The characteristics of phototransistor based on the grown $MoSe_2$ by molecular beam epitaxy

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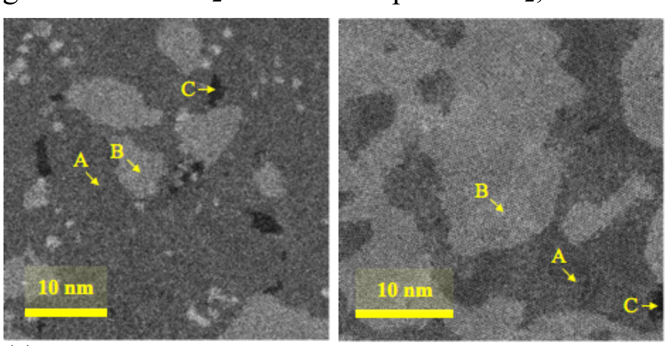
Transition metal dichalcogenides (TMDs) have been explored as the promising active layer for the optical and electronic devices because they have a bandgap corresponding to visible light range and the high mobility at the subnanometer thickness. We studied molecular beam epitaxy (MBE) method in order to grow uniform $MoSe_2$ on large area substrate. The high-purity Se and Mo were evaporated by e-beam evaporator and Knudsen cell, respectively. The quality of the film was confirmed by spectroscopic measurement. The chemical composition and elemental ratio were studied by high resolution X-ray photoelectron spectroscopy (HRXPS). Scanning transmission electron microscopy (STEM) was conducted to observe growth mechanism and Moirè pattern. The growth mechanism involves layer by layer growth, expanding the bilayer gradually on the covered monolayer with the deposition time in figure 1. We also observed that the localized strain is induced by grain boundary between rotational stacking layer and oriented stacking. The band alignment of the film was confirmed by ultraviolet photoelectron spectroscopy (UPS) and spectroscopic ellipsometry (SE): The grown $MoSe_2$ by MBE is n-type semiconductor, having the optical band gap as 1.39eV and the valance band as 1.10eV. In addition, we fabricated the phototransistor based on the grown $MoSe_2$. The device exhibited the fast rising and decay time, 6ms and 8ms, respectively, at wavelength of 532 nm in figure 2. The variable on/off current with gate bias and laser power was measured, indicating the excellent photoresponsivity. Finally, we have successfully grown the $MoSe_2$ film on amorphous SiO_2, demonstrating phototransistor device applications.



(a) (b)

Figure 1 The arrows, A, B, and C are monolayer, bilayer, and empty space, respectively. (a) Monolayer dominant and partially bilayer. (b) Increasing deposition time, the bilayer is dominant.

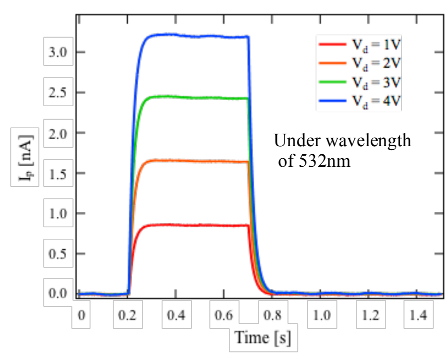


Figure 2 Photocurrent at wavelength of 532nm

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Supplementary Pages (Optional)

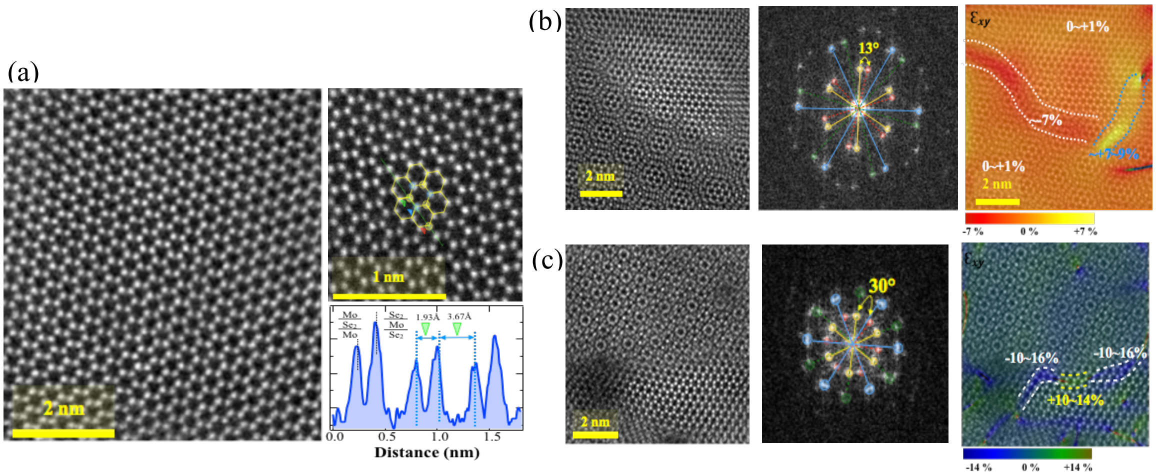

Figure 1

- ✓ **Annular Dark Field (ADF) image**
  : (figure 1a) 2H structure representing the honeycomb arrangement of the atoms.
- ✓ (figure 1b and 1c)Moirè pattern: The rotational stacking structure can be attributed to **the formation energy and interlayer interaction.**
- ✓ **Strain is induced around the grain boundary**
  Shear strains of approximately ±7−8% at the lower tilted grain boundary and approximately ±10−14% at the higher tilted grain boundary are induced.

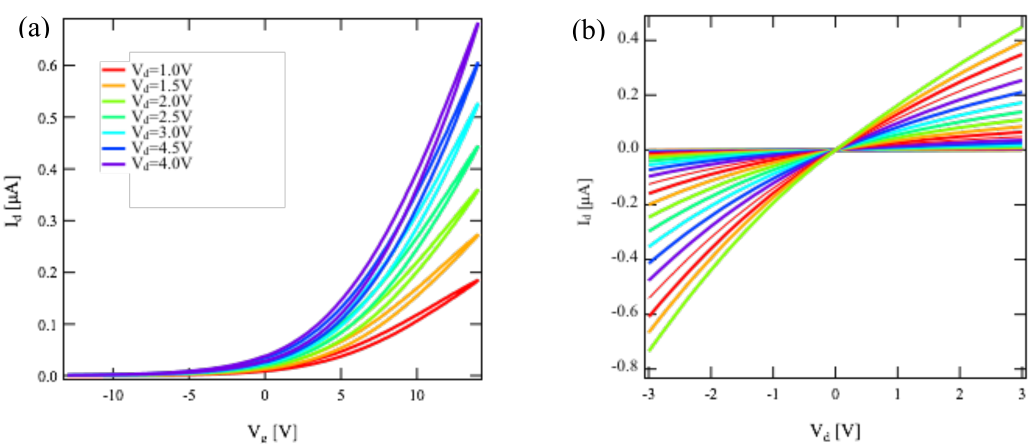

Figure 2

- ✓ **Phototransistor based on the grown $MoSe_2$ by MBE**
  The device was fabricated, with channel length and width 5μm and 20 μm, respectively.
- ✓ (figure 2a) Transfer curve of MBE-$MoSe_2$ FET on SiO_2 substrate at V_d=1.0V to 4.0V, (figure 2b) drain current versus drain bias showing ohmic contact.