High Crystalline Quality $PtSe_2$ Films For High Frequency Optoelectronics

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$PtSe_2$ exhibits high carrier mobility [1] and infrared absorption [2] which are particularly suitable for high frequency optoelectronics at the 1.55 µm telecom wavelength [3]. We have studied $PtSe_2$ films grown by molecular beam epitaxy (MBE) to demonstrate high-frequency photodetectors and mixers. We first measured the optical absorption at 1.55 µm and the conductivity of $PtSe_2$ films as a function of the number of monolayers (ML) and focused our studies on thick (10-15 MLs) semimetallic films that exhibit both good IR absorption [2] and high conductivity [1]. These are key parameters for demonstrating highly efficient optoelectronic mixers [4]. To this end, we have carried out in-depth studies on the growth of $PtSe_2$ by MBE. To evaluate the crystalline quality of $PtSe_2$ films, most groups measure the full width at half maximum (FWHM) of the in-plane Eg Raman peak: Lukas [5] proposed an Eg FWHM ≤ 5 cm^{-1} as an indicator of high crystalline quality. Using this indicator as well as film conductivity, we have optimized the MBE growth of large-scale $PtSe_2$ films on sapphire substrates. By performing a post-growth annealing (red symbols in Fig. 1), we demonstrated that the E_g and A_{1g} FWHM values reach the exceptionally low values of 3.6 cm^{-1} and 3.5 cm^{-1} respectively, as well as a high conductivity of 1.6 mS. Based on these studies, we propose a new figure of merit (Fig. 1) showing that both Eg and A1g FWHM values are required to evaluate the crystalline quality of $PtSe_2$ films. We show that the electrical conductivity of our films can be efficiently predicted using the FWHM of the out-of-plane A1g peak. Furthermore, using X-ray diffraction and advanced transmission electron microscopy techniques [6], we have identified correlations between the crystalline structure and the electrical conductivity.
A14MLs-thick $PtSe_2$ film of high crystalline quality was grown on a 2-inch wafer and we fabricated $PtSe_2$ based coplanar waveguides exhibiting photodetection at 1.55 µm with a record bandwidth of 60 GHz (Fig. 2). To further improve these performances, we are targeting monocrystalline $PtSe_2$ films. For this purpose, we are investigating the step-guided epitaxy on sapphire. This consists of growing $PtSe_2$ films on vicinal surfaces to promote oriented nucleation of the crystals at the step edges. We will also present promising results on van der Waals (vdW) epitaxy of $PtSe_2$ films on h-BN flakes.

References

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[2] Tharrault et al. https://arxiv.org/abs/2311.01847
[3] Wang et al., ACS Photonics 7, 2643 (2020)
[4] Hamidouche et al., ACS Photonics 8, 369 (2021)
[5] Lukas et al., Adv. Funct. Mater. 31, 2102929 (2021)
[6] Dosenovic et al, 2D Mater. 10 045024 (2023)

Figures

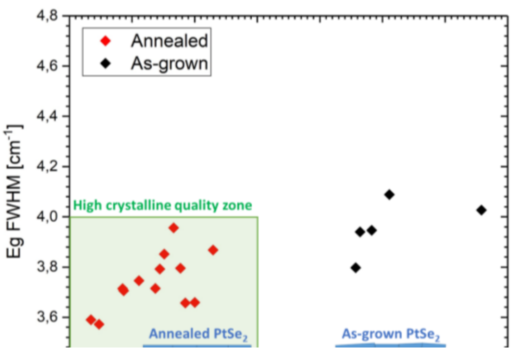

Figure 1: Proposed figure of merit for $PtSe_2$ thick (10-15 MLs) films with (red symbols) or without (black symbols) a post-growth annealing.

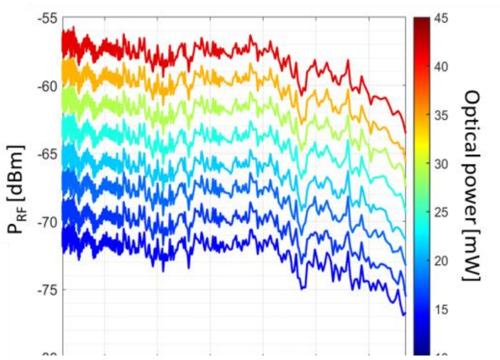

Figure 2: 60 GHz bandwidth photodetection with a $PtSe_2$ based coplanar waveguide fabricated on a 2-inch sapphire wafer.