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Study on solid/solid- and solid/liquid-interface-dependent material properties for an artificial multiferroic system and additive manufacturing process

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Abstract

We investigated the magnetic characteristics of an interface consisting of Ni and $LiNbO_3$ substrate. We also studied solid-liquid-interface induced material properties. X-ray-radiolysis-induced photochemical reaction of a liquid solution enables the direct synthesis and immobilization of particles onto a desired area of substrate immersed in the liquid solution.

1. Introduction

Interface is a region that always appears when various materials are joined, and is a place that brings about modulation of various electronic states depending on boundary conditions. Further, in joining dissimilar materials, their mechanical joining strength and their mechanical properties compete with each other. In most cases, it is often the starting point for its destruction and vulnerability. Therefore, it can be said that the control of interfacial bounding and interface physical and chemical properties is a very important research and development issue in device creation and system integration that combine different materials and components.

Here, we focus on the differences between the physical properties that appear when different materials are joined and the substances that are generated at the interface between property modulation mechanism and substrate generation mechanism from the view point of the interface.

In this study, we investigated two systems. First is the magnetic property modulated by the formation of heterojunction between ferromagnetic thin film and ferroelectric substrate for an artificial multiferroic material [1 -3]. Second is the solid/liquid-interface dependence of particles nucleated and immobilized on various substrates for three dimensional printing and additive manufacturing process [4 – 6].

2. Experimental results and discussion

Solid/solid interface

As an artificial multiferroic material, a junction between ferromagnetic Ni layer and a ferroelectric $LiNbO_3$ substrate is formed. At this time, the Ni layer is strongly influenced by the lattice strain from the $LiNbO_3$, and modulates its magnetic characteristics. In this study, we evaluated the interfacial electronic properties using surface sensitive measurement techniques such as X-ray photoelectron spectroscopy (XPS) and X-ray magnetic circular dicroisom photoelectron emission microscopy (XCMD-PEEM) to understand the physical mechanism which generates the uniaxial magnetic anisotropy through the interface. Figures 1(a) and 1(b) show typical XMCD-PEEM images of Ni wires deposited onto a LiNbO3 substrate. We found that the magnetic domain structure depended on the wire alignment angle to the X-axis of the substrate. To understand the magnetic domain structure formation, the micromagnetic simulations were performed as shown in Fig. 1(c). In addition, to investigate the interface induced modulation of electronic states of Ni layer, we prepare some heterojunctions such as Au-cap/Ni/$LiNbO_3$, Au-cap/Ni/Au/LiNbO$_3$, and Au-cap/Ni/Si. Figure 1(d) displays a typical depth profile of XPS for the Au-cap/Ni/LiNbO$_3$. By comparing the data obtained from these systems, we found that the XPS peak of Ni 2p was shifted as approaching the interface between the Ni layer and LiNbO$_3$ substrate. This is attributed to the modulation of electric state distribution near the interface. In addition, we investigated the Ni film thickness of XMCD-PEEM imaging and spectroscopy. These synchrotron radiation based measurement enables us to detect the response derived from polishing agent. The LiNbO$_3$ substrate is polished by chemical mechanical polishing. Despite being mirror-finished surface, the polishing agent remained. The polishing agent was too tiny to influence the magnetic properties of Ni ultra thin film. Ni layer exhibit the uniaxial magnetic anisotropy due to the magnetostriction from the lattice mismatch at the interface. So, we can control the magnetic domain structure and magnetization reversal characteristics by the formation of heterojunction.

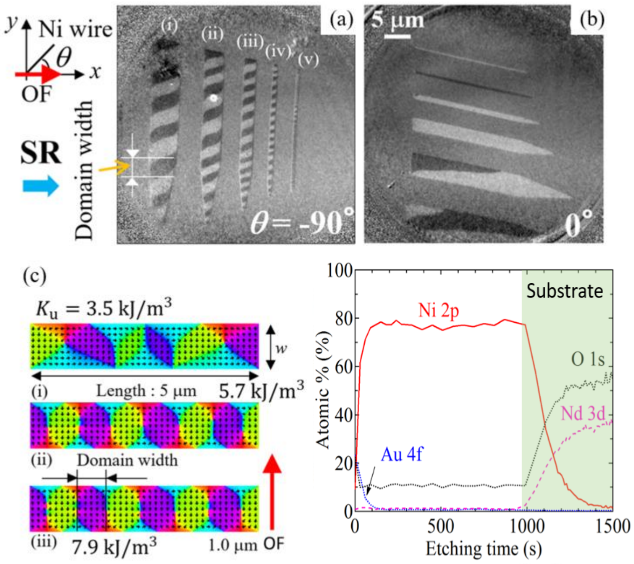

Fig. 1 XMCD-PEEM images of Ni wires aligned (a) perpendicular and (b) parallel to X-axis of LiNbO$_3$. (c) micromagnetic simulation results (d) XPS depth profile.

Solid/liquid-interface

X-ray radiolysis-induced synthesis of metallic and oxide particles onto a desired area has attractive significant attention because of both their fundamental mechanism and applications of 3D printing and additive manufacturing process.

Here, we investigate for the first time the X-ray radiolysis-induced photochemical reaction at the interface between liquid solution and substrate. Here, we prepared copper (II) acetate [Cu(CH$_3$COO)$_2$] solution with methanol and conducted the X-ray irradiation experiments changing various materials of substrate immersed into the copper acetate solution.. The irradiation experiments using the synchrotron radiation facility were performed at the Beamline BL8S1 of Aichi Synchrotron Radiation Center. [5, 6] After 5 min. X-ray irradiation, the specimen was washed with deionized water to remove residual materials which leaving the particles behind.

Figure 2 shows scanning electron microscope (SEM) images of the synthesized and deposited cupric particles onto a silicon (100), aluminum, and copper substrates, respectively. In order to evaluate the composition of the particles, we analyzed them by energy-dispersive X-ray (EDX) spectroscopy and micro-Raman spectroscopy using 532-nm-green-laser-souce. By comparing these SEM images, we found that the morphology and crystal shape of synthesized particles are dependent on substrate material. In addition, EDX analysis results indicate that the composition is also influenced by the

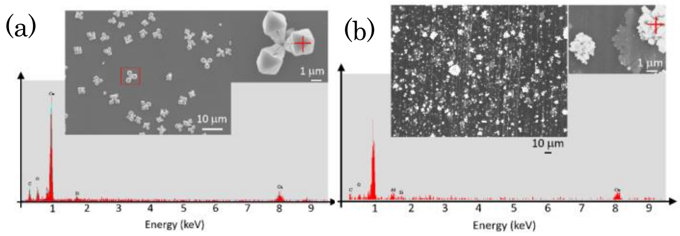

Fig. 2 SEM images and EDX analysis of particles synthesized onto Si and Al substrates by 5min. X-ray irradiation of [Cu(CH$_3$COO)$_2$].

substrate material. For example, caltrop shaped particles made of cupric oxide were synthesized and deposited onto Si substrate, while pure copper particles were deposited onto Cu substrate. These results suggest that the generation of second electron was induced by the X-ray radiolysis at the interface and nucleation of particles and their ripening process is strongly influenced by the ions and interface. These results indicate that the combination of liquid solution and immersed substrate is key to understand the fundamental mechanism and their applications.

3. Conclusions

Thus, our results that the magnetoelastic effects from the hetero-junction can induce magnetic anisotropy and control the magnetic properties, proving the novel functional material and sensor devices for the microsystem. In addition, a suitable X-ray irradiation of metallic solutions enables the formation of nano/micro-scale particles to the desired area. The morphology, crystal shape, and composition of 3D printing or additive manufacturing process induced by the X-ray radiolysis depend on the combination of solution and immerse substrate.

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