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Homogeneous Recrystallization of Si Islands through Wafer by Dual Laser Beam Irradiation

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By using the dual laser beam recrystallization method in which the two dimensional shape of the trailing edge of molten zone is precisely controlled, Si islands formed in the area of 5 cm x 5 cm were homogeneously recrystallized all over the wafer. The ratio of the single crystalline islands to the all recrystallized islands was above 70 %. The ratio of the islands having (110) surface crystal orientation to all islands was about 65 %. The mean value ($\bar{\mu}_n$) and the standard deviation (σ) of the field effect mobility of n-MOS transistors, fabricated in these recrystallized Si islands, were calculated as 540 $cm^2/V{\cdot}sec$ and 84 $cm^2/V{\cdot}sec$, respectively.

1. Introduction

Recently, there is a great interest in the recrystallization of poly-Si on insulating substrate (SOI) by radiative energy. For the application to the 3-D devices, the laser beam or electron beam recrystallization methods have been intensively investigated since these methods do not affect the characteristics of underlying devices[1,2,3]. In particular, the laser recrystallization method is more attractive because it does not have the charge up problem as shown in the case of electron beam recrystallization.

To obtain a large single-crystalline area by a laser recrystallization method, the concave trailing edge of molten zone must be realized during laser irradiation[4]. Several methods to realize the concave trailing edge of molten zone, such as beam shaping[5], Si island structure[6], split beam[7] and stripe patterned antireflection layer[8], have been investigated. We have been investigated the recrystallization of the Si island by the dual laser beam irradiation.

This paper describes a homogeneous recrystallization of Si islands all over the wafer by newly developed dual laser beam irradiation system.

2. Dual Laser Beam recrystallization Method

The schematic diagram of the dual laser beam irradiation system is shown in Fig. 1. The laser

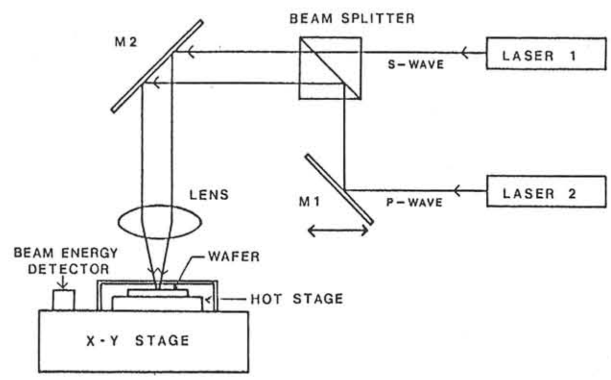


Fig.1 Schematic diagram of the dual laser beam irradiation system.

beam was composed of the two laser beams (CW Ar laser, 514.5 nm) through the polarization beam splitter and was focused on the wafer through the objective lens with the focal length of 100 mm. The distance between two peaks of the dual laser beam (d_p) was controlled by the movement of mirror M1 with the accuracy of 1 μm. The laser beam was scanned in the area of 5 cm x 5 cm by the movement of the X-Y stage with the accuracy of 2 μm. In this system, the energy intensity profile of the dual laser beam could be precisely controlled by d_p and laser power. The two dimensional intensity profile was directly measured by the photodiode which was mounted on the X-Y stage. Since an 1 μm pinhole was placed at the same level of the wafer over the photodiode, the equivalent intensity profile just on the wafer could be measured. The examples of two dimensional

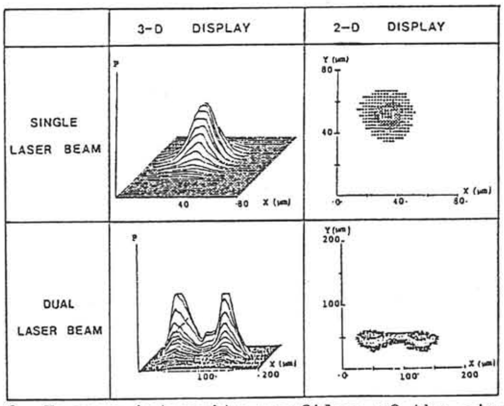


Fig.2 Energy intensity profiles of the single and dual laser beam.

measured intensity profiles are shown in Fig. 2. A circular intensity profile was obtained in the case of single laser beam and the expected concave intensity profile is obtained in the case of dual laser beam.

3. Experimental Results and Discussion

A continuous poly-Si film was recrystallized by the dual laser beam method. The poly-Si film was prepared as follows: a thermal SiO_2 of 0.5 μm thick was formed on a Si wafer and a poly-Si layer of 0.5 μm thick was deposited on the SiO_2 by LPCVD(610 °C). The laser irradiation was carried out under the following conditions: the substrate temperature of 400±5 °C, the scanning speed of 10 cm/sec and the ambient of nitrogen. Figure 3 shows the photomicrograph of the recrystallized continuous Si film after the delineation of grain boundaries by an anisotropic etching, resulting from the dual laser beam irradiation with d_p=18, 15 and 12 μm. In the case of d_p=15 μm, a single-crystalline region was grown at the center of the recrystallized band. However, in the case of

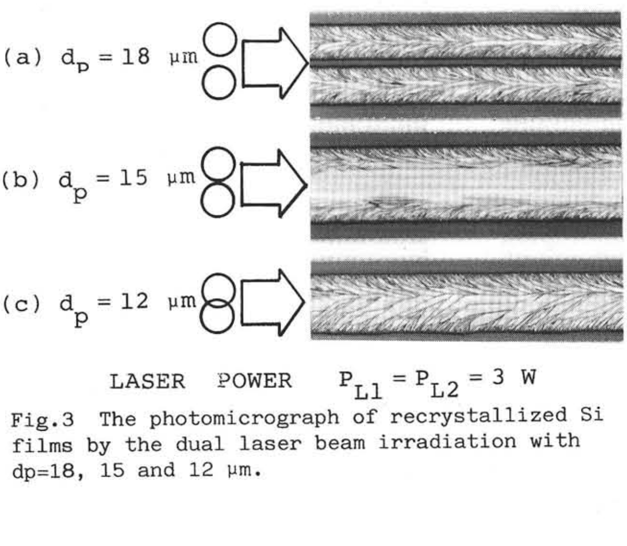


Fig.3 The photomicrograph of recrystallized Si films by the dual laser beam irradiation with dp=18, 15 and 12 μm.

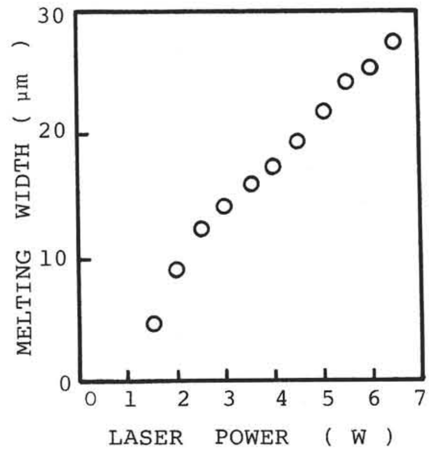
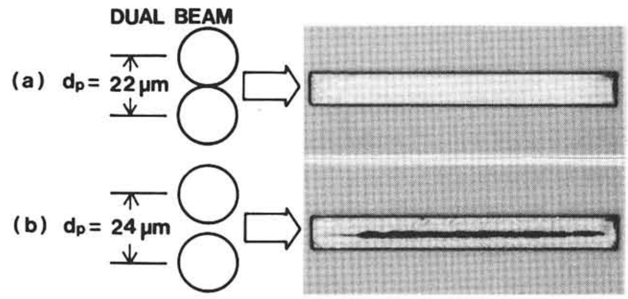


Fig.4 The dependency of melting width on laser power.

d_p=12, 18 μm, many grain boundaries appeared even at the center of the recrystallized band. Figure 4 shows the dependency of the recrystallized band width (W_s) on the laser power of single beam. Since the optimum energy profile was realized in the case that the peripheral edges of two recrystallized bands were just in contact as shown in Fig. 3, the recrystallized band width for the optimum d_p was about $2 \times W_s$. In this case, the single-crystalline zone grown at the center was about 15 μm. However, many micrograins originated in the peripheral edge of laser beam still existed.

We applied this dual laser beam recrystallization method to small Si islands. Rectangular poly-Si islands were made by a modified LOCOS method. To recrystallize poly-Si islands, the dual laser beam was aligned just on the center of these islands and scanned along the direction of the long axis of the islands.

Figure 5 shows typical photomicrographs of the recrystallized Si islands (W = 12 μm, L = 100 μm) after the delineation of grain boundaries. The conditions of recrystallization were as follows: the power of each laser beam P_{L1}=P_{L2}=3 W and d_p=22, 24 μm. In the case of d_p=22 μm, no grain boundary was observed, thus, the single-crystalline silicon covered all over the island. The result shows that the ideal concave trailing edge of molten zone was realized in the poly-Si island structure having the narrow width of W=12 μm. However, in the case of d_p=24 μm, the center of the island was kept polycrystalline. These results indicate that the steep temperature dis-



ISLAND W = 12 μm, L = 100 μm

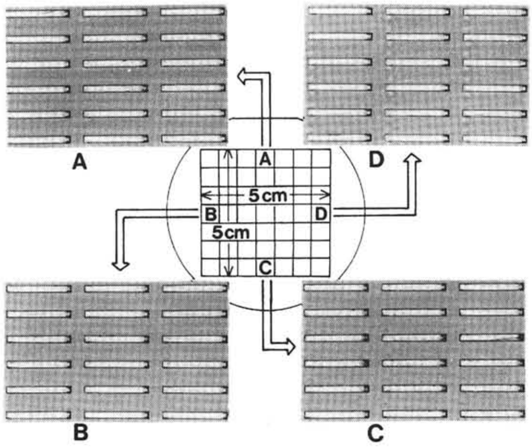
LASER BEAM $P_{L1} = P_{L2} = 3$ W

Fig.5 The photomicrograph of the recrystallized Si islands by the dual laser beam irradiation.

tribution, which strongly depends on d_p, was realized even in the narrow island of W = 12 μm.

The optimum d_p for the recrystallization of Si island having the width of 10 ∿ 14 μm was investigated. The crystallinity was estimated by the observation of grain boundaries after an anisotropic etching. The single-crystalline Si islands could be repeatedly obtained under the condition of d_p = 20 ∿ 23 μm.

With this optimized condition, a large area recrystallization was carried out by the dual laser beam irradiation. The Si island array was formed in the area of 5 cm x 5 cm on the 3 inch wafer. The island size was 12 μm x 100 μm. These islands were homogeneously recrystallized all over the wafer. The photomicrograph of a part of the recrystallized island array after the delineation of grain boundaries is shown in Fig. 6.



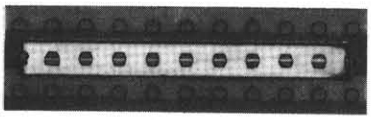
DUAL BEAM d_p=22 μm, $P_{L1}=P_{L2}=3$ w

ISLAND W=12 μm, L=100 μm

Fig.6 The photomicrograph of a part of the island array which was homogeneously recrystallized by the dual laser beam irradiation all over the area of 5 cm x 5 cm.

The generation of grain boundaries in each island all over the area of 5 cm x 5 cm was extremely suppressed by this dual laser beam recrystallization method. The ratio of the single-crystalline islands to the all recrystallized islands was above 70 %. The islands which includes the grain boundaries were randomly distributed all over the wafer. This result suggests that remaining grain boundaries were originated in the undesirable factors such as microstructural defects of Si islands, dusts or impurities in the poly-Si material and instantaneous fluctuation of the energy intensity profile during the laser irradiation process.

The surface crystal orientation of recrystallized Si islands was revealed by an anisotropic etching using a KOH solution. The photomicrograph of the typical etch pit pattern is shown in Fig. 7. In this case, it was found from the hexagonal etch pit pattern that the Si island had (110) surface crystal orientation[9]. The appearance frequency of the surface crystal orientation of the recrystallized Si islands in the array was roughly estimated by the observation of the etch pit pattern at the center of the island.



(1 1 0)

Fig.7 The photomicrograph of the etch pit pattern of (110) surface crystal orientation.

The result is summarized in Table I. The ratio of the islands having (110) surface orientation to all islands was about 65 %. The ratios of the islands having (111) and (100) surface crystal orientation to all islands were 7 % and 4 %, respectively. It has been previously reported that the as-deposited poly-Si film, which was grown at 610 °C by LPCVD, had the preferred (110) orientation[10]. To understand the strong (110) orientation anisotropy in the recrystallized Si islands, some effects due to the preferred orientation of the as-deposited poly-Si film must be considered.

The field effect mobility of the n-MOS transistors fabricated in the recrystallized Si islands was measured to evaluate the crystallinity. All of the 250 transistors having W/L =

Table I Distribution of the surface crystal orientation in the recrystallized Si islands.

ORIENTATION	RATIO (%)
(110)	65
(111)	7
(100)	4
OTHERS	24

(N=100)

10/3 μm are freely picked up all over the wafer to measure their properties. The distribution of the field effect mobility is shown in Fig. 8. The mean value ($\overline{\mu}_n$) and the standard deviation (σ) were calculated as 540 $cm^2/V{\cdot}sec$ and 84 $cm^2/V{\cdot}sec$, respectively. The mean value was about 90 % of that obtained in bulk Si. Within the limit of this evaluation, this average value of the mobility suggests that the crystal quality of the recrystallized Si islands was very close to that of bulk Si. Although the standard deviation of μ_n was improved from the value of about 30 %, which was obtained in the case of the conventional single laser beam recrystallization, to 15 %, the dispersion was not close to that of bulk Si. In this calculation of the mobility, it was assumed that the thickness of the gate oxide, the surface state density and the surface impurity concentration were constant all over the wafer, and the (110) surface crystal orientation was also assumed for the recrystallized islands. In further evaluation of a crystal quality by the μ_n, the dispersion of the above parameters in the recrystallized islands must be considered.

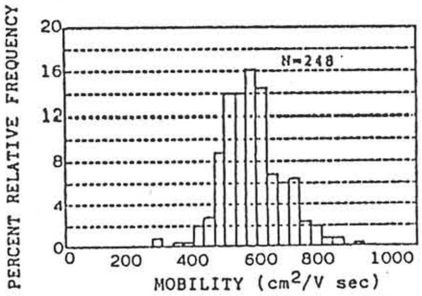


Fig.8 The distribution of the field effect mobility of the n-MOS transistors fabricated in the recrystallized Si islands.

4. Summary

1. The dual laser beam irradiation system was newly developed to realize the ideal two dimensional shape of the trailing edge of molten zone during laser irradiation.
2. Single-crystalline Si islands were successfully obtained in the area of 5 cm x 5 cm by the optimized dual laser beam irradiation method.

The possibility of homogeneous recrystallization through a wafer by the dual laser beam irradiation method was confirmed.

Acknowledgement

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