Direct Heteroepitaxy of Orientation-Patterned GaP on GaAs by Hydride Vapour Phase Epitaxy for Quasi-Phase-Matching Applications

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***Abstract*—Heteroepitaxial growth of orientation-patterned GaP on patterned GaAs template was developed by using hydride vapor phase epitaxy for quasi-phase-matching applications. We present the growth with well-defined periodic boundaries between (001) and (00$\bar{1}$) GaP domains. The GaP layer on planar GaAs was characterized by terahertz time-domain spectroscopy and the conductivity of GaP (0.16 S cm^{-1}) was obtained in terahertz range.**

***Keywords*—Hydride vapour phase epitaxy; Orientation patterned GaP on GaAs; Terahertz time-domain spectroscopy**

I. INTRODUCTION

Orientation-patterned GaP (OP-GaP) has been investigated for achieving optical down-conversion by exploiting quasi-phase-matching (QPM) scheme to enable lasing in the infrared range because of its low 2-photon absorption and improved thermal properties [1]. One major obstacle for using GaP in QPM scheme is the lack of process development for high-quality OP-GaP substrates. By growing on GaAs substrates, the benefits of GaP can be utilized while relying on the more mature GaAs technology [2].

II. EXPERIMENTAL

In this work, OP-GaP was grown heteroepitaxially on OP-GaAs template samples in a low pressure hydride vapor phase epitaxy (LP-HVPE) reactor. As shown in Fig. 1, the OP-GaAs template consisted of 200 nm thick and 45 µm wide (00$\bar{1}$) GaAs stripes on (001) GaAs substrate with 45 µm spacing, which were prepared by a method described in Ref [3]. Three GaP growths were conducted at 20 mbar and 710 °C, using GaCl and PH_3 flows shown in Table 1 to achieve high growth rate and well-defined vertical boundaries between (00$\bar{1}$) and (001) domains. The flows used were based on prior experiments performed on selective area growth (SAG) on GaP patterned with stripe openings along [110] and [$\bar{1}$10] directions. Cross-sections of the OP-GaP growths on OP-GaAs template were stain-etched to delineate the domain boundaries and studied by scanning electron microscopy (SEM) and Nomarski microscopy. Semi-insulating (SI) GaAs substrates were loaded during growth as reference and the grown GaP/SI-GaAs was characterized by terahertz time-domain spectroscopy (THz-TDS).

III. RESULTS AND DISCUSSION

A cross-sectional SEM image of sample A is shown in Fig. 2, which has a growth rate of 22 µm/hour and vertical domain boundaries. The tilted facets on the top of domains shown in Fig. 2 are low growth-rate planes. The formation of such facets could be beneficial for achieving vertical domain boundaries. For sample B a higher growth rate of 55 µm/hour was achieved. Cross-sectional Nomarski microscopy images of sample B are shown in Fig. 3. While the growth rate is higher, the tilted facets are less pronounced (Fig. 3(a)). The boundaries at transitions from (001) to (00$\bar{1}$) domains are vertical but that from (00$\bar{1}$) to (001) domains start to develop laterally with growth and become less vertical (Fig. 3(b)). In order to maintain vertical domain boundaries with high growth rate, the growth conditions used in sample A and B were combined for sample C. The growth was conducted for 80 min with an average growth rate of 28 µm/hour. As shown in Fig. 4, the domain boundaries in sample C become more vertical as anticipated. The THz TDS was used to extract the complex permittivity and conductivity of the GaP layer grown on reference semi-insulating GaAs in the THz range (0.2 THz ~ 0.9 THz) by comparing the transmission spectra through GaP/SI-GaAs and SI-GaAs substrate (Fig. 5(a)). The conductivity spectrum of GaP shown in Fig. 5(b) is fitted to Drude model to estimate the characteristic relaxation time (305 fs) and carrier concentration (1.29×10^{15} cm^{-3}) in GaP. The conductivity of GaP from the TDS measurement (0.16 S cm^{-1}) is consistent with the value obtained from the Hall effect measurement (0.17 S cm^{-1}).

IV. CONCLUSION

Promising initial results of OP-GaP heteroepitaxy on GaAs have been presented, outlining a strategy to obtain vertical domain boundaries in OP-GaP by changing the flows of precursor gases. In addition, the obtained THz-TDS results indicate that the material quality makes it suitable for THz applications. This work will be used as a foundation towards realizing quasi-phase matched GaP on GaAs for optical down-conversion.

References

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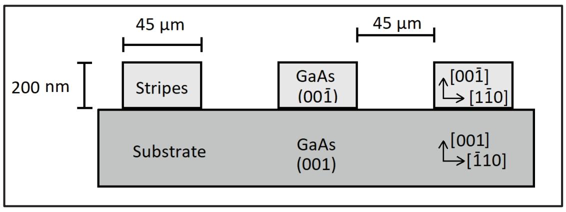

Figure 1: Schematic for the OP-GaAs template.

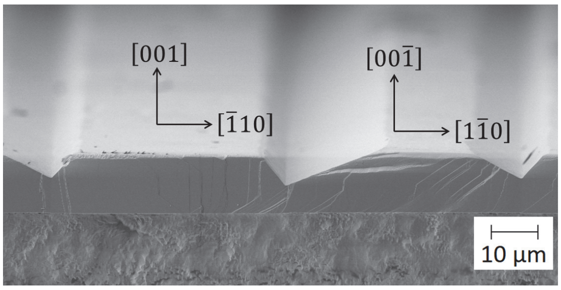

Figure 2: Cross-sectional SEM image of sample A showing two adjacent domains with pronounced tilted facets at the top of growth.

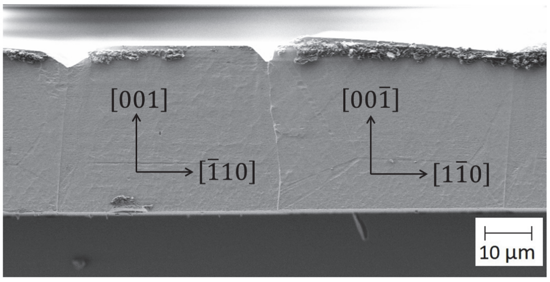

Figure 4: Cross-sectional SEM image of sample C. As compared with samples A and B, high growth rate is obtained in sample C while vertical domain boundaries are maintained.

Table 1. Summary of gas flows, growth times, and resulting growth rates for samples A, B, and C. Growth C was performed in two steps by combining the growth conditions used for samples A and B. The growth rate listed for C is an average of the two steps.

Sample	GaCl flow (sccm)	PH_3 flow (sccm)	Time (min)	Growth rate (µmh^{-1})
A	5	25	30	22
B	10	50	45	55
C	5 / 10	25 / 50	30 / 50	28

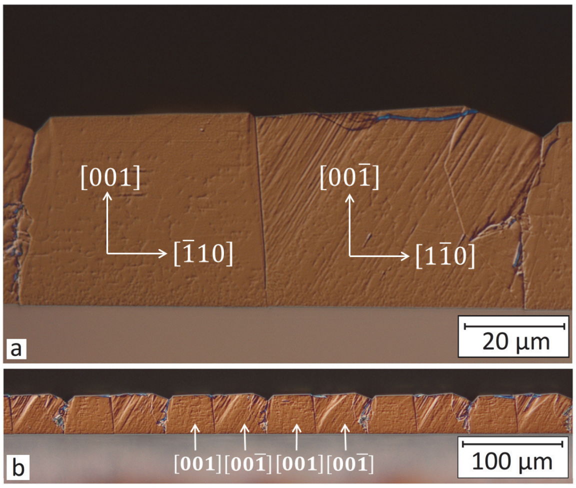

Figure 3: Cross-sectional Nomarski microscopy images of sample B. (a) Close up of two adjacent domains. (b) Overview of multiple domains demonstrating the tendency of domain boundaries to develop laterally with growth at transitions from (00 $\bar{1}$) to (001) domains.

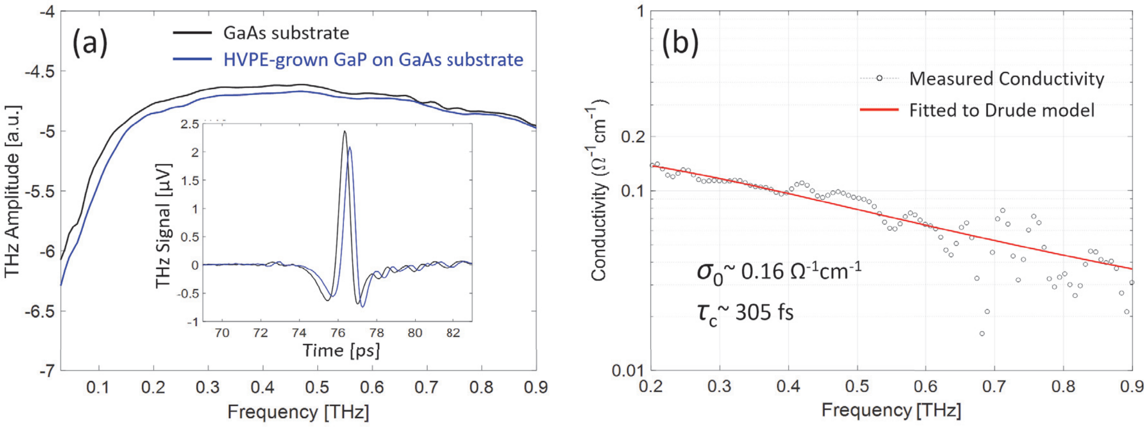

Figure 5: Measurement of conductivity of GaP on SI GaAs by terahertz time-domain spectroscopy. (a) Comparison between two THz transmission spectra, one through the GaP on SI GaAs reference sample (blue) and one through the SI GaAs substrate alone (black). The inset shows the transmitted THz signals in time-domain. The approximately 0.5 ps delay in the reference sample signal corresponds to the grown GaP layer thickness (~ 50 µm). (b) The extracted conductivity of the GaP layer in the THz range is fitted to the Drude model, where we obtain a characteristic relaxation time $\tau_c \approx 305$ fs and a carrier concentration $n \approx 1.29\times10^{15}$cm^{-3}.