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Extending Rotation Range of Spatial Light Modulator by Metal-Induced Lateral Crystallization of Amorphous Si Using Ni Ferritin Molecules

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1. Introduction

Thin film of Si is indispensible for constructing MEMS/NEMS devices. Controlling residual stress in the Si thin film is one of the important factors for achieving superior performance of MEMS/NEMS devices [1,2]. For optical application, buckling or bending of the film should be avoided to achieve optical flat [3]. Residual stress in the Si film affects the actuation of MEMS/NEMS devices. For example, rotation angle of micromirror devices can be expanded by increasing tensile stress in the Si thin film of torsion bars that suspend the mirror part [4]. Thus far, crystallization-induced stress is used to obtain tensile stress [5]. Annealing transforms amorphous Si film into poly-crystallized one. The crystallization causes volume shrinkage of the film to generate tensile stress. However, conventional annealing process randomly generated crystallization nuclei. There were many grain boundaries that do not contribute to generate the tensile stress. To increase tensile stress, it is necessary to expand the grain size. So far, we have shown that metal-induced lateral crystallization (MILC) of amorphous Si using Ni NPs synthesized within ferritin molecules increases grain size and residual tensile stress in the film [6]. In this study, the MILC with Ni NPs were is applied to the fabrication of a spatial light phase modulator (SLM) that is driven by electrostatic actuation. Characteristics of the fabricated SLM device characteristics are discussed.

2. MILC with Ni ferritin molecules

Crystallization of amorphous Si film can be promoted by metal-induced lateral crystallization (MILC) [7,8]. The MILC uses silicidation reaction. Here, we used Ni nanoparticles (NPs) that is synthesized within a cage-shaped protein molecule, ferritin [9,10]. Ferritin molecule is 12nm in diam. and has ϕ7nm cavity inside. We can use the cavity of ferritin molecules as a spatially restricted chemical reaction chamber. Therefore, fabricated NPs have homogeneous structure. Process flow of MILC using Ni ferritin molecules is schematically shown in Fig. 1. We prepared amorphous Si film (600nm) deposited on a Si substrate with 3μm SiO_2 layer by low pressure chemical vapor deposition [3]. Ni ferritin molecules are adsorbed on the amorphous Si substrate. The cage proteins are removed by heat treatment (annealing at 500°C for 1h under O_2 gas flow) to leave Ni NPs on it [11]. After the protein removal, the amorphous Si substrate is annealed for metal-induced crystallization. The crystalized structures are analyzed by electron backscatter diffraction (EBSD). Residual stress in the crystallized Si film is evaluated by fabricating MEMS stress monitor with the Si film itself [12]. Among the materials that cause silicidation, Ni is the most promising material. The silicide of $NiSi_2$ has lattice constant similar to Si. Mismatch of the lattice constant is less than 0.4%. Moreover, $NiSi_2$ is formed at less than 400°C, which is much lower than the annealing temperature for obtaining poly-Si from amorphous Si (650-800°C) [13]. Therefore, before crystallization nuclei are spontaneously generated in the amorphous Si, the formed $NiSi_2$ products functions as nuclei for crystallization. Grains grow larger.

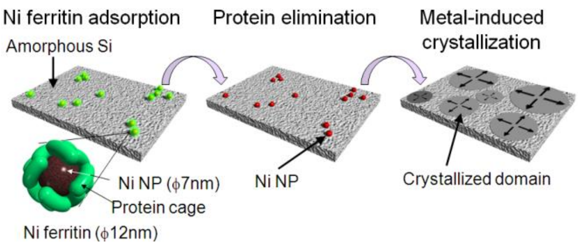

Fig.1: Metal-induced lateral crystallization using Ni ferritin supuramolecules.

3. MEMS spatial light modulator

Using the crystallized film with Ni ferritin, SLM device is fabricated. Schematic of the SLM structure is shown in Fig. 2(a). The mirror part is suspended by the torsion bars at the end of the mirror part. The parts of the mirror are rotated by applying a voltage to the driving electrode. When the electrostatic force becomes larger than mechanical spring force of the torsion bar, the mirror is pulled by the driving electrode to attach with it. This is called "pull-in". Theoretical model predicts that pull-in occurs when the rotation angle exceeds 44% of the geometrically determined limit of rotatable angle [14].

Fabrication process on the SLM device is as follows. Amorphous Si film (600nm) is deposited on a Si substrate with 3μm SiO_2 layer by LPCVD. After ion implantation

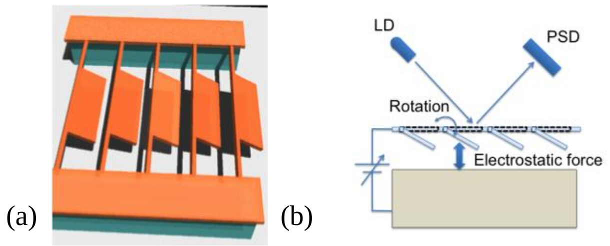

Fig.2: (a) Schematic drawing of MEMS spatial light modulator. (b) Experimental setup for mirror rotation.

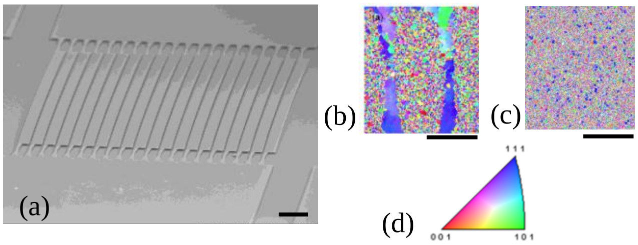

Fig.3: (a) Fabricated SLM. (b) EBSD images of (b) torsion bar and (c) Si film without MILC. Scale bars are 50μm. (d) Color mapping of crystalline orientation in the EBSD images.

process, the MILC is carried out using Ni ferritin. The obtained poly-Si film is patterned by ICP-RIE using SF_6 gas. Underlying sacrificial layer of SiO_2 is etched by vapor HF to release SLM structure. Displacement of the SLM is measured by optical lever method as shown in the inset of Fig. 2.

4. Results and Discussions

Fabricated MEMS SLM is shown in Fig. 3(a). Grain structures in the torsion bar measured by EBSD are shown in Fig. 3(b). It is shown that the torsion bar is crystallized. The torsion bar has almost the same color. This indicates that the torsion bar is crystallized along the same orientation. When the amorphous Si film is annealed but without Ni ferritin, the grain size in the Si film is less than 1 μm as shown in Fig. 3(c). The MILC with Ni ferritin expands the grains in the Si thin film. Tensile stress is increased from 300-350MPa without MILC to 650-700MPa with MILC.

Frequency characteristics of the SLM are shown in Fig. 4(a). Two resonance peaks are observed for the each fabricated device. The SLM device with MILC has resonance frequencies at 105kHz and 234kHz while that without MILC has at 86kHz and 219kHz. It is easily understood that tension in the torsion bars enhanced by MILC increase the resonance frequency. Next, we investigated the pull-in instability of the SLM. Bias voltage is gradually increased until a mirror is pulled by the driving electrode. Rotation angle is shown as a function of bias voltage in Fig. 4(b). Pull-in angle of 44% corresponds to 4.36 deg. for the SLM structure. While the pull-in is observed at 4.23 deg. for the reference sample (without MILC), the sample with MILC achieves pull-in angle of 4.42 deg. The pull-in angle is extended. Increasing tension makes the torsion bar rigid to the vertical displacement.

The tension should be increased more to extend the rotation angle. Removing the grain structure from the torsion

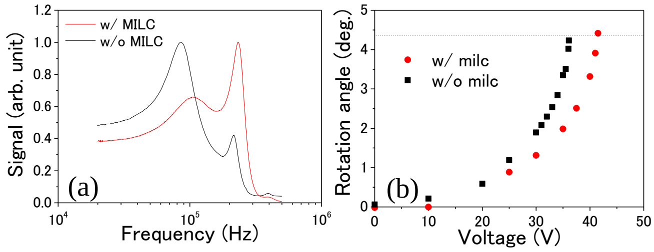

Fig.4: Characteristics of fabricated MEMS spatial light modulator. (a) Frequency response. (b) Rotation angle. Dotted line indicates pull-in angle of 44% (4.36deg.).

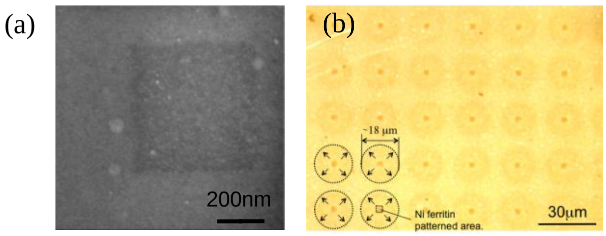

Fig.5: Position-controlled MILC. (a) Ni ferritin molecules are patterned in 500nm square area. (b) Crystallization expanded radially outwards from the patterned area.

bars by patterning Ni ferritin adsorption area will increase the tensile stress. Using electrostatic interaction, Ni ferritin molecules are patterned as shown in Fig. 5(a). After MILC, the sample is etched by mixed solution of HF and HNO_3 to reveal grain position. It is clearly shown that grain grows radially outwards from the Ni ferritin patterned area.

5. Conclusions

Amorphous Si film is crystallized by using Ni ferritin molecules. The crystallized Si film is applied to the SLM fabrication. Resonance frequency is increased and mirror rotation angle is increased. To expand the rotation angle further, the tension in the Si film should be increased. Position controlled MILC will contribute to improve the device characteristics further.

Acknowledgements

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