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Electric field-dependent Ni-mediated lateral crystallization of a-Si on SiO_2

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Abstract

Ni-mediated lateral crystallization of amorphous Si has been investigated under a wide range of electric fields (0–4000 V/cm). In the low field region (<100 V/cm), lateral growth velocity at the cathode side was enhanced by applying an electric field. This achieved formation of poly-Si with a large area (~50 μm) during low-temperature annealing (525 °C, 25 h). When the electric field exceeded 100 V/cm, the lateral growth velocity decreased with increasing the electric field strength. Under the extremely high electric field (>2000 V/cm), directional growth aligned to the electric field was observed. These new findings will be a powerful tool to achieve new poly-Si with highly controlled structures.

Keywords: Crystallization; Field effect; Silicon

1. Introduction

The low-temperature formation of high quality polycrystalline Si (poly-Si) films on insulating films has been expected to enable system-in-displays and three-dimensional ultra large scale integrated circuits (ULSI). To prevent the diffusion of dopant atoms and the softening of glass substrates, the processing temperature for the crystallization of amorphous Si (a-Si) should be lower than 550 °C. To achieve this, various recrystallization processes of a-Si on SiO_2 have been widely investigated. However, only poly-Si with small grains (<0.1 μm) was obtained by solid-phase crystallization (SPC), even after a very long annealing time (~20 h) [1,2]. Melt-grown processes such as laser annealing realized poly-Si with large grains (~5 μm); however, surface ripples with ~15 nm height were observed [3].

The low-temperature solid-phase crystallization of a-Si has been developed using the catalytic effect of some metals [4–8], e.g., Al, Pd, Ag, Au, and Ni. Among them, Ni shows a significant effect. Ni reacts with Si at a low temperature and forms silicide ($NiSi_2$) with a lattice constant very close to that of crystalline Si (c-Si). Consequently, such a silicide acts as a seed for solid-phase epitaxial growth. This Ni-mediated lateral crystallization has achieved poly-Si with large grains (~10 μm) on insulating films. This technique has been also developed for crystallization of amorphous silicon-germanium (a-SiGe) films and a-Si/a-Ge-layered structures [9–11].

Recently, it has been reported that the Ni-mediated lateral crystallization velocity was enhanced by applying an electric field during annealing [12,13]. However, the range of electric field strength was limited to a narrow region (0–200 V/cm), and the mechanism for the enhanced crystallization has not been established. The present paper reports the Ni-mediated lateral crystallization of a-Si under a wide range of electric fields (0–4000 V/cm) and new findings under extremely high electric fields (>2000 V/cm).

2. Experimental procedures

In the experiment, a-Si films (50 nm thick) were deposited on quartz substrates using a molecular beam epitaxy system (base pressure $=5\times10^{-11}$ Torr). Here a-Si films were deposited using an electron-beam gun at a rate of 0.1 nm/s, keeping the substrates at room temperature. Subsequently, Ni films (15 nm thick) were deposited on the a-Si and then patterned into electrodes by using the photolithography technique. The spacing between the anode and the cathode was varied between 40 and 6000 μm. Finally, the samples were annealed at 525 and 550 °C in an evacuated quartz tube. A DC bias was applied to the Ni electrodes using a DC power supply during annealing. Such experimental procedures are schematically shown in Fig. 1. The electric field strength E was estimated as $E=V/d$, where

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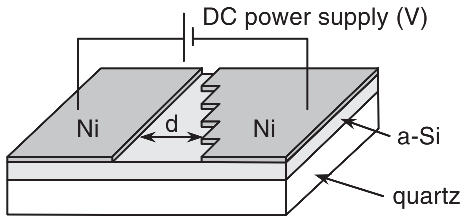

Fig. 1. Schematics of sample structure, where d indicates spacing length between anode and cathode.

V is the applied voltage and d is the spacing between electrodes. The lateral growth lengths from Ni-pattern were evaluated by using Nomarski optical microscopy and scanning electron microscopy (SEM).

3. Results and discussion

Fig. 2a, b, and c show Nomarski optical micrographs of grown regions after annealing (525 °C, 25 h) under the electric fields of 1.7, 100, and 2000 V/cm, respectively. Dark regions in the photographs show the anode and the cathode (Ni-patterns). Bright regions near the electrodes are the crystallized regions (poly-Si regions). It is clear that poly-Si regions at the cathode side were wider than those of the anode side, which is in agreement with the previous studies [12,13]. Jang et al. reported that Ni atoms in $NiSi_2$ are negatively charged [14]. Recently, Yoon et al. calculated the averaged charge of a Ni atom in Si as $-0.33e$, where e is an electron charge [15]. These results suggest that migration of negatively charged Ni atoms is enhanced by an electric field, which results in the enhanced lateral crystallization at the cathode side.

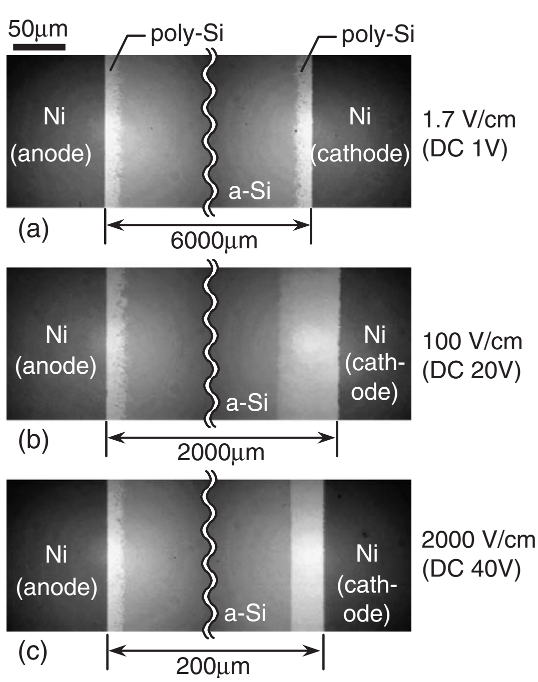

Fig. 2. Nomarski optical micrographs of grown regions after annealing (525 °C, 25 h) under electric fields of 1.7 (a), 100 (b), and 2000 V/cm (c).

Annealing characteristics of the lateral growth lengths under electric fields at 525 and 550 °C are summarized in Fig. 3a and b, respectively, as a function of annealing time. The growth length at the anode side hardly depended on the applied electric field. On the other hand, the growth at the cathode side significantly depended on the electric field. The lateral growth velocity was summarized as a function of the electric field strength in Fig. 3c. In the case of 525 °C annealing, the lateral growth velocity at the cathode side increases from 0.5 to 2.0 μm/h by increasing the electric field strength from 0 to 100 V/cm. In addition, the lateral growth velocity at 550 °C increases from 1.0 to 3.3 μm/h by increasing the electric field strength from 0 to 40 V/cm. Consequently, long growth lengths (~50 μm at 525 °C and ~120 μm at 550 °C) were obtained after annealing for 25 h as shown in Fig. 3a and b. These phenomena

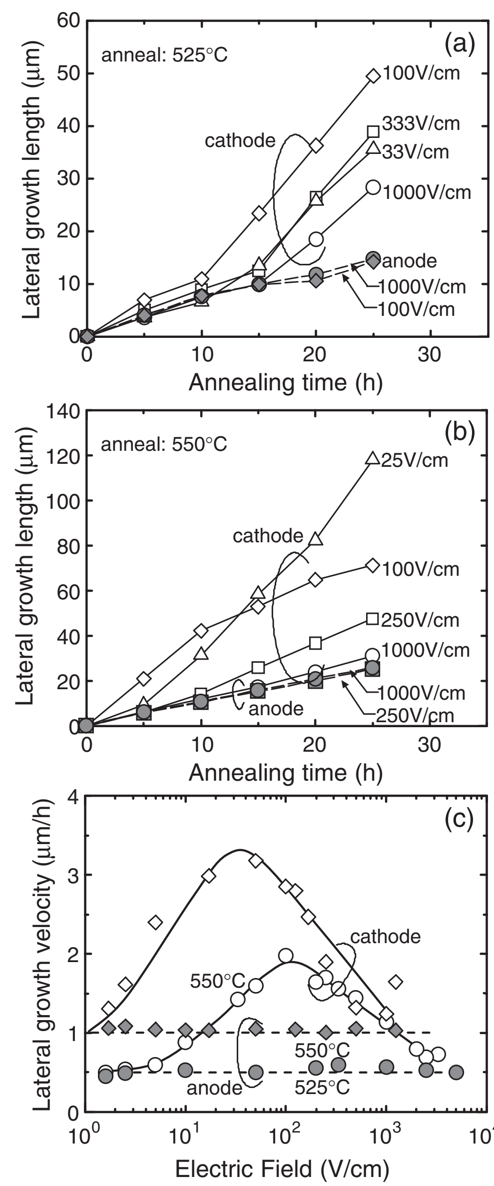

Fig. 3. Lateral growth characteristics as a function of electric field strength at annealing temperatures of 525 °C (a) and 550 °C (b), and lateral growth velocity as a function of electric field strength (c).