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Selective growth of single-grain lines in Al thin film by laser annealing

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Abstract

Selective growth of single-grain lines in metal films would open a new concept of boundary-free interconnection lines or electrodes for various microelectronic applications. This study focused on the growth of ultra-long single-grain lines in Al thin films. The grain growth with the variation of laser beam's parameters and characteristics of the Al film was investigated.

1. Introduction

A boundary-free metal line made of a single-grain is probably ideal for suppression of electromigration and for improvement of electrical conductivity. However, as the metal lines are often fabricated from metal thin films which have an ultra-fine grain size of few hundreds of nanometers, the density of grain boundary in the metal lines is very high. Currently, post-deposition annealing can only increase the grain size to few micrometers, which is not sufficient to achieve single-grain lines.

Laser annealing has been proposed and realized for growth of single-grain Si stripes in a-Si film, but a similar approach to metal thin films has not been reported so far. This study focused on the selective growth of single grain on Al thin film by using a chevron-shaped cw laser beam. The relations between laser parameters, Al film thickness and the characteristics of the Al crystals were analyzed.

2. Experimental procedures

A chevron-shaped cw laser beam [1] was received by using a one-sided dove prism (OSDP), which is composed of a dove prism and a cuboid prism (Fig. 1). A 1.2 W blue multimode laser diode of 405 nm wavelength was used as a linear laser source. The apex angle of the chevron-shaped laser beam was 60 ^{o}.

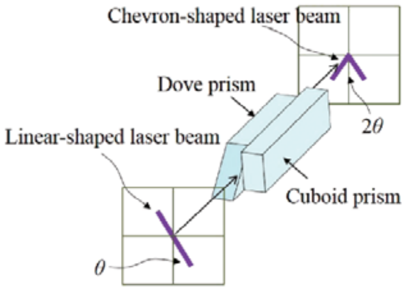

Fig. 1 Formation of a chevron-shaped laser beam from a linear-shaped beam passing through a one-sided dove prism with a tilt angle θ from the junction plane of the prism [1].

Al thin films were deposited on quartz substrates by using thermal and sputtering evaporation techniques. The thickness of Al films was 60 ± 20 nm confirmed by atomic force microscope.

The substrate with Al film was attached to the sample stage, which was placed at right angle to the incident laser beam. The chevron-shaped laser beam was focused on the Al film. The beam scanned the sample surface as the sample stage moved in its horizontal direction at a given speed.

The laser annealing was conducted in three different scanning patterns designated as SP1, SP2, SP3. In SP1 the sample stage moved away from the chevron apex, while in SP2 it moved towards the apex. SP3 is a double scan combining of one SP1 scan and one SP2 scan. The scanning speed was 13, 20 and 40 mm/s. The laser power was in a range of 265-390 mW.

After laser annealing, local crystal orientations of the recrystallized regions were measured by using electron backscatter diffraction (EBSD) technique. The EBSD measurements were carried out on JEOL 7001FA scanning electron microscope (FE-SEM) operating at 15 kV.

3. Results and discussions

The as-deposited film is polycrystalline with a grain size of 275 ± 80nm measured EBSD. After a single scan of the laser beam (290 mW) following the pattern SP1, polycrystals grew laterally along the scan direction with a grain size of 3.0 ± 1.1µm (Fig.2a). The width of the recrystallized zone was 9.5 µm and the orientations of the polycrystals are random.

By using the pattern SP2 with the scan direction inverse to that of the pattern SP1, a single grain of Al was obtained along the scan line (Fig.2b). The term "single grain" was used to indicate a continuous crystal grain without the presence of grain boundary (boundaryless). Unlike a single crystal, the crystal orientation of the single grain can vary continuously as seen in Fig.2b. The crystal orientation of this single grain rotates continuously towards the scan direction. The rotation axis, which lies between the [001] and [101] directions of the crystal, oscillates around the TD axis of the Al film (Fig.2).

When double scans following the pattern SP3 were applied, single-grain lines were also observed (Fig. 2c). The single grains grow along the scan direction with their crystal orientations rotates about the TD axis (transverse direction) of the film, at a constant rotation rate. With laser power <303 mW, the rotation axis is [001] direction, which aligns with the

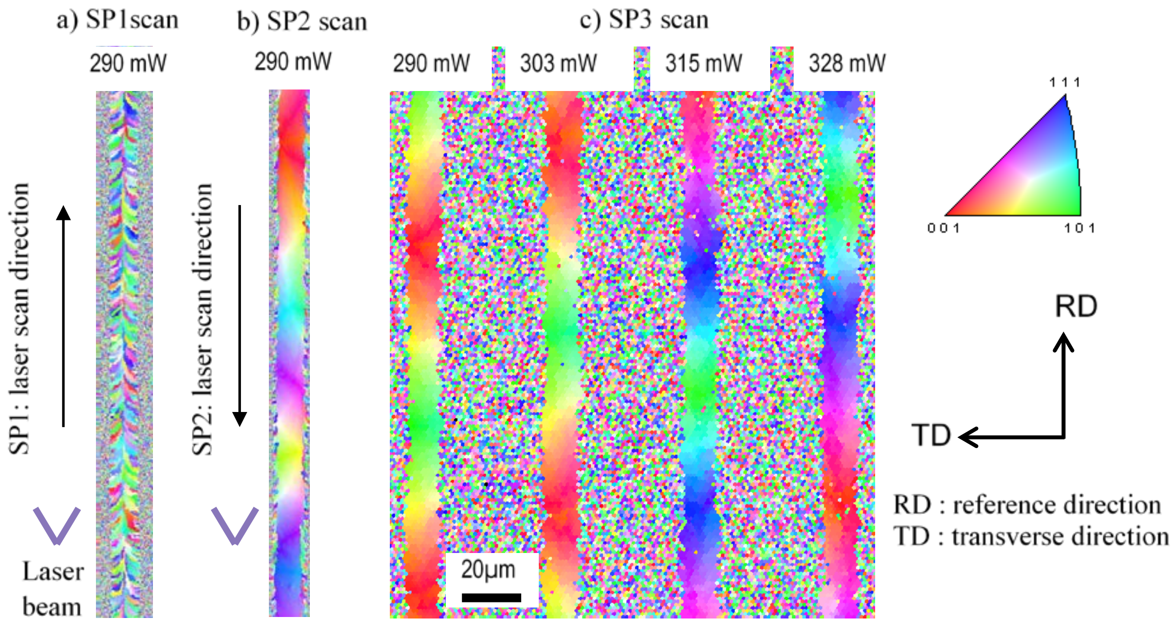

Fig. 2 EBSD orientation map showing (a) lateral growth of polycrystals after a single 290-mW laser scan following the pattern SP1; (b) single-grain growth after a single 290-mW laser scan following the pattern SP2; (c) double laser scan following the pattern SP3, with variation of laser power. The crystals are colored following the inset triangle color code, which corresponds to the alignment of the crystal directions with the surface normal of the Al film.

TD axis of the film. With laser power >315 mW, the rotation axis is [101], which also aligns with the TD axis.

The laser scan with the sample stage moving away from the apex of the chevron-shaped beam (SP1) facilitates the lateral growth of polycrystals, whereas scan in the inverse direction (SP2) produces a single grain. Both of SP2 and SP3 scans are effective for single-grain growth, but the quality of recrystallized crystals is different. In case of SP2 the crystal rotation axis, which is not a low-index crystal direction, oscillates around the sample TD axis. In SP3 scan, the crystal rotation axis is a low-index crystal direction, which aligns perfectly with the TD axis, indicating a higher quality of the recrystallized grain.

The microstructure of the Al film before single-grain growth in the SP2 scan is as-deposited sub-micron polycrystals, but it changes to lateral polycrystals in the SP3 scan. The initial microstructure prior to the single-grain growth may explain the difference in the quality of the recrystallized grains obtained by SP2 and SP3 scans. However, the reason for the selection of either [001] or [101] rotation axes depending on the power of the laser beam in SP3 scan is not clear in this study.

Because the laser beam was well focused during the scan path, an ultra-long single grain can be obtained with the length comparable with the scan distance.

4. Conclusions

Single-grain lines of 9 µm in width can be grown selectively in Al thin film by using a chevron-shaped laser beam annealing. The crystal quality and the morphology of the recrystallized grains depend on both the parameters of laser annealing and the parameters of the Al film. Details of the investigation results will be presented.

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References

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