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Research articles

# Growth mechanism and magnetic properties of Co nanowire arrays by AC electrodeposition

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ABSTRACT

Co nanowire arrays with diameters of 25 nm, 50 nm and 75 nm were prepared in pores of anodic aluminum oxide (AAO) templates via an AC electrodeposition technique. Filling rate of Co nanowires in the pores of AAO template was studied at various voltages. Studies showed that Co nanowire can be full of the pores of AAO template at high voltage, which suggested a two dimensional (2D) titled plane growth mode for Co nanowire growing up by AC electrodeposition technique. The growth process of Co nanowires was illustrated in detail. Theoretical analysis indicated that thermodynamic factor was responsible for the filling rate of Co nanowires in the pores of AAO template. The magnetic behaviors of Co nanowire arrays with varying diameters were investigated at room temperature. The results have confirmed that coercivity ($H_c$), remanent magnetization ($M_r$) and squareness (SQ), measured along wire axis, decrease with increasing of Co nanowires diameter. Moreover, the SQ of Co nanowire arrays with diameter of 25 nm was much higher than those of others in this direction. It can be attributed to both the magnetostatic coupling among the wires and the arrangement of Co grains in the AAO pores. This work will be beneficial for a magnetic media with perpendicular anisotropy to allow a smaller bit size and increase the recording density.

## 1. Introduction

Smaller sensors, actuators, and improved data-storage densities have been the public demand and have motivated researches to reduce the size of components [1]. In particular, special attention has been focused on one dimensional ferromagnetic material such as nanowires to address not only fundamental physical questions, but also for technological reasons, owing to the potential applications in production of magnetic information carriers [2–4], biomedical materials, sound sensors and gas detectors [5–8], as well as diodes and transistors in electronics [9].

To obtain well-aligned various metals or alloys nanowire arrays [10–13], porous and ordered alumina layer turns out to be a useful template. AAO template-based electrodeposition is widely adopted for its preferable insulativity, chemical and heat stability, and the convenient, versatile and inexpensive characteristics. Metals with magnetic properties like Fe, Co, Ni, and their alloys can be built into AAO pores in the process of cathodic deposition from solutions of appropriate composition [14–17]. However, diameter of the nanowires was single due to the limit of pores size in AAO. Particularly, growth process for nanowires fabricated by an AC electrodeposition technique was rarely reported. Although intensive research has been devoted to understanding the magnetic properties of nanowire arrays in terms of coercivity and remanence, to date, experimental research on diameters dependent magnetic properties of nanowire arrays embedded in the pores of AAO has been almost neglected. Herein, we take Co as an example to firstly elaborate the growth mechanism of nanowire arrays by AC electrodeposition technique. Magnetic property of the Co nanowire arrays with different diameters was then discussed. This work will benefit the understanding of the growth mechanism and magnetic property of ferromagnetic nanowire arrays by AC electrodeposition.

## 2. Experimental details

The AAO templates are fabricated as follows: a high-purity (99.999%) aluminum (Al) foil was thermally treated in an argon atmosphere at 400 °C for 2 h and then brought to room temperature. Next, the heat-treated Al foil was electropolished in a mixed solution of $C_2H_5OH$ and $HClO_4$ (ratio by volume 4:1) for 5 min to smooth the surface. To obtain highly ordered pores, a two-step anodization was used. In the first step, the Al foil was anodized at 5 °C in oxalic acid electrolyte for about 6 h. 45 V DC, 0.3 and 0.5 M concentrations, and

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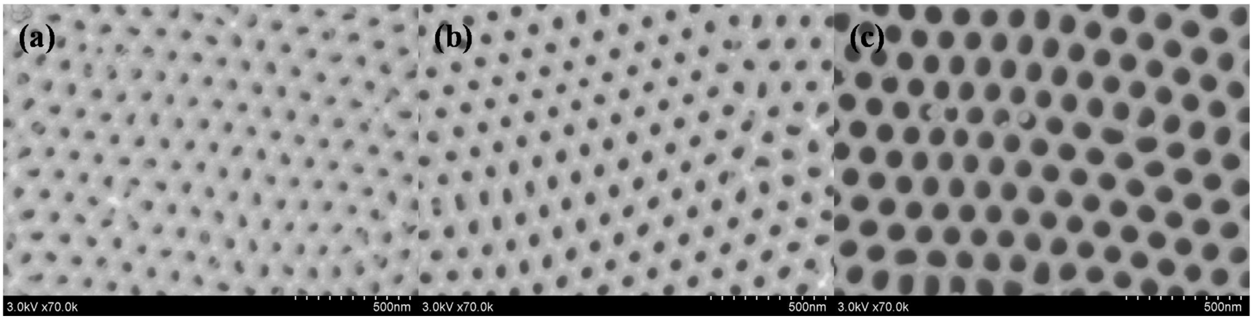


**Fig. 1.** SEM images of AAO prepared in oxalic acid electrolyte with different concentrations and voltages (a) 0.2 M, 30 V (b) 0.3 M 45 V and (c) 0.5 M 45 V.

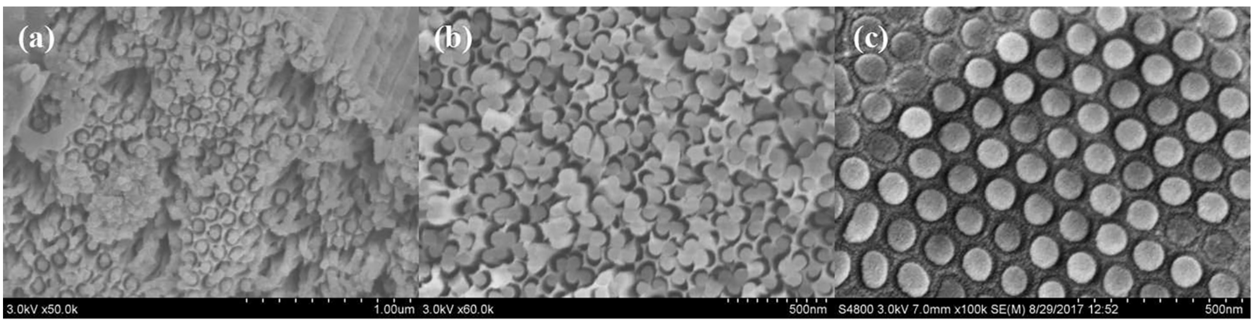


**Fig. 2.** SEM images of Co nanowires using AAO with pore size of 75 nm and prepared at different AC voltages (a) 10 V (b) 15 V (c) 20 V.

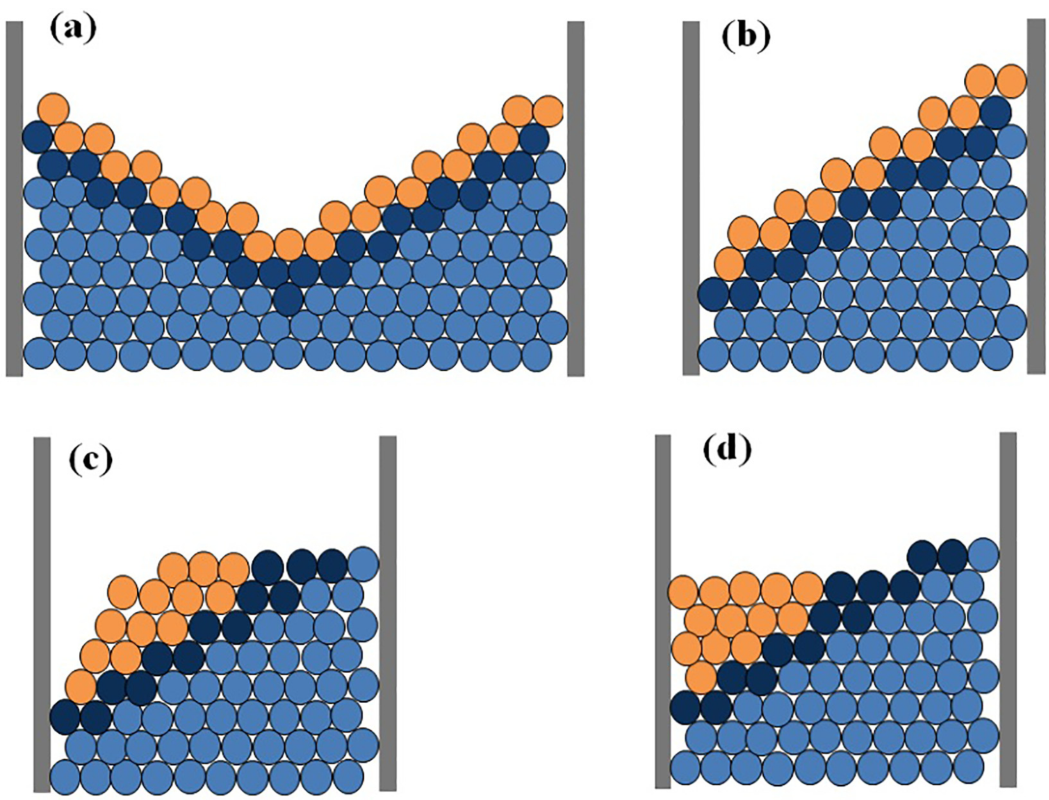


**Fig. 3.** Schematic representation of growth process (a) and (b) nanowires tip with a shape of shallow pan and title plane the cathodic half-cycle of the AC, (b) and (c) rearrangement of the nascent atoms at the tip of nanowires with a low and fast rates at the anodic half-cycle of the AC. The orange atoms represent the nucleus center at tip of nanowires, the dark cyan atoms represent the growth front and the growth plane of the nanostructure.

30 V DC, 0.2 M concentration were employed respectively. The resulting aluminum oxide layer was then removed by immersing the anodized Al into a mixed solution of 0.4 M chromic acid and 0.6 M phosphoric acid (ratio by volume 1:1) at room temperature. Subsequently, the samples were reanodized at the same conditions as the first step. To make the barrier layer thin, at the end of the second step, the anodization voltages were step-decreased to 15 V at a rate of 5 V/min. Finally, AAO templates with different diameters in range of