MOCVD 法による InGaP 成長における GaAs 基板微傾斜の影響
Impact of GaAs substrate mis-orientation on InGaP grown by MOVPE

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1 Introduction

We reported previously in this community [1] the development of InGaP solar cells grown in a planetary MOVPE reactor using tertiarybutyl-phosphine (TBP) as P source which has a relatively lower intrinsic toxicity than PH_3. Despite the fact that InGaP layers grown with TBP generally have worse quality than that grown with PH_3 [2], we have realized acceptably good InGaP solar cells with open circuit voltages (V_{oc}) of about 1.40 V [1]. This is owing to the optimization of growth conditions, especially reactor temperature, and device structure utilizing rear homo or hetero junctions with thick n-type InGaP base layer. To further improve the conversion efficiency of our InGaP cells, we focus on the control of Cu-Pt ordering effect in InGaP. In addition to the growth temperature, the degree of ordering in MOVPE grown InGaP is also altered by mis-orientation of substrates. Therefore, in this work, we investigated the influences of mis-orientation of GaAs (001) substrates on the growth behavior, crystal quality, and performance of InGaP solar cells.

2 Experimental details, results and discussion

The experiment was carried out in a planetary MOVPE reactor. The reactor pressure and substrate temperature during the growth were kept at 100 mbar and 560 °C, respectively. Zn-doped GaAs (001) wafers with various mis-orientration including exact, 5° toward (110), 5° toward (111)A, and 6° toward (111)B were used. First, double-hetero (DH) samples comprising of 1-μm thick InGaP sandwiched between InAlGaP cladding layers were fabricated. In-situ reflectance measurement revealed that the growth rate of InGaP on 6B was the fastest, followed by 5A, exact and 5(110). X-ray diffraction patterns showed lattice matched InGaP for all mis-orientation, except for 6B sample with a very slightly In-rich condition. Indium incorporation rate into InGaP seemed to be enhanced with a miscut toward (111)B. The 5A sample had the strongest PL intensity and closely followed by the exact sample, but the 5(110) and 6B had only one fifth and one tenth of 5A intensity, respectively. The carrier lifetime was the longest for 5A and the shortest for 6B, while the other two samples had a very similar lifetime, as shown in Fig. 1(a). These results suggested that the quality InGaP grown 5A substrate was possibly the best, and the degree of ordering was considerably the smallest. After that, InGaP solar cells with rear p-InAlGaP/n-InGaP hetero-junction were grown on GaAs wafers with various mis-orientations. The I-V measurement in Fig. 1(b) showed that the 6B solar cell had a low V_{oc} of about 1.30 V, compared to 1.38 V of exact and 5A cells. Although the InGaP grown on 6B had a slightly In-rich condition, this could not be an only reason of V_{oc} degradation. Additional explanation could be the quality of InGaP on 6B which was deteriorated from the accented ordering effect. The 5(110) solar cell had also a degraded V_{oc} of 1.36 V, but this decrease was not as much as 6B case. Although the carrier lifetime in InGaP on 5A was much longer than that on exact GaAs, their V_{oc} were almost similar. Hence, there should be other factors, for example, hetero-interfaces, in addition to the quality of InGaP that limit the cell efficiency.

3 Summary

GaAs (001) substrates with 5° miscut toward (111)A are considered as the best choice for growth of InGaP solar cells by MOVPE using TBP as P source. The Cu-Pt ordering effect in InGaP seemed to be suppressed resulting in a long carrier lifetime and good solar cell efficiency.

[1] H. Sodabanlu et al, 82nd JSAP, 11a-N204-2 (2021).
[2] I. Garcia et al., JCG 310, 5209 (2008).

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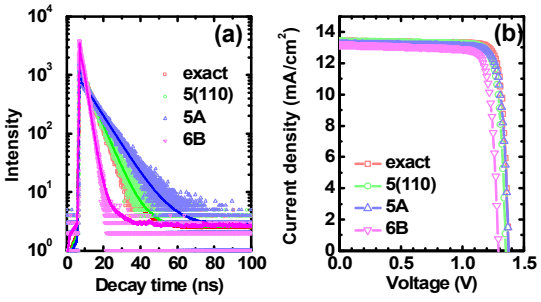

Fig. 1 (a) TRPL transients of InGaP DH and (b) I-V characteristics under AM1.5G of InGaP solar cells on various miscut GaAs substrates