Summary report of the ISS-Kibo utilization mission, “Crystal Growth of Alloy Semiconductor Under Microgravity (Alloy Semiconductor)”

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1. Background and Purpose

$In_xGa_{1-x}Sb$ is a ternary alloy that has tunable properties between its binary compounds InSb and GaSb. The cut-off wavelength of $In_xGa_{1-x}Sb$ can be varied in the range 1.7 - 6.8 μm, and hence it can be used as infrared detectors. However, it is difficult to grow high-quality bulk crystals of the alloy under terrestrial (1G) conditions because the solute and heat transport are influenced by convection, which affects the quality of the crystals. Under microgravity (μG) conditions, it is feasible to suppress the complex convective heat and mass transports to gain deeper insight into the transport phenomena. The purpose of the present space mission was to make clear the factors for crystal growth mechanism by investigating (1) solute transport in liquid and (2) surface orientation dependence of growth kinetics under μG and 1G.

2. Experimental procedure

Samples with a GaSb/Te-doped InSb/GaSb sandwich structure were used for the growth of the $In_xGa_{1-x}Sb$ bulk crystal under μG at the ISS-Kibo by a vertical gradient freezing method. We were making a sequence of experiments to understand the orientation-dependent growth properties along different primary planes of GaSb (111)A, (111)B, (110), and (100) seeds. The dissolution lengths of the seed and feed crystals, the growth rate, and the composition and the etch pit density in the grown crystal were measured. Heat pulses were applied during the process at intervals of two hours to induce the impurity striations corresponding to the growth interface.

3. Results

The composition and the growth rate for all the samples were compared with those of numerical simulations. The following phenomena were found under μG experiments.

1) The composition uniformity and quality of the crystals were improved under μG than 1G. The growth rate was enhanced under μG than 1G. (**Figs. 1 and 2**). Under 1G the growth rate was damped because buoyancy convection prevented diffusive transport of GaSb in InGaSb melt to the growth surface from the feed.
2) The initial growth morphology for both (111)A and (111)B samples were almost flat because of the anisotropic growth kinetics (**Fig. 3**). The dissolution of GaSb (111)B was higher than that of (111)A and the growth rate of InGaSb from GaSb (111)B was greater than that of GaSb (111)A.The differences of the dissolution length and growth rates can be explained by attribution of different number bonds in unit cell at the crystal surfaces.

Moreover, the numerical simulation showed a possibility that the growth kinetics of the seed crystal influenced the dissolution rate of the feed crystal.

4. Achievements

The project results contribute the following achievements: 13 peer-reviewed original articles, 2 reviews, 30 presentations at international conferences, 15 presentations at domestic conferences, 1 newspaper article, 3 degrees, 7 awards, and 2 external funds.

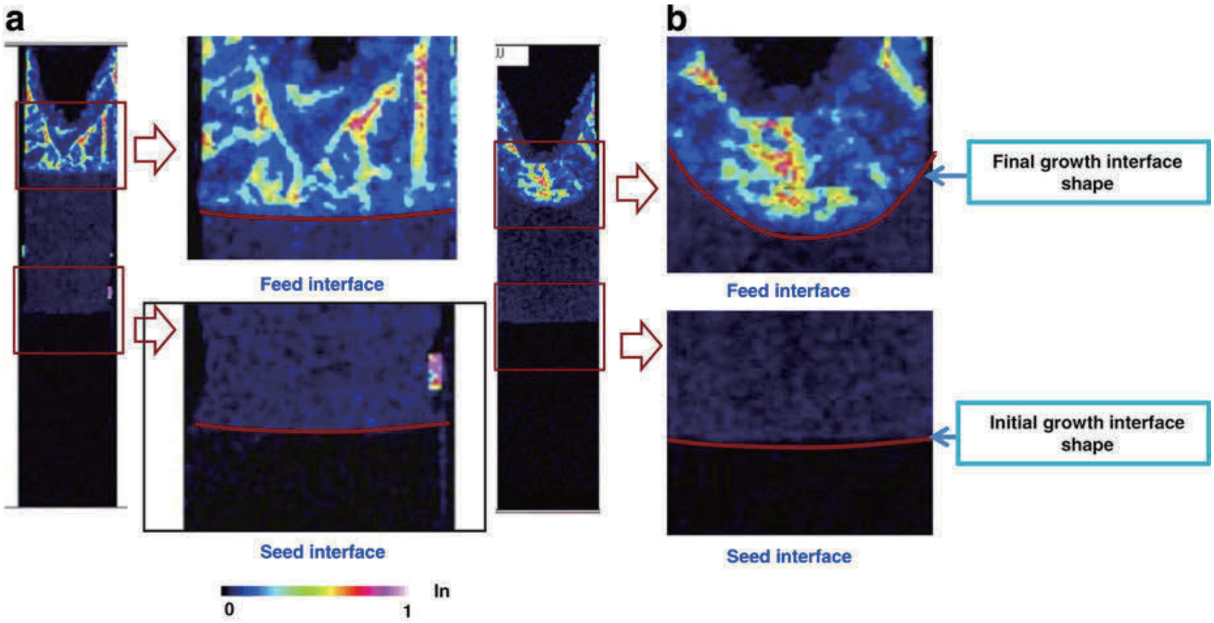

Fig. 1 EPMA mapping of indium distribution in (a) μG and (b) 1G. [1]

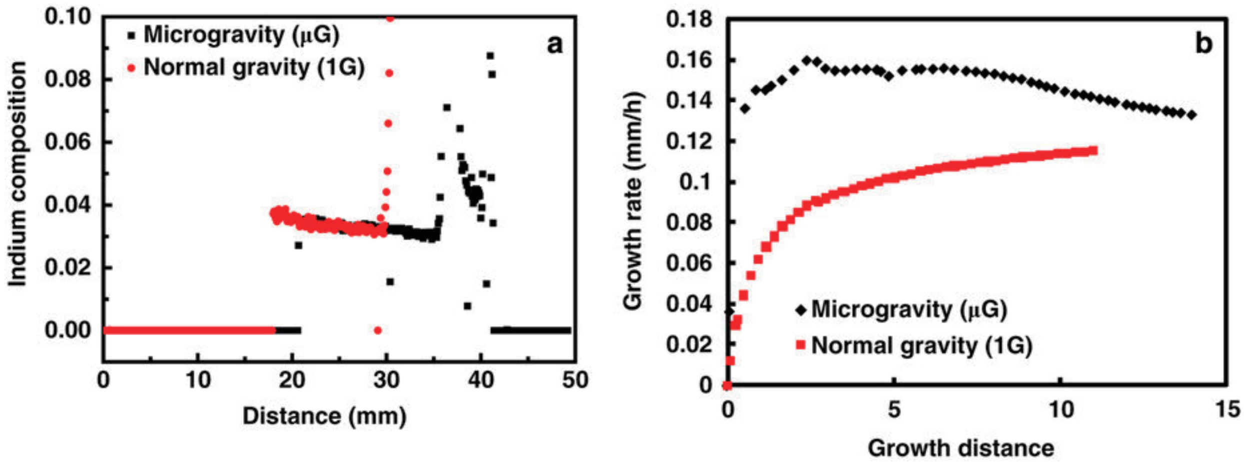

Fig. 2 (a) Indium composition profile and (b) growth rate variations along growth direction. [1]

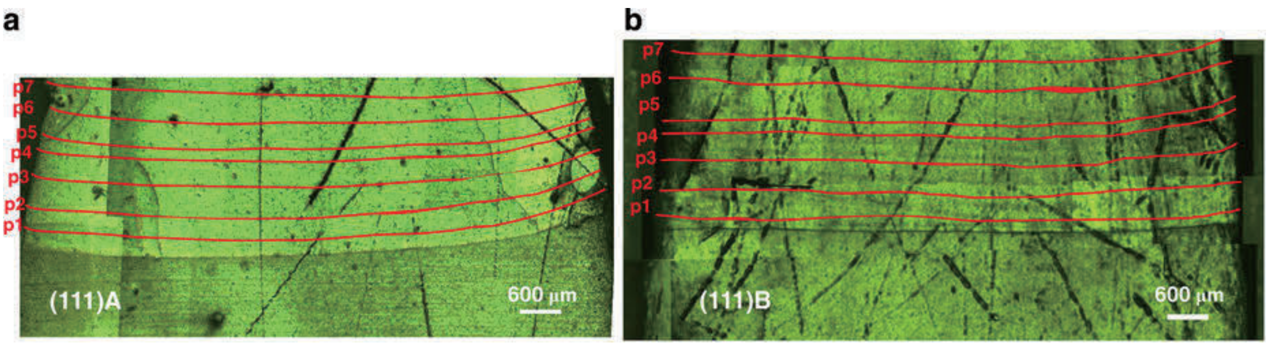

Fig. 3 Initial seed interface shape and impurity striations of (a) (111)A and (b) (111)B samples. The striations are marked as solid lines in the optical microscopic images of the etched samples. [2]

References

1) Y. Inatomi *et al.*, *npj Microgravity* **1** (2015) pp. 15011 1-6.
2) V. Nirmal Kumar *et al.*, *npj Microgravity* **2** (2016) pp. 16026 1-7.