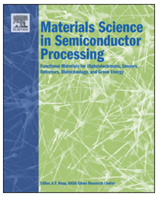
Materials Science in Semiconductor Processing 29 (2015) 294–299

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp



Green synthesis of iron oxide thin-films grown from recycled iron foils

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ARTICLE INFO

Available online 21 May 2014

Keywords:
Iron oxide
Recycling process
Green synthesis
Discontinuous grain
Sustainable device

ABSTRACT

Green synthesis of iron oxide thin-films grown from recycled iron foils were done by high-vacuum evaporation and thermal oxidation processes. Dynamic hysteresis loops of samples of grain-oriented oxide were studied with a RF-resonant circuit and its residual magnetic field was related with the perturbing RF-resonant field. Phase formation and structural parameters in all iron oxide thin-films was evaluated by X-ray diffraction as well as Raman studies have demonstrated that structural properties can be connected with its magnetic behavior based on discontinuous grain growth. In the near future, sustainable devices could be designed using special properties of iron oxide thin-films from recycling processes at effective cost.

1. Introduction

Reliable access to recycle metals is persistent challenge to enable sustainable growth with products such as modern transport, wind-power energy and energy-efficient lighting. However, metals are being extracted at increasing rates and end life of recycling for many of them are low [1]. Nevertheless, metals such as iron are widely recycled in applications such as construction, transportation and industrial machinery at a high cost. In principle several materials can be recovered and reused in the future, thus taking their special properties in alloy form. For example, iron foils can be obtained from electronic waste and it can be easily processed at effective cost to developing of iron-based devices [2]. Silicon-based devices could be replaced in the future with iron-based devices in applications such as analog signal processing, magnetic sensing with rapid response at alternating-magnetic fields and middle-power electronics [3,4].

It is well known that grain-oriented iron is processed in such mode that its properties are developed by rolling processes proposed by Norman P. Goss, due to discontinuous grain growth during high-temperature annealing at the end of the industrial production process with (1 1 0) preferred crystal orientation. Recent studies indicate that discontinuous grain growth can be influenced to an oriented nucleation mechanism based on differences in cohesive forces related to grain size and special boundary properties [5–7].

Discontinuous oxide growth on the iron oxide samples has been recently demonstrated with magnetic interactions on Fe doped ZnO thin-films by doping a very low amount of Fe ions, which has gotten weak magnetic ordering at room temperature with promising applications such as biosensing with rapid response at alternating-magnetic fields [8,9], as well as nonlinear-electronic transport of iron oxide thin-films with current flow modulated has been studied and it can be useful for the designing of adaptive oxide electronic devices based on space-charge effects from the discontinuous oxide [10,11].

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http://dx.doi.org/10.1016/j.mssp.2014.05.014
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This work is focused on survey of grain-oriented iron oxide properties with micro and nano-scale thickness and with special properties such as structural and magnetic properties influenced by discontinuous oxide. A procedure to grow iron oxide based on thermal oxidation as green synthesis is described. It method offers advantages in terms of recycling opportunities and easy processing at effective cost. Special properties of grain-oriented oxide should contribute to the development of the next generation of sustainable devices.

2. Experimental procedure

Grain-oriented iron foil is a soft magnetic material that is assembled to form laminated cores in magnetic components. In the following synthesis, grain-oriented iron foils have been obtained from cores of low-power transformers with thickness of 0.18 mm. These foils are usually coated to reduce the eddy currents and to provide resistance to corrosion.

Both grain-oriented oxide and iron oxide thin-films by thermal oxidation processes and under air atmosphere conditions have been synthesized. Before thermal processes, foils with cross-sectional area of 1 cm^2 were mechanically polished and cleaned using organic solvents and de-ionized water.

Samples of grain-oriented oxide at intermediate temperature (<600 °C) were thermally oxidized under temperature range from 400 °C to 500 °C with duration of 30 min. A first monolayer of iron oxide was grown and corresponds to Fe_2O_3 phase with lattice parameter similar to grain-oriented iron foil. After, the oxide continues to grow with this pattern with strong cohesive forces [12–14].

The mechanisms by which oxygen ions diffuse through the oxide layer and oriented Fe ions move during the oxidation process are shown in Fig. 1(a).

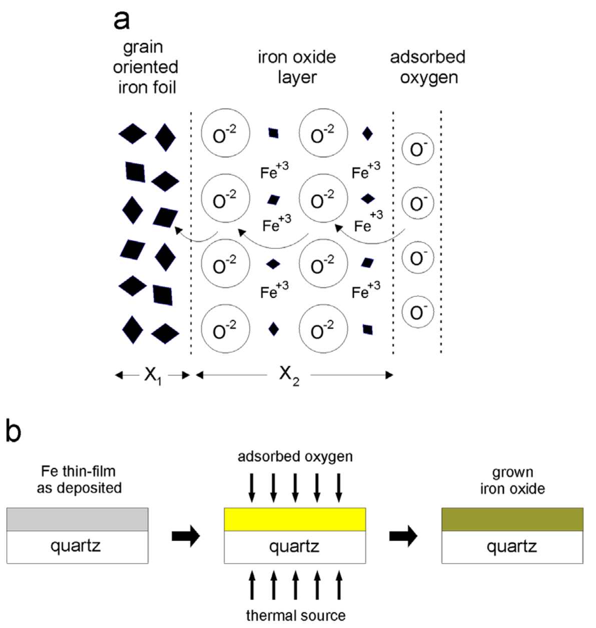

Fig. 1. (a) Mechanisms of diffusion of oxygen ions and oriented Fe ions during the oxidation process and (b) Used steps for the synthesis of the iron oxide samples.

After evaporation process of grain-oriented foils under high vacuum (10^{-5} Torr) on quartz substrate, iron oxide thin-films were assisted at 500 °C, 600 °C and 700 °C with duration of 20 min by thermal oxidation processes as shown in Fig. 1(b). The measured thickness of the samples was about 250 nm and was measured by a Tencor profilometer.

Schematic view of vacuum evaporation followed by a thermal oxidation process is shown in Fig. 2. Horizontal quartz tube under air atmosphere is placed inside of resistively heated quartz tube furnace. Grain-oriented foils and evaporated iron thin-films were placed into the furnace for its oxidation processes.

Dynamic magnetization for samples of grain-oriented oxide was recorded employing a RF-resonant circuit and displaying dynamic-hysteresis-loops as Lissajous figures on the screen of a Digital Storage Oscilloscope (Tekctronix, TDS1002B). Phase formation and structural parameters of

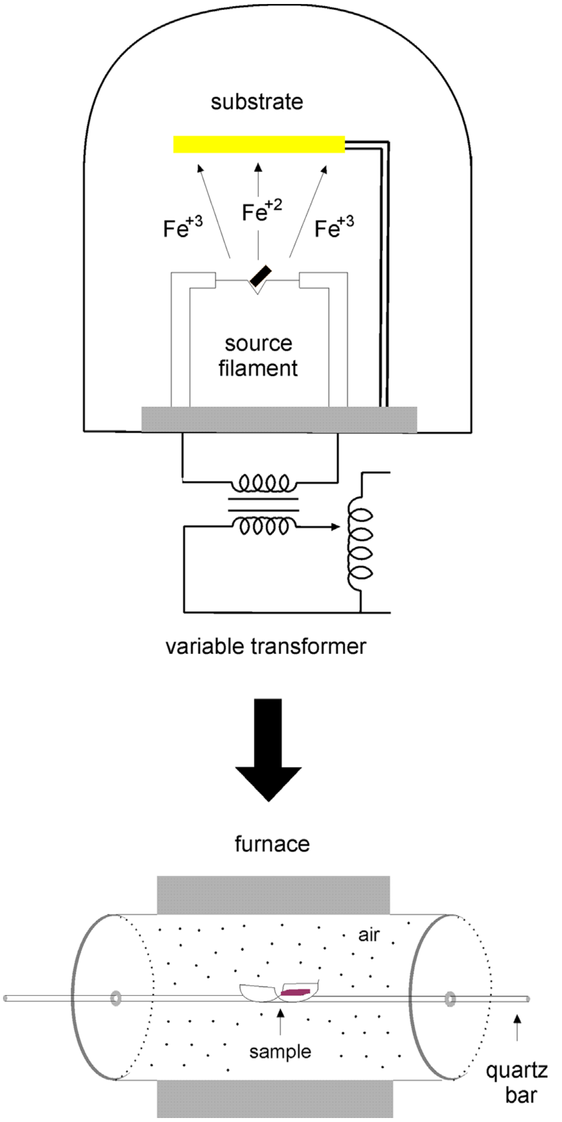

Fig. 2. Schematic view of vacuum evaporation followed by a thermal oxidation process of the iron oxide samples.