Magnetic Composite Electrodeposition of Hard Magnetic Materials for Magnetic MEMS Applications

Shan Guan, Karl Vollmers, Bradley J. Nelson
Department of Mechanical Engineering,
University of Minnesota-Twin Cities,
Minneapolis, MN 55455

Recent years have witnessed the rapid development of electrodeposition for fabricating MEMS devices. However, it is still difficult to electrodeposit hard magnetic materials with a high $(BH)_{max}$ and a strong coercivity field (H_c) to generate a large but stable magnetic torque for microstructure actuation. The existing electrodeposited CoNiP or CoPt hard magnetic films cannot generate enough force for a long distance movement of a magnetic microactuator.

We proposed a new technique of magnetic composite electrodeposition (MCE) for producing hard magnetic particles-metal matrix composite materials. The hard magnetic particle used in MCE technique is $BaFe_{12}O_{19}$ with a diameter of about 1~4 µm. The matrix metals were electrodeposited from a nickel plating electrolyte (EP Nickel), an electroless nickel plating electrolyte (EN Nickel) and a CoNiMnP plating electrolyte. The $BaFe_{12}O_{19}$ particle has a B_r of 2.45~2.58KG and an H_c of 3.2~3.8KOe. It cannot be electrodeposited from an aqueous electrolyte, but can be deposited by the MCE technique we proposed.

The particles were pre-treated by stirring them in a solution containing surfactants, and then, this solution with particles was added to a metal matrix electrolyte for magnetic composite electroplating under a moderate agitation. The plating substrates are p-type <100> silicon wafers with RF-sputtered electrical contact seed layers of Ti/Au or Ti/Cu. SEM images showed that particles were incorporated into all metal matrices (Figure 1 for an example). The material composition of the particle embedded in composite films was detected by EDS. Hysteresis loops of metal matrices (without particles) and composite materials were measured by a vibrating sample magnetometer (VSM). The results showed that perpendicular magnetic properties of composite materials have been improved greatly (Table 1).

These results proved the feasibility of MCE technique in fabricating excellent hard magnetic materials for MEMS applications. In these composite materials, the particles and metal matrices are in separated phases, so M_s of the composite materials can be expressed as $M = M_pW_p + M_mW_m$ with W_p and W_m denoting weight fraction of the particle and the metal matrix phase, respectively. M_p and M_m are the corresponding magnetization. As can be seen, more particles incorporated into the metal matrix will increase the corresponding saturation magnetization. Through the MCE technique, hard magnetic materials with excellent magnetic properties can be obtained by increasing the magnetic particle incorporation fraction in the composite films.

In conclusion, MCE has the potential of becoming an important technique compatible with the magnetic MEMS fabrication.

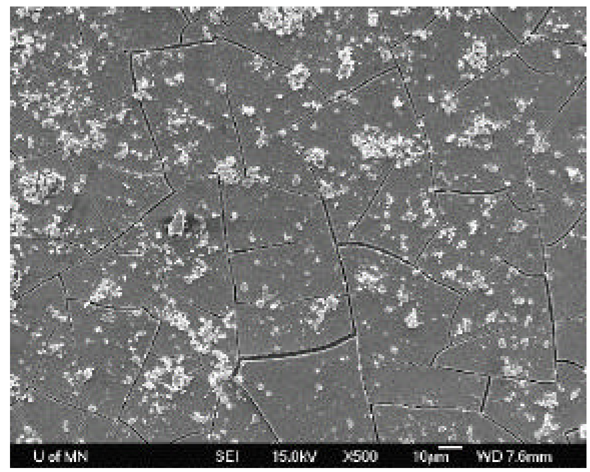

Figure 1.An $BaFe_{12}O_{19}$-CoNiMnP composite film with magnetic particle clusters.

Table 1. A comparison of perpendicular magnetic properties of metal matrices and magnetic composite materials

Film (Metal matrix)	Film (Particles)	H_c (Oe)	B_r (kG)	B_s (kG)	$(BH)_{max}$ (kJ/m^3)
EN Ni	/	65~80	0.05~0.1	0.15~0.24	/
	$BaFe_{12}O_{19}$	205~480	2.5~3.4	4.7~4.9	1.4~1.8
EP Ni	/	100~150	2.5~3.0	6.8~7.0	0.5~0.8
	$BaFe_{12}O_{19}$	160~240	4.8~6.0	13~14	0.7~1.1
EP CoNiMnP	/	800~1700	0.8~1.0	4.5~6.0	2.0~2.6
	$BaFe_{12}O_{19}$	960~1830	3.2~4.9	9.3~11.8	7.2~8.0