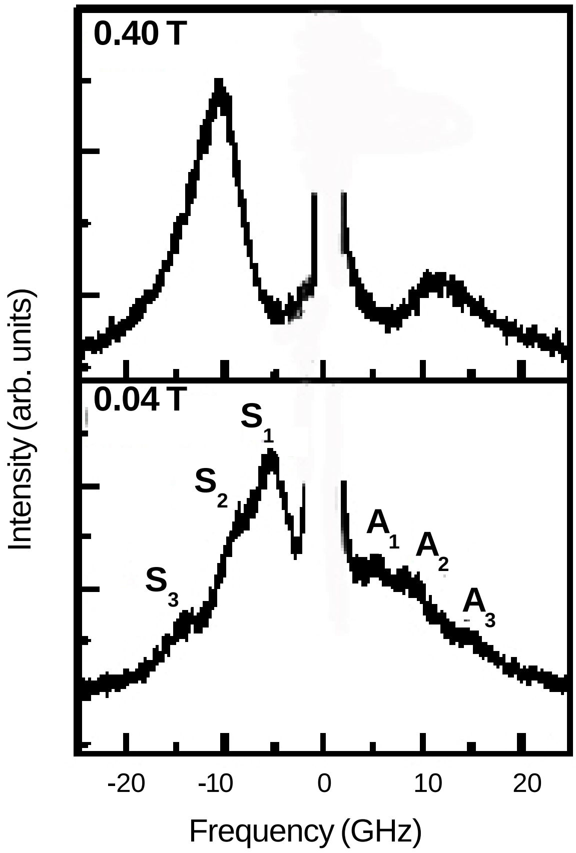

Fig. 2. *p-s* Brillouin spectra, recorded at incidence angle of 45° and different magnetic fields, of 30nm-diameter Ni nanowires in Al_2O_3 membrane on an Al substrate.

Fig. 3 shows the *p-p* polarized Brillouin spectra, recorded at θ = 60°, of the 30nm- and 40nm- diameter nanowire samples. Each of the spectra contains a sharp Brillouin peak, with that of the 30nm-diameter nanowire sample having the higher frequency. No other peak was found in the *p-p* polarization. The sharp peak is attributed to the surface Rayleigh wave, which propagates on the sample surface and is polarized in the sagittal plane. Its frequency is linearly proportional to sinθ, which is characteristic of a true surface wave. We estimate that the phase velocity, V (= $\lambda\nu/2\sin\theta$), of the Rayleigh wave is 3400 m/s, for the 30nm-diameter nanowire sample. This value is higher than the Rayleigh wave velocity of ≈2500 m/s for bulk Ni [6] but lower than that (≈5500 m/s) for amorphous Al_2O_3 [14]. Interestingly, an increase in the nanowire diameter from 30 nm to 40 nm results in a slight decrease of about 380 m/s in the Rayleigh wave ve-

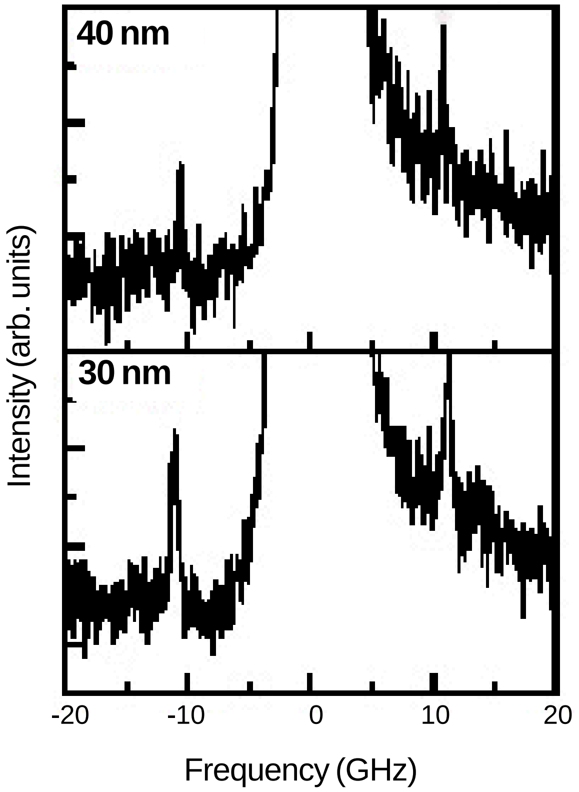

Fig. 3. The *p-p* Brillouin spectra, recorded at incidence of 60° and zero magnetic field, of 30nm- and 40nm-diameter Ni nanowires in Al_2O_3 membranes on Al substrate.

locity. The velocity of this wave approaches that of bulk Ni as the nanowire diameter becomes increasingly large.

4. CONCLUSION

We have successfully used Brillouin backscattering to investigate the magnetic and acoustic excitations in respective periodic arrays of 30nm- and 40nm-diameter Ni nanowires, in 1μm-thick Al_2O_3 membranes on Al substrates. Three bulk magnons, whose intensities were strongly dependent on the magnitude of the transverse applied magnetic field, were found. The existence of the Rayleigh mode was detected on the surface of the Ni-filled Al_2O_3 membranes.

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REFERENCES

[1] D. Al Mawlavi, N. Coombs and M. Moskovits // *J. Appl. Phys*. **70** (1991) 4421.

[2] F. Li, R. M. Metzger and W. D. Doyle // IEEE *Trans. Magn.* **33** (1997) 3715.

[3] E. Wackelgard // *J. Phys. Condens. Matter* **8** (1996) 5125.

[4] K. Nielsch, F. Muller, A-P. Li and U. Gosele // *Adv. Mater.* **12** (2000) 582.

[5] K. Nielsch, R. B. Wehrspohn, J. Barthel, J. Kirschner and U. Gosele // *Appl. Phys. Lett.* **79** (2001) 1360.

[6] J. R. Sandercock // *Solid State Commun.* **26** (1978) 547.

[7] J. R. Sandercock and W. Wettling // *J. Appl. Phys*. **50** (1979) 7784.

[8] H. Sato, A. Yoshihara, A. Yamaguchi, M. Shinosaka, K. Kameyama, H. Nakajima and H. Fujimori // *Jpn. J. Appl. Phys.* **36** (1997) 3324.

[9] L. Giovannini, O. Donzelli, J. M. V. Ngaboyisonga, F. Nizzoli, G. Carlotti, G. Gubbiotti, G. Socino, L. Pareti and G. Turilli // *J. of Magn. Magn. Mater.* **198-199** (1999) 366.

[10] D. J. Lockwood, P. Hawrylak, P. D. Wang, C. M. Sotomayor Torres, A. Pinczuk and B. S. Dennis // *Phys. Rev. Lett*. **77** (1996) 354.

[11] A. P. Li, F. Muller, A. Birner, K. Nielsch and U. Gosele // *J. Appl. Phys*. **84** (1998) 6023.

[12] A. P. Li, F. Muller, A. Birner, K. Nielsch and U. Gosele // *Adv. Mater.* **11** (1999) 483.

[13] F. Grunberg and F. Metave // *Phys. Rev. Lett*. **39** (1997) 1561.

[14] P. D. Warren, C. Pecorari, O. V. Kolosov, S. G. Roberts and G. A. D. Briggs // *Nanotechnology* **7** (1996) 295.