# High mobility sputtered InSb film by blue laser diode annealing

Cite as: AIP Advances **9**, 045009 (2019); https://doi.org/10.1063/1.5087235
Submitted: 30 December 2018 . Accepted: 25 March 2019 . Published Online: 10 April 2019

C. J. Koswaththage, T. Higashizako, T. Okada, T. Sadoh, M. Furuta, B. S. Bae, and T. Noguchi

# High mobility sputtered InSb film by blue laser diode annealing

Cite as: AIP Advances 9, 045009 (2019); doi: 10.1063/1.5087235
Submitted: 30 December 2018 • Accepted: 25 March 2019 •
Published Online: 10 April 2019



C. J. Koswaththage,[1,a] T. Higashizako,[1] T. Okada,[1] T. Sadoh,[2] M. Furuta,[3] B. S. Bae,[4] and T. Noguchi[1,b]

## AFFILIATIONS

[1] Faculty of Engineering, University of the Ryukyus, 1 Senbaru, Okinawa 903-0213, Japan
[2] Graduate School of Information Science and Electrical Engineering, Kyushu University, Fukuoka 819-0395, Japan
[3] Department of Environmental Science and Engineering, Kochi University of Technology, Kochi 782-8502, Japan
[4] Department of Display, Hoseo University, Cheonan, Asan 31499, South Korea

[a] **Author to whom correspondence should be addressed:** charithjayanada@gmail.com
[b] **E-mail:** tnoguchi@tec.u-ryukyu.ac.jp

## ABSTRACT

InSb thin film was deposited on glass by r.f. sputtering using the InSb (atomic ratio of 1:1) target. The film was capped by $SiO_2$ film to prevent the effusion of Sb of low melting point. After that, blue laser beam at 445 nm of controlled power density was irradiated using CW scanning mode. The film was crystalized successfully with keeping the ratio of In and Sb as (1:1). High electron Hall mobility of 1,050 $cm^2/(Vs)$ was obtained without degrading under glass. New device applications such as magnetic or infrared sensor system with poly Si TFTs are expected not only on glass but also on flexible panel such as on plastic sheet.



## I. INTRODUCTION

Indium Antimonide (InSb) is widely used in magnetic field sensors, in thermal imaging cameras and in infrared detectors due to its high carrier mobility.[1–6] Generally, as InSb layer with high carrier mobility is obtained by epitaxial growth on single-crystal substrate using semiconductor process such as molecular beam epitaxy (MBE), the size is limited due to the high fabrication cost. That is why the application of InAb material is limited even if the performance is high relating to the high carrier mobility. On the other hand, fabricating InSb film on glass substrate has high potential from the perspective of low-cost process and functional applications as a system on panel which is widely applied to functional display systems.

Conventionally, in the Hall device fabrication process, InSb film deposited on mica substrate is thermally annealed to crystallize it. As the sheet mica is a natural material of limited source and by its high commercial demand, fabrication cost on mica substrate is becoming expensive. In this case, glass substrate is a preferable candidate. In case of forming InSb film on a glass substrate by thermal evaporation, the electron mobility shows lower compared to the case of depositing on conventional mica substrate. Previously, various studies have been done on annealing effect of InSb.[7,8] On glass, by heat treating using furnace annealing (FA), rapid thermal annealing (RTA) or blue laser diode annealing (BLDA)[9] after forming amorphous InSb film using thermal evaporation method, the enhancement of the crystallinity of the InSb film and high carrier mobility can be expected.

Low Temperature Poly Silicon (LTPS) Thin Film Transistors (TFTs) with high mobility have many advantages for Organic Light Emitting Diode (OLED) pixel and for Liquid Crystal Display (LCD) such as low power consumption and integrating the functional circuits on a panel. However, fabrication cost for LTPS TFT process adopting ELA is high. In addition, source and drain (S/D) of the top gate poly Si TFT is formed by using ion implantation, the equipment and maintenance cost become expensive and subsequent high temperature activation is required. Excimer laser annealing (ELA) is an effective crystallization technique, as high energy of the UV pulse is absorbed effectively in thin Si film. LTPS fabrication process is applicable to high performance flexible panel. It has been reported that LTPS TFT with metal S/D was fabricated by ELA without using impurity ion doping.[10] Some amount of cost reduction and weight

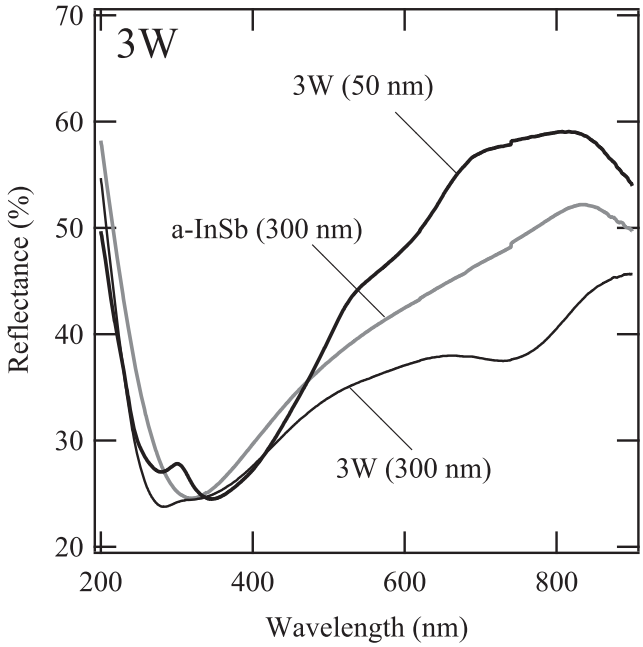


**FIG. 1**. Reflectance spectra of InSb films after BLDA.[13]

reduction can be expected by fabricating TFT on plastic substrate. On the other hand, BLDA has been proposed as a new LTPS process because the grain size can be controllable by just changing the power with maintaining the surface of Si films smooth.[11]

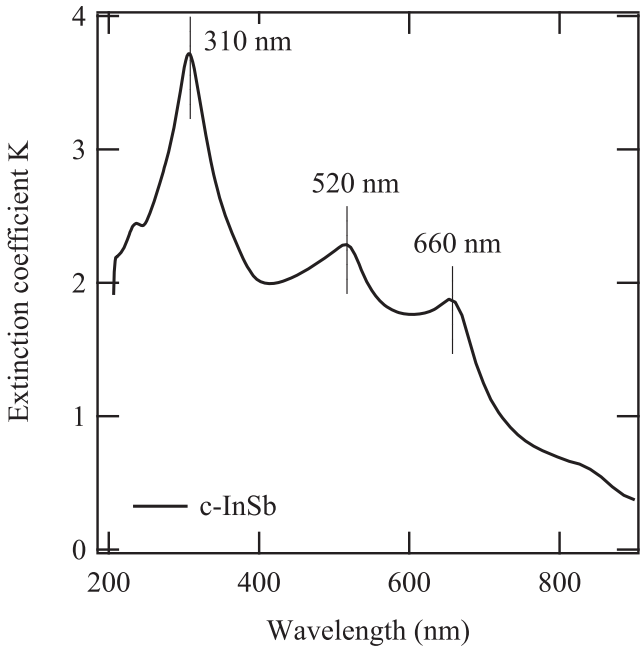


**FIG. 2**. Extinction coefficient of crystalline InSb. (Source: Winelli Database).

In this research, InSb films were subjected to BLDA in place of RTA on glass to be applied on flexible sheet as a functional sensor system on panel, and the crystallinity, composition and electrical properties of the films were investigated.

## II. FABRICATION OF InSb FILM

Sputtering has advantages such as room temperature deposition and large area deposition compared to vacuum evaporation. InSb films of 50 and 300 nm thickness were deposited on glass substrates, respectively, using sputtering with Ar (7.0 mTorr) atmosphere and subjected to BLDA. Films were capped with 50 nm thick $SiO_2$ layer before performing BLDA to keep the ratio of In and Sb in the film.[12]

BLDA was controlled to 3W or 4W laser power with a scanning speed of 500 mm/s. Crystallinity and electrical properties of the films were investigated. In the range between 200 nm to 900 nm wavelength, reflectance spectrum was measured before and after annealing to evaluate the crystallinity of InSb films.

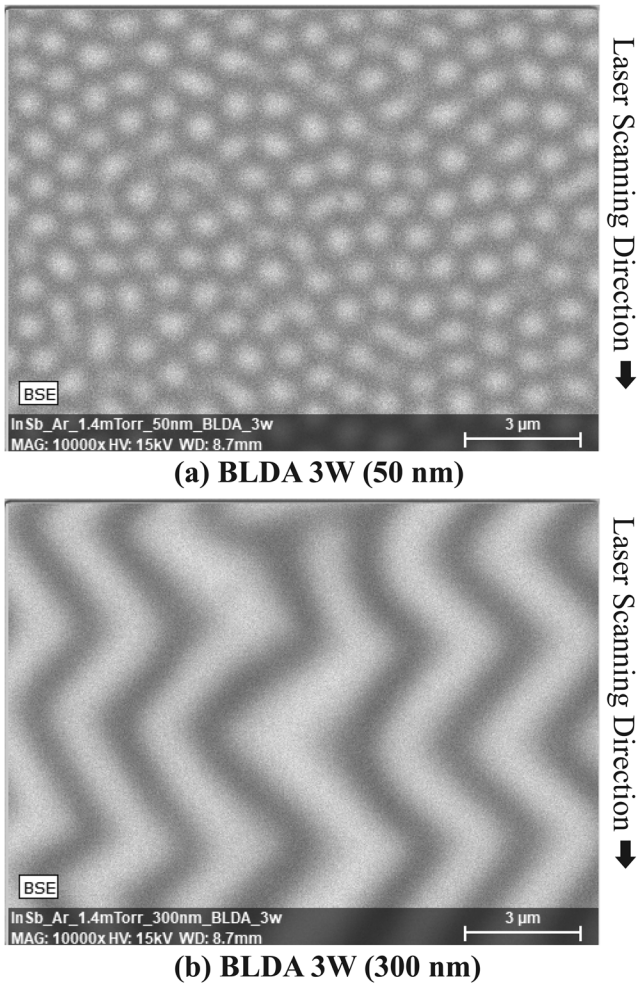


**FIG. 3**. Surface morphology by SEM of sputtered InSb films after BLDA.[13]

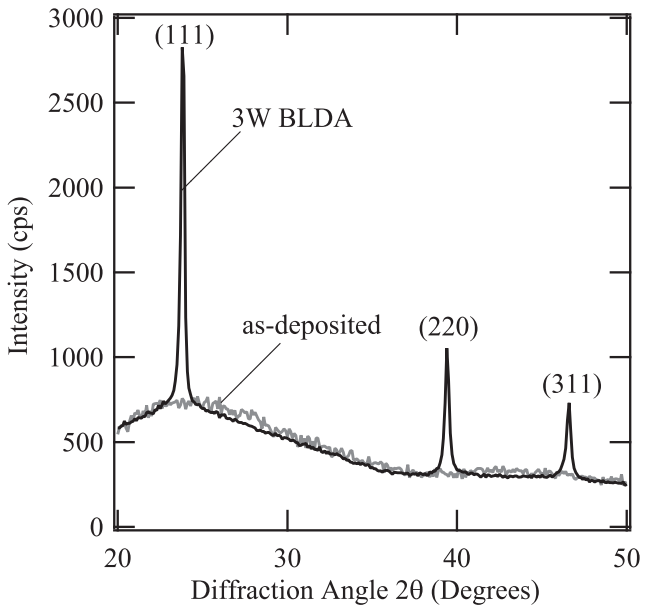


**FIG. 4**. XRD analysis results of InSb film after BLDA.[14]

After evaluating the surface morphology and the crystallinity in the films, Au electrodes were deposited on InSb film using vacuum evaporation for Hall mobility measurement. Distance among each electrode was 9 mm. Hall effect measurement was conducted under flux density of 0.31 T.

## III. RESULTS AND DISCUSSION

### A. Crystallinity analysis of InSb films by spectral transmittance

Fig. 1 shows the reflectance of InSb films. As a result of Reflectance spectroscopy, peaks were observed at around 310, 520 and 660 nm after BLDA (Fig. 1), which corresponds to the extinction coefficient peaks of crystalline InSb (Fig. 2). It is considered as InSb films were crystalized after BLDA.

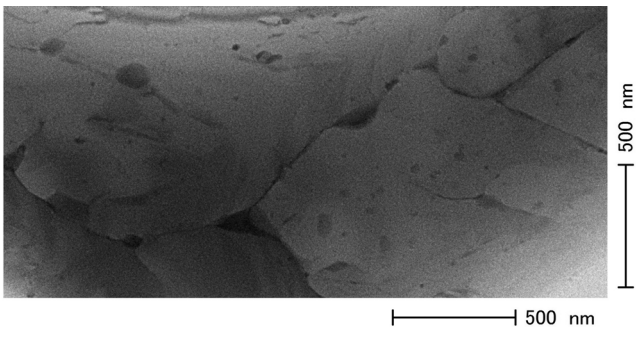


**FIG. 5**. TEM image of InSb film after BLDA.

### B. Surface morphology by SEM

Fig. 3 shows the scanning electron microscopy (SEM) images of InSb; (a) for the film of 50 nm thickness after BLDA, (b) for the film of 300 nm thickness after BLDA.[13] Compared to 50 nm thick InSb film, long and continuously large grain-like structure was observed in Fig. 1. It is speculated that, thin InSb film will reach to a higher temperature than that of thick film. Therefore, the surface is melted completely and crystallized. But in the case of thick film, BLDA moves before the surface is completely melted, and long grains may

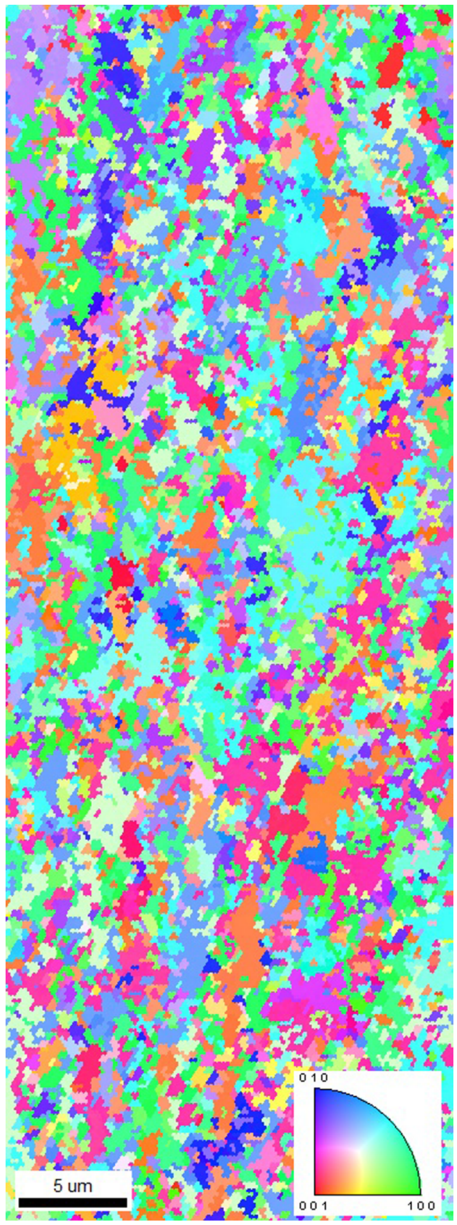


**FIG. 6**. EBSD results of InSb film (orthogonal direction).

**TABLE I**. EDS analysis of InSb films after BLDA.

| Ar 1.4 mTorr | | In % | Sb % |
|---|---|---|---|
| 300 nm | as-depo | 52.6% | 47.4% |
| | 3 W | 51.3% | 48.7% |
| | 4 W | 51.6% | 48.4% |

have formed along the BLDA scanning direction. It is speculated that larger grains are formed for thicker films.

### C. Crystallinity evaluation by XRD

Grain structure of the InSb film after applying BLDA was analyzed by X-ray diffraction (XRD). From the results by XRD analysis as shown in Fig. 4, peak of (111) crystal orientation was observed in the vicinity of 23°. Moreover, since the peak is also confirmed in (220) and (311) angles, InSb film is believed to be poly-crystallized.

### D. Crystal structure analysis by TEM and EBSD

Fig. 5 shows a plane-view TEM (Transmission Electron Microscopy) image of 300 nm thick InSb after applying 3W BLDA. Large grains roughly larger than 1$\mu$m were obtained.

To investigate the crystal orientation of the crystal grains, electron backscatter diffraction (EBSD) analysis was performed. Fig. 6 shows the EBSD map showing the crystal orientation perpendicular the sample surface for 300nm InSb films after applying 3 W BLDA. The EBSD result shows that the grown layer consists of randomly oriented crystal grains (diameter: 2-3 μm), where the value of the diameter well agrees with the TEM observation, as shown in Fig. 5.

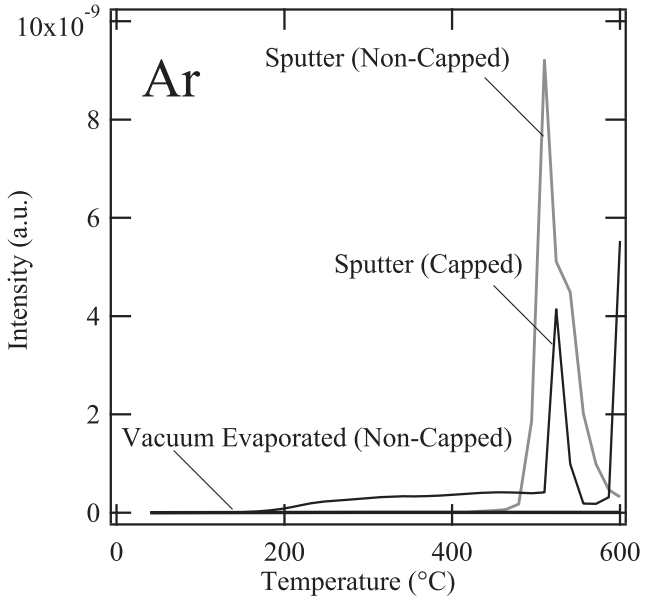


**FIG. 7**. TDS results of InSb film for Ar gas.[14]

Dominant nuclear generation in the bulk may cause different oriented structure. However, precise grain growth mechanism of III-V compound should be studied.

### E. In:Sb composition ratio by EDS analysis

Table I shows the energy-dispersive X-ray spectroscopy (EDS) analysis results for InSb films before and after BLDA. From the In:Sb composition results, it is certain that ratio of In vs Sb (1:1) is

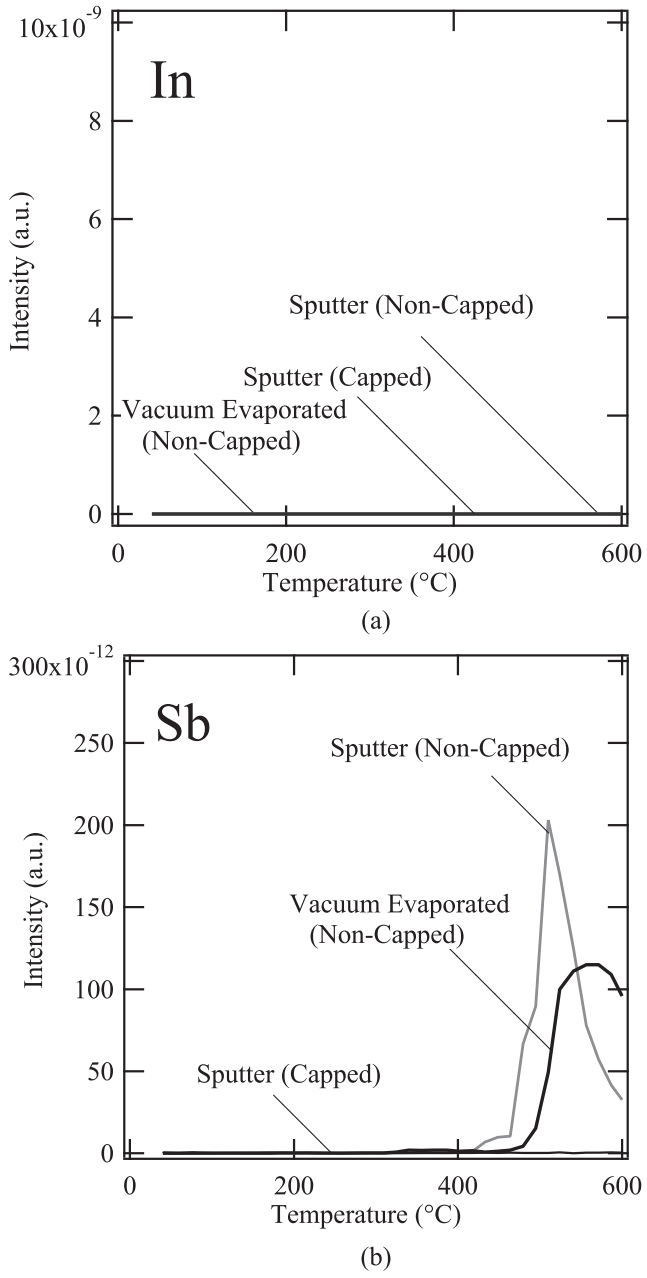


**FIG. 8**. (a) TDS results of InSb film for In.[14] (b) TDS results of InSb film for Sb.[14]

maintained when the films are annealed by keeping the $SiO_2$ cap. Therefore, $SiO_2$ capping is effective not only in RTA but also in BLDA.

### F. De-gas analysis of InSb films by TDS

De-gas analysis of InSb films were conducted using Temperature Desorption Spectrometry (TDS). InSb film of 300 nm thickness was deposited using RF sputtering at the pressure of 7 mTorr. For the InSb film deposition, Ar was used as the sputter gas. After InSb deposition, one of the sputtered films was capped with 50 nm thick $SiO_2$ film by sputtering. Furthermore, thermal evaporated InSb film of 1$\mu$m thickness and $SiO_2$ was also prepared. All films were subjected to TDS (Device name: ESCO TDS 1200 II). Temperature was increased from room temperature to 600°C at the rate of 60°C/min in a vacuum of $1\times10^{-7} \sim 1\times10^{-8}$ Pa.

Fig. 7 shows the TDS results of InSb film for Ar gas.[14] For sputtered film, gas release started early (490°C) in the case of non-capped film than that of capped film (510°C). This proves that $SiO_2$ capping is effective. Any of the gas was not released for the non-capped thermal evaporated InSb film. Sputtered film has high intensity compared to thermal evaporated film. This suggests that evaporated InSb film has less impurities than that of sputtered film.

Fig. 8 shows the TDS results of InSb film for (a) In and (b) Sb. In or Sb was not released for both capped sputtered and thermal evaporated InSb films.[14] However, Sb was released in the case of non-capped sputtered and thermal evaporated films. From Fig. 8(b) shows that release of Sb started earlier (430°C) in the case of non-capped sputtered film than that of non-capped thermal evaporated film (480°C). This result suggests that extending the annealing time near 430°C may improve the crystallinity of sputtered InSb films by capping with $SiO_2$ or another material.

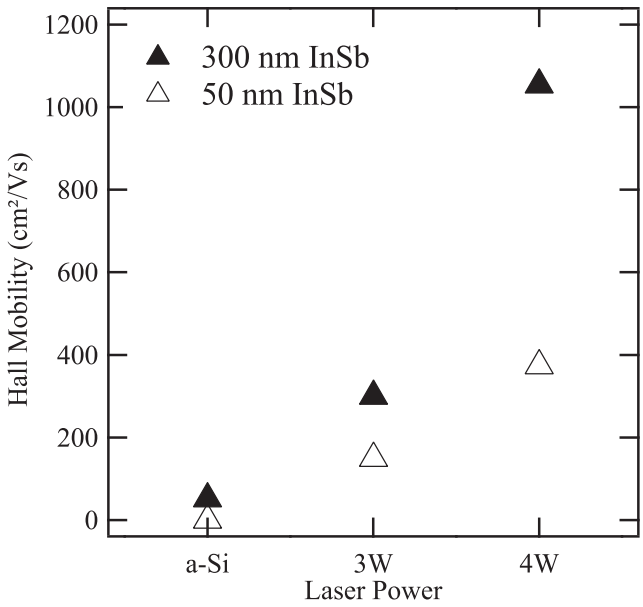


**FIG. 9**. Dependency of Hall mobility on BLDA power for InSb on glass.[13]

### G. Hall mobility

Fig. 9 shows the dependence of electron Hall mobility on laser power for the InSb samples sputtered with Ar gas at a pressure of 1.4 mTorr. The Electron Hall mobility was measured for the samples of both 50 nm and 300 nm thickness after removing capped $SiO_2$. High electron Hall mobility was obtained with InSb films of thicker 300 nm film than that of 50 nm thick film. In case of changing BLDA power, higher electron Hall mobility was obtained for the film with rather higher 4 W laser irradiated sample than that 3 W laser irradiated film. It is speculated that large grains are expected to be formed with thicker films at high laser power condition.

## IV. CONCLUSION

For the sputtered InSb film with effective SiO2 capping, after BLDA, maximum Hall mobility of 1,050 $cm^2/(Vs)$ was obtained with the InSb film sputtered with Ar gas at the pressure of 7.0 mTorr. InSb film having a high mobility keeping the stoichiometry was realized by BLDA on glass at a temperature lower than the melting point (525°C) of the single-crystal InSb.

New high mobility device applications such as high-resolution IR detectors, magnetic field sensors and ultra-speed transistors are expected by crystallizing the InSb film not only on glass by RTA, but also on flexible substrate by BLDA.

## REFERENCES

[1] R. Phelan, Appl. Phys. Lett. **10**, 55 (1967).
[2] T. Ashley, A. Dean, C. Elliott, G. Pryce, A. Johnson, and H. Willis, Appl. Phys. Lett. **66**, 481 (1995).
[3] I. Bolshakova, Sens. Actuator A-Phys. **76**, 152 (1999).
[4] K. Togawa, H. Sanbonsugi, A. Lapicki, M. Abe, H. Handa, and A. Sandhu, IEEE Trans. Magn. **41**, 3661 (2005).
[5] I. Shibasaki, J. Jpn. Soc. Powder Powder Metall. **61**, S335 (2014).
[6] R. Masutomi and T. Okamoto, Appl. Phys. Lett. **106**, 251602 (2015).
[7] J. Chyi, D. Biswas, S. Iyer, N. Kumar, H. Morkoç, R. Bean, K. Zanio, H. Lee, and H. Chen, "Molecular beam epitaxial growth and characterization of InSb on Si," Appl. Phys. Lett. **54**(11), 1016 (1989).
[8] M. Tomisu, N. Inoue, and Y. Yasuoka, "Annealing effect of vacuum evaporated InSb thin films," Vacuum **47**(3), 239–242 (1996).
[9] T. Noguchi, Y. Chen, T. Miyahira, J. de Dieu Mugiraneza, Y. Ogino, Y. Iida, E. Sahota, and M. Terao, "Advanced micro-polycrystalline silicon films formed by blue-multi-laser-diode annealing," Jpn. J. Appl. Phys. **49**, 03CA10 (2010).
[10] T. Noguchi, Y. Chen, T. Miyahira, J. de Dieu Mugiraneza, Y. Ogino, Y. Iida, E. Sahota, and M. Terao, Jpn. J. Appl. Phys. **49**, 03CA10 (2010).
[11] K. Shirai, J. de Dieu Mugiraneza, T. Suzuki, T. Okada, T. Noguchi, H. Matsushima, T. Hashimoto, Y. Ogino, and E. Sahota, Jpn. J. Appl. Phys. **50**, 021402 (2011).
[12] C. J. Koswaththage, T. Okada, T. Noguchi, S. Taniguchi, and S. Yoshitome, "Ultra-high carrier mobility InSb film by rapid thermal annealing on glass substrate," AIP Advances **6**(11), 115303 (2016).
[13] C. J. Koswaththage, T. Higashizako, T. Okada, and T. Noguchi, "Electrical characteristics of InSb films after BLDA," The 78th JSAP Autumn Meeting (2017).
[14] C. J. Koswaththage, T. Higashizako, T. Okada, and T. Noguchi, "Electron hall mobility of Ne and Ar sputtered InSb films for advanced sensor applications on glass," 14th International Thin-Film Transistor Conference (2018).