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Glancing angle deposition of Fe triangular nanoprisms consisting of vertically-layered nanoplates

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ABSTRACT

Fe triangular nanoprisms consisting of vertically-layered nanoplates were synthesized on Si substrate by glancing angle deposition (GLAD) with an electron beam evaporation system. It was found that Fe nanoplates with a crystallographic plane index of BCC (110) were stacked vertically to form triangular nanoprisms and the axial direction of the nanoprisms, BCC ⟨001⟩, was normal to the substrate. The effects of experimental parameters of GLAD on the growth and morphology of Fe nanoprisms were systematically studied. The deposition rate played an important role in the morphology of Fe nanoprisms at the same length, the deposition angle just affected the areal density of nanoprisms, and the rotation speed of substrate had little influence within the parameter range we investigated. In addition, the crystal growth mechanism of Fe nanoprisms was explained with kinetically-controlled growth mechanism and zone model theory. The driving force of crystal growth was critical to the morphology and microstructure of Fe nanoprisms deposited by GLAD. Our work introduced an oriented crystal structure into the nanomaterials deposited by GLAD, which provided a new approach to manipulate the properties and functions of nanomaterials.

1. Introduction

Nanowires have shown unique optical, magnetic, and electrical properties and have a lot of applications in the fields of energy conversion, magnetic recording, photonics, bio-sensors and etc. [1–13]. Among which, Fe nanowires have demonstrated a great potential in perpendicular magnetic recording, microwave devices, and catalytic precursors [14–18].

Recently, exploring novel nanostructured nanowires has attracted considerable attention in order to tune or improve the properties of nanowires. Helical, polygon and many other nanostructures were synthesized by techniques including lithography, electrodeposition in templates, glancing angle deposition (GLAD) and etc. [19–23] Among these methods, GLAD has attracted much interest. GLAD or oblique angle deposition (OAD) is a physical vapor deposition method of depositing materials at a highly oblique angle (usually larger than 75° away from the substrate normal) [22,24–26]. GLAD usually entails electron beam bombardment, which uses a collimated vapor flux to induce a ballistic shadowing effect to synthesize various nanostructures. In conventional GLAD processes, there are three crucial parameters that determine the morphology of nanostructures: deposition rate, deposition angle, and rotation speed of substrate. Specific combination of these parameters corresponds to helical, polygon or other nanostructures [22,24–26]. For instance, Liu et al. used GLAD to fabricate arrays of Fe pillars, helices, and posts. [27] LaForge et al. introduced ⟨111⟩ fiber texture and in-plane texture to Fe nanowires by GLAD [28] and deposited a vertical nanoarray with a faceted, tetrahedral apex.

In this work, we reported a new type of Fe nanowires synthesized by GLAD, which were triangle nanoprisms consisting of vertically layered nanoplates. We observed the microstructure and crystal orientation of Fe nanoprisms by high-resolution transmission electron microscopy and grazing incidence X-ray diffractometry. We also investigated the influence of deposition rate, deposition angle, and rotation speed of substrate on the growth and morphology of Fe nanoprisms and found that the deposition rate played an important role in the morphology of Fe nanoprisms at the same length, the deposition angle affected the areal density of nanoprisms, and the rotation speed of substrate had little influence within the parameter range we investigated. We analyzed the crystal growth mechanism of the Fe nanoprisms with kinetically-controlled growth mechanism and zone model theory. The experimental results were very consistent with the proposed growth mechanism for Fe nanoprisms.

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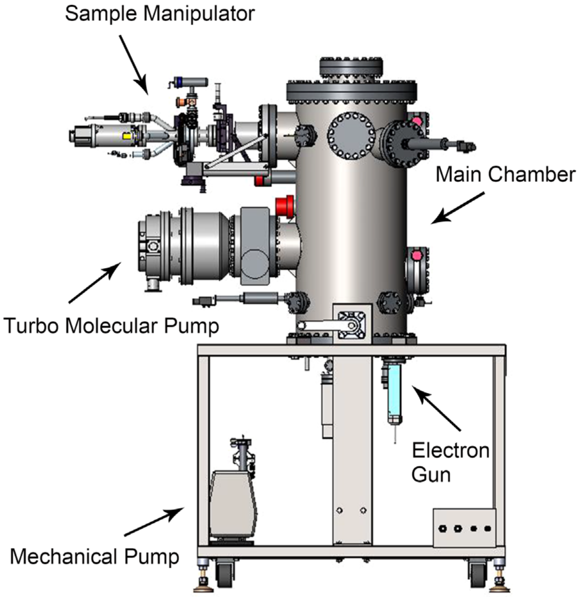

Fig. 1. Schematic of the customer-designed electron-beam system (Thermionics Laboratory, Inc.).

2. Experimental

Fe nanoprisms were deposited on Si (001) substrate by GLAD in a customer-designed electron-beam system (GLAD, Thermionics Laboratory, Inc.) with a background vacuum of 10^{-6} Pa at room temperature. A schematic of the system is shown in Fig. 1 [29]. The system mainly consists of a main chamber with a height of one meter, a load lock chamber, an electron gun, and a sample manipulator with a precision of 1°.

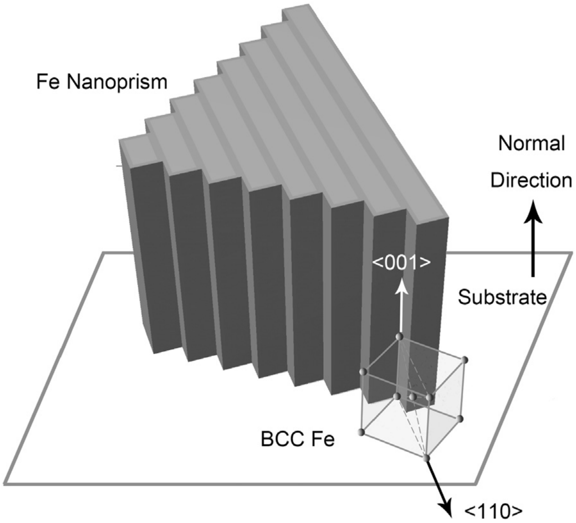

Fig. 3. Schematic of a Fe nanoprism. The cube represents the unit cell of BCC Fe.

Fe nanoprisms with a length of 20, 70, 150, or 300 nm were deposited on Si (001) substrate. Before deposition, Si substrate was ultrasonically-cleaned with ethanol for 10 min. The tunable deposition parameters included deposition rate, deposition angle,

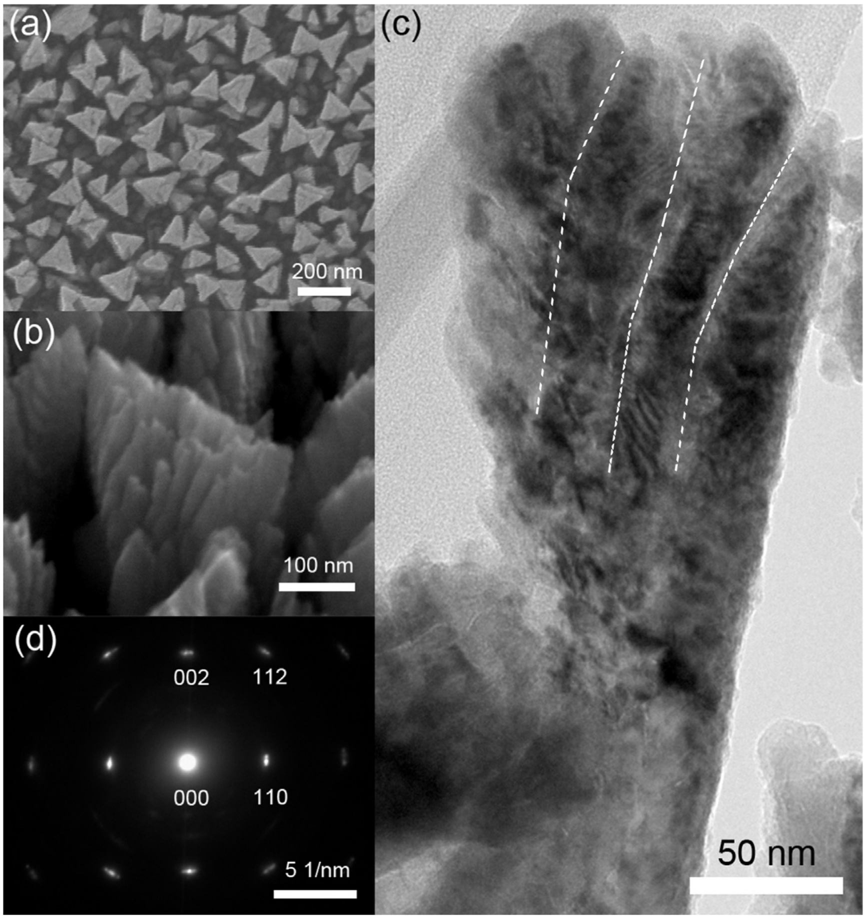

Fig. 2. Morphology and microstructure of Fe nanoprisms. (a) and (b) are the top-view and tilted-view SEM images of Fe nanoprisms, respectively. (c) is the side-view TEM image of an Fe nanoprism. (d) is the SAED pattern of the nanoprism in (c).