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Extended Abstracts of the 2022 International Conference on Solid State Devices and Materials, Makuhari, 2022, pp15-16

Controllability of Luminescence Wavelength from GeSn Wires Fabricated by Laser Zone Melting on Quartz Substrates

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Abstract

We examined the effects of laser scan speed and power on the Sn fraction and crystallinity of GeSn wires fabricated by laser zone melting on quartz substrates. The Sn fraction increased from 1 to 3.5% with the increase in the scan speed from 5 to 100 μm/s, corresponding to luminescence wavelength from 1770 to 2070 nm. This result can be understood as the scan speed dependence of the non-equilibrium degree during crystal growth. The increase in laser power reduced the Sn fraction and caused blue shift of luminescence wavelength. We discuss these phenomena based on the growth kinetics of zone melting.

1. Introduction

Silicon photonics is a technology that integrates optical devices using microfabrication technology that has been developed as silicon technology [1]. Since it is possible to integrate optical and electronic circuits, various applications are being investigated not only for optical communication but also for quantum computing and environment/life sensing. However, the light sources are made of III-V materials and they are stacked by bonding process. If the light source can be formed of group IV materials such as Ge, a much broader range of applications is expected because of dramatic cost reduction.

Ge is indirect bandgap semiconductor as Si, but the energy difference at the bottom of the conduction band between the Γ and the L point is only 137 meV [2]. Therefore, various studies have been attempted to improve the optical properties. One of them is the incorporation of Sn atoms into Ge crystal, enabling the direct bandgap GeSn semiconductor. However, there are many subjects to solve in growing the GeSn single crystal layer.

Currently, we are evolving growth method using laser annealing [3]. In this method, amorphous GeSn wires covered with SiO_2 are partially melted by laser annealing (Fig. 1). Crystal growth proceeds with laser scan along the wires. This method is called as zone melting, commonly employed to grow bulk crystals or to control impurities in materials. In our case Sn fraction in the crystalline GeSn wires depends on the initial Sn fraction, zone width, and segregation coefficient (the ratio of Sn atoms in the crystal to that in the liquid phase).

In this study we investigated the effects of laser scan speed and power on the Sn fraction and crystallinity of the crystalline GeSn wires towards the precise control of Sn fraction. Laser scan speed changes the segregation coefficient depending on the non-equilibrium degree of growth. Laser power affects the zone width.

2. Experimental

Amorphous GeSn layers of 200 nm thickness were formed at 300°C on quarts substrates by molecular beam deposition. Sn fraction is approximately 2% inside the film, but many Sn atoms segregated on the surface, so that the total Sn fraction is much larger than 2%. Wire patterns of 1 μm width, 1 μm space, and 1 mm length were fabricated by photo lithography and reactive ion etching. After capping with 1 μm thick SiO_2 layer, laser anneal was performed. The wavelength of laser light is 808 nm, the illumination area is approximately 0.16 mm × 3 mm. The laser scan speed was ranging from 5 to 100 μm/s. The laser light power was ranging from 10.7 to 19 W.

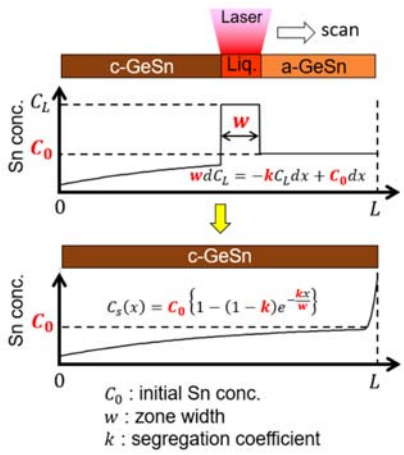

Fig. 1 Schematics of laser zone melting

3. Results and Discussion

Figure 2 shows optical images of the GeSn wires fabricated by laser zone melting with different scan speed. The GeSn wires of 5 μm/s have many wire breakings and short Sn precipitates of several micrometer length. At this scan speed the melting time at a certain position of the GeSn wires is as long as approximately 32 s, so that the Ge atoms aggregated during the long melting time.

The GeSn wires of 25 μm/s still have many breakings, but the number of breakings decreased comparing to the wires of 5 μm/s. This is because the melting time has become shorter. In addition, we consider that most of breakings are partially connected since the length of Sn precipitates became longer, typically 20 μm length. The Sn precipitates are distributed from the center to the growth end of the wires. Slow scan speed causes equilibrium growth and the Sn fraction in the melting zone rapidly increases during the scan because it is determined by the difference in the Sn fraction in between the amorphous GeSn wires and the crystalline ones, resulting in the Sn precipitates during the growth.

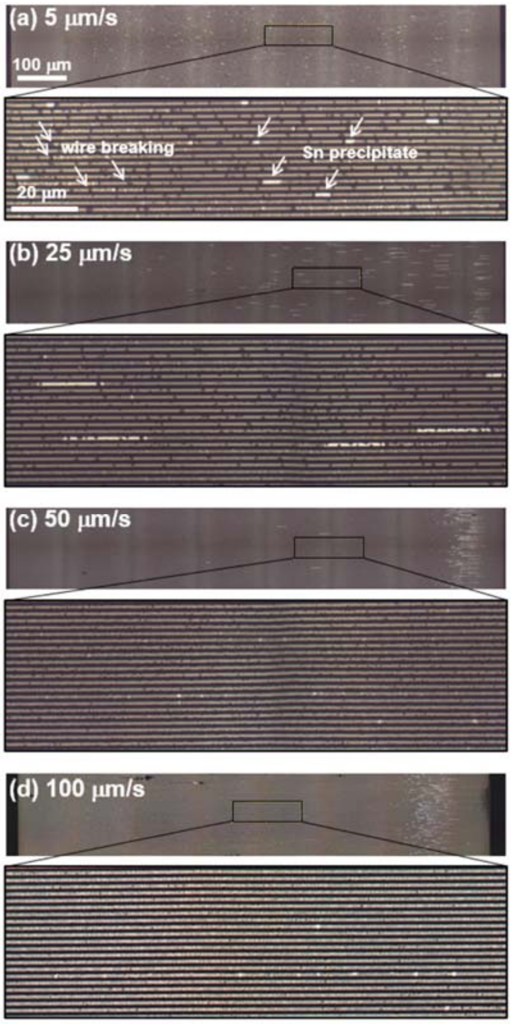

Fig. 2 Optical images of the GeSn wires fabricated by laser zone melting with different scan speed. Arrows show some of wire breakings and Sn precipitates. Scan direction is from left to right.

In the GeSn wires of 50 μm/s, wire breaking is not seen and most of Sn precipitates exist at the growth end of wires. This result indicates that standard crystal growth by zone melting has progressed. Fast scan causes non-equilibrium growth, resulting in high Sn fraction in the crystal GeSn wires. The rapid increase of Sn fraction in the melting zone and the Sn precipitates during the scan were suppressed.

We see the similar results in the GeSn wires of 100 μm/s, where wire breaking is not seen and most of Sn precipitates exist at the growth end of wires. However, we see small Sn precipitates on the wires. This is due to excess non-equilibrium growth caused by very high scan speed.

Figure 3 shows typical PL spectra from these wires. We see that peak wavelength increases from 1770 to 2070 nm with the increase in the scan speed. If we assume 0.4% tensile strain in the GeSn wires originated from the difference in the thermal expansion coefficient between the GeSn wires and the substrate, Sn fractions are estimated to be from 1 to 3.5%. This means that we can control the Sn fraction by changing the scan speed. The PL peak intensity changes depending on the crystallinity of the GeSn wires. However, it should be noted that the PL peak intensity of pure Ge crystal obtained by the same setup is much weaker than these peaks. The peak intensity of the GeSn wires of 50 μm/s is approximately 100 times as that of the Ge crystal.

We also investigated the effects of laser power on Sn fraction of the GeSn wires. As the results, we found that the increase in laser power causes the reduction of Sn fraction accompanying with the blue shift of the PL peaks.

These results indicate that laser zone melting is a very effective method to control the luminescence wavelength and crystallinity of GeSn wires.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Numbers 20H02620, 21K04880, 22H01528.

References

[1] D. J. Lockwood, and L. Pavesi, Silicon Photonics IV: Innovative Frontiers (Switzerland: Springer) (2021).
[2] J. Michel *et al.*, Nat. Photonics **4** (2010) 527.
[3] H. Oka *et al.*, 2017 IEEE International Electron Devices Meeting (IEDM), 2017, pp. 16.3.1-16.3.4.

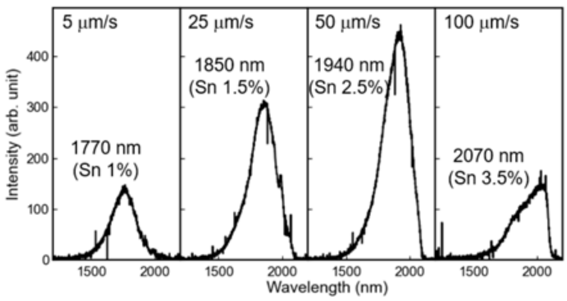

Fig. 3 PL spectra of the GeSn wires fabricated by laser zone melting with different scan speed. Sn fractions estimated from peak wavelengths assuming 0.4% tensile strain are shown. The measurements were performed at RT.