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Among the large family of van der Waals (vdW) crystals, the two-dimensional (2D) layered compound InSe is attracting increasing interest for its desirable electronic and optical properties.[1] More generally, indium selenide compounds with different stoichiometry, In_xSe_y, and their different polytype phases, *e.g.* α, β, γ, possess physical properties relevant for several applications in electronics, thermoelectrics and optoelectronics.[1,2] In particular, they have band gaps in the near infrared region, high electron mobility at room temperature (> 0.1 m^2/Vs) and band properties that are very sensitive to the layer thickness.[2] Here, we present our work on the growth of 2D In-Se crystals[2] and their implementation in novel vdW heterostructure devices.[1–3]

We show that unlike other 2D vdW crystals, such as black phosphorus, InSe nanolayers are stable under prolonged exposure ambient conditions. Furthermore, we can use both thermal- and photo-annealing in air to convert near surface atomic layers of InSe into crystalline In_2O_3 (Fig.1a). The oxidation can be activated in selected areas by a focused laser beam or prevented by capping the InSe surface with a film of hBN. This propensity of InSe crystals to oxidize at high temperatures (T>100°C) or when illuminated with intense laser light can be turned to advantage by exploiting the optical transparency and *n*-type conductivity of In_2O_3. Controlled oxidation of *p*-type InSe enables the fabrication of InSe/In_2O_3 *p-n* junction rectifiers with room temperature (RT) electroluminescence and photoresponsivity from the near-infrared to the ultraviolet ranges (Fig.1b).[3]

We demonstrate strong quantum confinement effects in 2D In-Se and heterostructures obtained by exfoliation or growth by physical vapor deposition. In_2Se_3 layers with thickness ranging from 2.8 – 80 nm can be grown on different substrates such as SiO_2/Si, mica, graphite and GaSe. The as-grown layers are chemically stable at room temperature and exhibit a blue-shift of the photoluminescence emission when the layer thickness is reduced due to strong quantum confinement (Fig. 1c). The layers show high photoresponsivity of up to ~ 2×10^3 A/W at λ = 633 nm revealing the great potential of these materials for high sensitivity, fast 2D photodetectors.[2]

Our findings on indium selenide compounds and its use in novel heterostructures demonstrate the technological potential of this 2D material and new routes to miniaturized devices for electronics and optoelectronics.

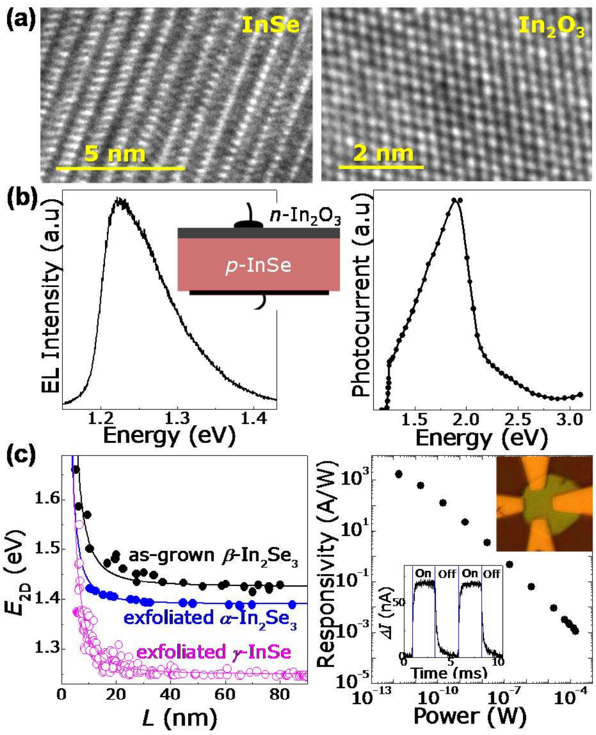

Fig.1: (a) Transmission Electron Microscopy images of InSe and In_2O_3. (b) Electroluminescence and photoresponse of an InSe/In_2O_3 *p-n* junction diode. (c) Quantum confinement effect of In-Se layers and photoresposivity of as-grown layer of β-In_2Se_3.

References
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