Development of Orientation-Patterned GaP Growth on GaAs for Nonlinear Frequency Conversion

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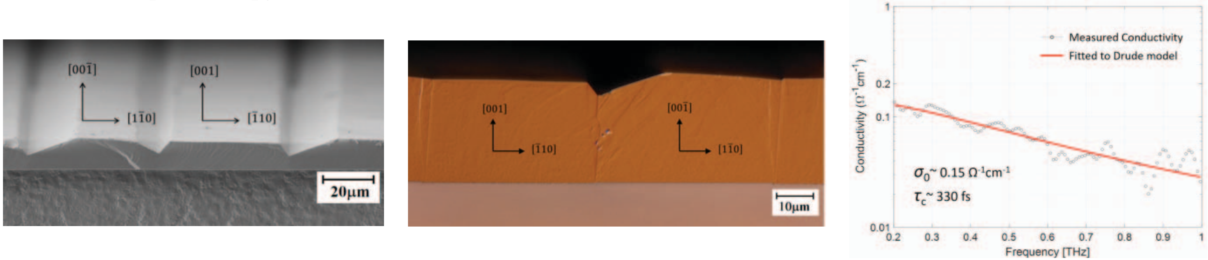
Quasi-phase-matched orientation-patterned GaP (OP-GaP) is an attractive technology for achieving mid-IR and terahertz (THz) radiation enabled by nonlinear frequency conversion, because of its low two-photon absorption (2PA) down to 1 µm. High crystalline quality of OP-GaP template and subsequent thick layer growth is required to exploit the benefit of low 2PA of GaP pumped with short wavelength lasers [1]. In this work, we present the development of heteroepitaxial growth of OP-GaP on wafer fused OP-GaAs template with high growth rate and good domain fidelity. The conductivity of the GaP grown on planar GaAs was investigated in the THz region.

The OP-GaAs template consisting of alternating $(00\bar{1})$ and (001) domains on a GaAs substrate with a domain period of 90 µm was fabricated by the wafer bonding approach [2]. The heteroepitaxial growth of GaP on OP-GaAs was conducted in a low-pressure hydride vapor phase epitaxy (LPHVPE) reactor at 710 °C and 20 mbar. The gas flows of HCl flowing over molten gallium for GaCl formation and PH_3 were optimized to achieve OP-GaP growth with high growth rate and high domain fidelity. The cross-sections of OP-GaP on GaAs were examined by scanning electron microscopy (SEM) and Nomarski microscopy after stain-etching to delineate the domain boundaries. The conductivity of GaP grown on planar semi-insulating (SI) GaAs was studied by THz time-domain spectroscopy (THz-TDS).



(a) (b) (c)

Fig. 1 (a) Cross-sectional SEM image of OP-GaP on GaAs grown with PH_3=25 sccm and GaCl=5 sccm for 30 min. (b) Cross-sectional Nomarski microscopy image of OP-GaP on GaAs grown with PH_3=50 sccm and GaCl=20 sccm for 30 min. (c) The extracted conductivity of GaP layer grown on SI-GaAs in the THz range fitted with the Drude model with obtained characteristic relaxation time of $\tau_c \approx 330$ fs and a carrier concentration $n \approx 1.12\times10^{15}cm^{-3}$.

By using 25 sccm PH_3 and 5 sccm GaCl flows, a GaP growth rate of 22 µm/hour and a maintained domain fidelity of OP-GaP were obtained with vertical boundaries between alternating $(00\bar{1})$ and (001) GaP domains, as shown in Fig. 1(a). Low growth rate facets were formed on the top of domains, which facilitate the realization of vertical domain boundaries and maintaining domain fidelity. In order to achieve higher growth rate, 50 sccm PH_3 and 10 sccm GaCl flows were used. A GaP growth rate of 55 µm/hour was obtained but the boundaries at the transitions from $(00\bar{1})$ to (001) domains developed laterally with growth. As shown in Fig. 1(b), by increasing the GaCl flow to 20 sccm, GaP growth rate more than 60 µm/hour was achieved, and vertical domain boundary was retained. The conductivity of GaP in the THz range (0.2-0.9 THz) was extracted by comparing the transmission spectra through GaP/SI-GaAs and SI-GaAs substrate, fitted with the Drude model in Fig. 1(c). A characteristic relaxation time of 330 fs and a carrier concentration of $1.12\times10^{15}cm^{-3}$ were estimated. The GaP conductivity measured by TDS ($0.15\ S\cdot cm^{-1}$) is comparable to the value measured by Hall effect ($0.17\ S\cdot cm^{-1}$).

In summary, we present heteroepitaxial OP-GaP growth on an OP-GaAs template by LPHVPE with a growth rate as high as 60 µm/hour and maintained domain fidelity. The conductivity of heteroepitaxial GaP growth on SI-GaAs was studied in the THz range. The outcomes of this work will pave the way for realizing quasi-phase-matched OP-GaP for nonlinear frequency conversion in the mid-IR and THz range.

References

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