# Scalable Two-dimensional Semiconductors: From Photogating to Deep UV Optoelectronics

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Two-dimensional semiconductors (2SEM) offer opportunities to advance modern science and technologies. However, transforming the semiconductor landscape requires high-quality materials with well-defined electronic properties, which are still difficult to control and scale. Here, these challenges are addressed by integration of growth, scanning probe microscopy and electron spectroscopy of 2SEM in ultra-high vacuum (UHV). We use a bespoke facility (EPI2SEM) for EPitaxial growth and In-situ analysis of 2SEM in UHV [1,2]. A centrosymmetric polymorph ($D_{3d}$) of gallium selenide (GaSe) is obtained by epitaxy onto large-area sapphire [3] and graphene/SiC [4] substrates. Atomically thin layers of GaSe align in the layer plane with graphene, and possess an electronic band structure and electric field dipole at the interface with graphene that are tuneable by the layer thickness (Fig 1).

Epitaxial GaSe represents a scalable building block for nanoelectronics. We present two proof of concept devices. In our first type of device, the electric dipole at the interface of single layer GaSe and graphene is very sensitive to photogenerated charges in GaSe. The indirect nature of the band gap of GaSe and the heavy hole masses can retard band-to-band recombination and facilitate an accumulation of positive charge in GaSe, thus acting as a photogate for graphene. These properties offer prospects for further developments in low-power opto-electronic components on different platforms, including CMOS. In the second proof of concept, the grown materials provide a platform for scalable optical sensors. The optical anisotropy and resonant absorption of GaSe in the UV spectrum are exploited for photon sensing in the technological UV-C spectral range, offering a scalable route to deep-UV optoelectronics [3].

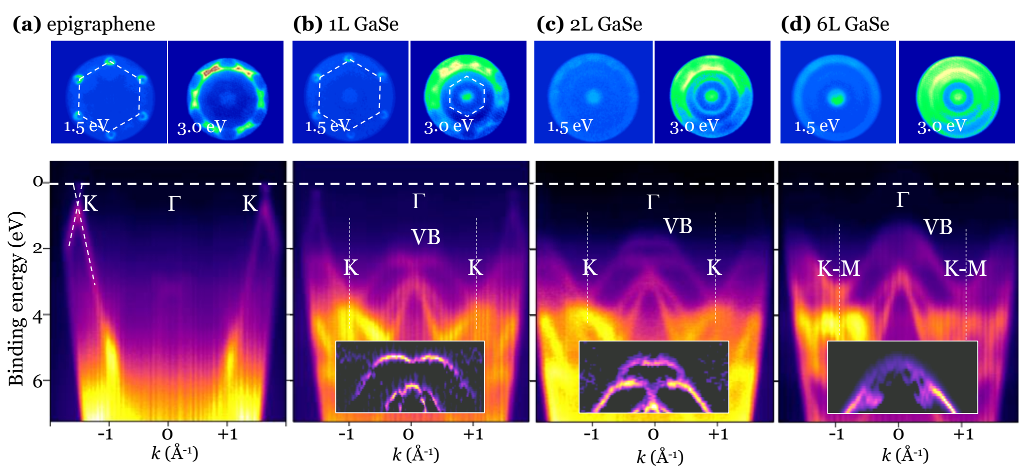


**Fig 1.** Constant energy ARPES (angle resolved photoemission spectroscopy) slices taken near the Dirac cone and valence band (VB) of 1layer (L) GaSe for (a) graphene, (b) 1-layer (L), (c) 2L and (d) 6L GaSe. The hexagonal Brillouin zones for graphene and GaSe are overlayed on the plots in parts (a) and (b). ARPES data along high symmetry directions are shown for each sample. Energies (in eV) are referenced to the Fermi level (dashed line). Insets in parts (b-c-d) show the second derivative of the photoelectron intensity versus energy and k-momentum, revealing the shape of the VB.

[1] EPI2SEM Animation, YouTube, rb.gy/iuaht8.
[2] EPI2SEM Interviews, YouTube, rb.gy/sm21ti.
[3] M. Shiffa et al., Small 2024, 20, 2305865.
[4] J. Bradford et al., unpublished.