Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp302-303

Novel Direct Patterning Technique of Vapor-Deposited Si Thin Films by Laser-Induced Si/Ag Layer Exchange

Masahiro Kiyooka and Hiroshi Ikenoue

Kochi National College of Technology, Advanced Course of Mechanical and Electrical Engineering
200-1, Monobe-otsu, Nankoku city, Kochi 783-8508, Japan
Phone: +81-88-864-5695 E-mail: ikenoue@ee.kochi-ct.ac.jp

1. Introduction

Direct patterning of Si films is one of promising methods for TFT display fabrication to achieve low cost. We have proposed direct patterning of Si films by laser-induced Si/Ag layer exchange. In this method, an Ag film was deposited for middle layer between an a-Si film and a substrate. Next, pulsed laser was locally irradiated to the Si/Ag film, and the Ag film was segregated to Si film surface. After that, the Ag film at irradiation area and the Ag film of middle layer at non-irradiation area were etched off by nitric acid treatment. In the result, direct patterning of Si thin films can be achieved at laser irradiation area. Moreover, in order to observe segregation behavior of Ag to Si surface, CW laser was coaxially inserted to the exchange region with the pulsed laser, and reflective intensity of the CW laser was measured by Si-photo detector.

Poly-Si TFT fabrications need a lot of processes such as photolithography, etching and so on. Therefore, fabrication cost and environment load become larger, and direct patterning methods such as ink jet print, nano-imprint and direct patterning have been suggested. In particular, direct patterning of Si thin films is promising method to achieve low cost. We have proposed a direct patterning of Si films by laser-induced Si/Ag layer exchange.

2. Experimental

Figure 1 shows an experimental procedure of laser direct patterning method. Structure of sample used for this experiment was a-Si (30 nm) / Ag (10 nm) / t-SiO_2 (500 nm) / Si substrate. In this method, the Ag thin film and the a-Si thin film were continuously deposited on t-SiO_2 / Si substrate by Ar+ sputtering method. Next, pulsed laser was locally irradiated to the Si/Ag film, and the Ag film was segregated to the Si film surface. After that, the Ag film on Si surface at irradiation area and the Ag film of middle layer at non-irradiation area were etched off by nitric acid treatment. In the result, direct patterning of Si thin films can be achieved at laser irradiation area. Ag was used as middle layer between the Si and t-SiO_2 / Si substrate in order to lift off the Si film. Because nitric acid can dissolve Ag without Si dissolution and Ag is not brought into combination with Si.

Figure 2 shows a schematic of laser irradiation system. Q-Switch neodymium-doped yttrium aluminum garnet (Nd: YAG) laser was used in this experiment. The irradiation laser light had a wavelength of 355 nm, a pulse duration was approximately 12 ns, and a repetition rate of 50 kHz. Energy density at the sample surface was set at 11.5 - 115 mJ/cm^2 and laser beam diameter at the sample surface was Φ 20 μm. The scanning velocity of a sample stage was 1 mm/s.

Moreover, in order to observe segregation behavior of the exchange area, CW laser was coaxially inserted to surface with the Nd:YAG laser, and reflective intensity of the CW laser was measured by a Si-photo detector.

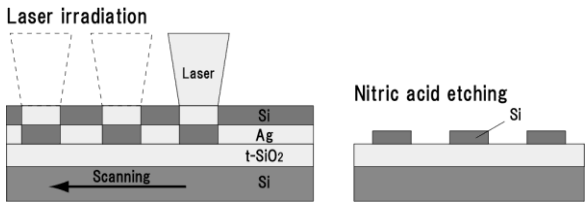

Fig. 1. Experimental procedure of laser direct patterning method

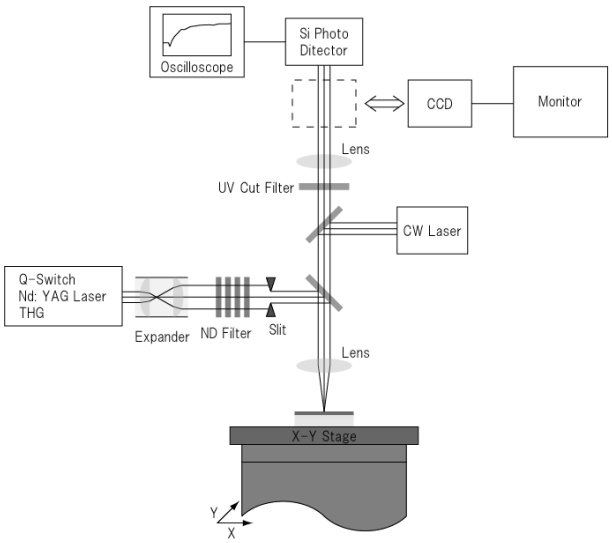

Fig. 2. Schematic of laser irradiation system

2. Result and Discussion

Figures 3 and 4 show an optical microscope image and an AFM image of patterned Si films after laser irradiation and nitric acid treatment. As shown in figure 3, Si films were patterned at the energy density more than 14.3 mJ/cm^2. At the energy density more than 34.4 mJ/cm^2, irradiation damage was induced to the Si film. As shown in figure 4, rectangular step shape can be observed in the AFM image. Thus, Si films were definitely patterned at the energy range

from 14.3 mJ/cm^2 to 28.6 mJ/cm^2. RMS surface roughness of patterned Si was 1.36 nm.

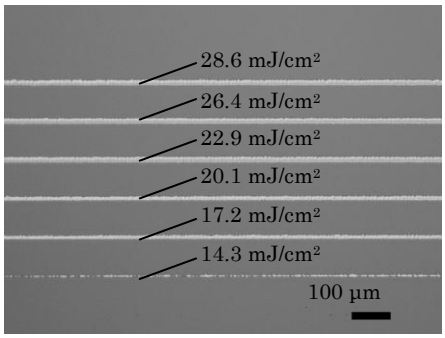

Fig. 3. The optical microscope image of patterned Si films after laser irradiation and nitric acid treatment

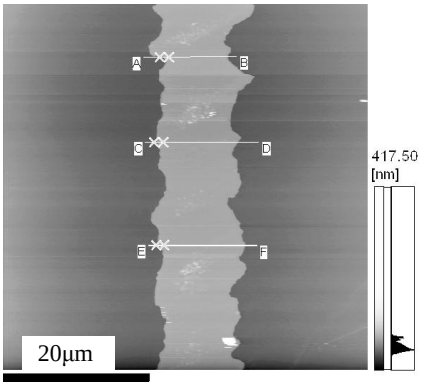

Fig. 4. AFM image of patterned Si

Figure 5 shows a cross-sectional AFM image of the patterned Si. A film thickness of the patterned Si was about 31 nm. The initial film thickness of deposited Si film was 30 nm. This result indicates that almost Si remained on the t-SiO_2 / Si substrate, and almost Ag was segregated to Si surface and removed from the Si surface. The equilibrium solubility of Ag in Si is reported to be negligibly small[1]. In addition, it is reported that Ag film can be completely segregated to Si surface and intrinsic Si layer can be obtained by Si/Ag layer exchange after annealing at 530 ℃for 22.5 hours. Therefore, we expect that intrinsic Si direct patterning becomes successful with Si/Ag layer exchange by local heating of laser irradiation and nitric acid treatment.

Figure 6 shows changes in the reflected light intensity of CW laser from pulsed laser irradiation area with increasing the number of laser pulse. At the 1st pulse irradiation, reflected light intensity dipped as compared with that before laser irradiation. However, the reflected intensity rose with increasing the number of laser irradiation more than 2 pulses. Above the 10 pulses, the intensity was saturated. From AFM measurement, the RMS surface roughness of the irradiation area at the 1 time and the 10 times of laser irradiation were 0.55 nm and 0.66 nm, respectively. In addition, the RMS surface roughness before laser irradiation was 1.0 nm. Therefore, degradation of surface roughness did not occur after laser irradiation. From these results, dip of the intensity at the 1 time laser irradiation indicates that degradation of roughness at the boundary of Si/Ag interface was induced by diffusion of Ag into Si layer. The increase of intensity more than the 2 times laser irradiation means that a part of Ag segregated to the Si surface, and the Si surface was completely covered with Ag layer more than the 10 times laser irradiation.

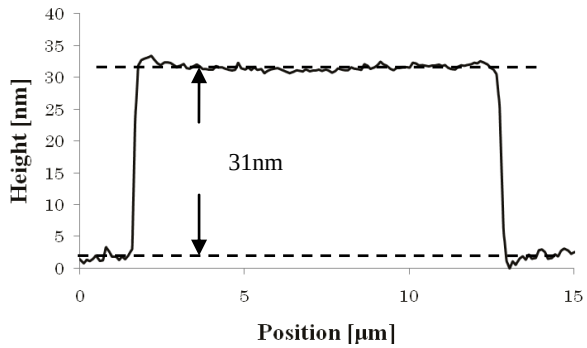

Fig. 5. Cross sectional AFM image of patterned Si

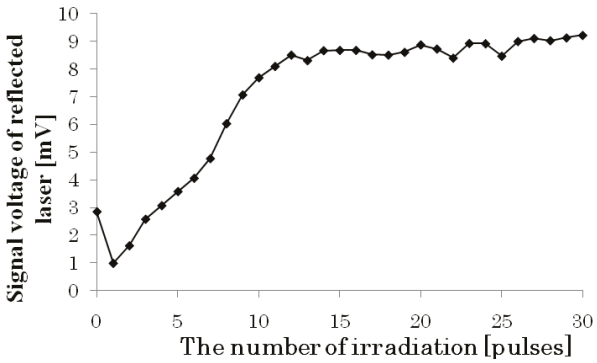

Fig. 6. Changes in reflected light intensity and the number of laser irradiation

3. Conclusions

We have proposed laser direct patterning of Si films by laser-induced Si/Ag layer exchange can be successful. An a-Si /Ag /t-SiO_2 /Si substrate is used in this experiment. Ag layer is segregated to the Si surface by local heating of laser irradiation. Ag can be dissolved by nitric acid treatment without Si dissolution. The Ag segregated to the Si surface and the Ag of middle layer at non-irradiation area were etched off by nitric acid treatment. In the result, Si thin films can be patterned at laser irradiation area. The film thickness of patterned Si is approximately equal to an initial film thickness of the deposited Si film. Segregation behavior of Ag to Si surface can be observed by measurement of reflected light intensity of CW laser from Ag segregation area.

References

[1] F. Rollert , N. A. Stolwijk, and H. Mehrer, J. Phys. D 20, 1148, 1987

[2] M. Scholz, M. Gjukic, and M. Stutzmann, Appl. Phys. Lett. 94 - 01208, 2009, pp.1-3