Supporting Materials

Hole Mobility Enhancement and p-Doping in Monolayer WSe₂ by Gold Decoration

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Methods

CVD Growth of WSe₂ and p-doping: WSe₂ monolayer film was synthesized based on our previous work.¹⁵ In brief, sapphire (0001) substrate (Tera Xtal Technology Corp) were first cleaned in a H₂SO₄/H₂O₂ (70:30) solution heated at 100 °C for 1 hr. The substrates were placed in the center of a 1” tubular furnace on a quartz holder. Precursors of 0.3 g WO₃ (Sigma-Aldrich, 99.5%) in ceramic boat was placed in the heating zone center of the furnace and Se (Sigma-Aldrich, 99.5%) powder in quartz tube was placed 8 cm away from furnace open-end at upstream position in a 1” quartz tube maintained at 270 °C during the reaction. The sapphire substrates for growing WSe₂ were put at the downstream side, where the Se and WO₃ vapors were brought to the targeting sapphire substrates by an Ar/H₂ flowing gas (Ar = 80 sccm, H₂ = 20 sccm, chamber pressure = 3 Torr). The center heating zone was heated to 925 °C at a ramping rate of 25 °C /min. Note that the temperature of the sapphire substrates was at ~750 to 850 °C when the center heating zone reaches 925 °C. After reaching 925 °C, the heating zone was kept for 15 min and the furnace was then naturally cooled to room temperature. For the p-doped effect, Au nanoparticle (1 nm) was thermally deposited onto the surface of the WSe₂ films.
**Fabrication of EDLT Devices:** For the EDLT source and drain electrodes, Au contacts with Ni adhesion layers (70 nm/2 nm) were thermally deposited onto the surface of the p-doped WSe$_2$ films. The ion gels, a mixture of a triblock copolymer, poly(styrene-block-methyl methacrylate-block-styrene) (PS-PMMA-PS; MPS = 4.3 kg/mol, MPMA = 12.5 kg/mol, Mw = 21.1 kg/mol), and an ionic liquid, 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl) imide ([EMIM][TFSI]) in an ethyl propionate solution, are used as the top gate dielectrics. Note that the weight ratio of the polymer, ionic liquid, and solvent was maintained at 0.7:9.3:20. This solution was drop-casted onto and covered the surfaces of WSe$_2$ film and the source and drain electrodes. The transistor channel was then covered with a thin Pt foil (thickness of 0.05 mm) to form the top-gate electrode. Finally, a thin gold wire was inserted into the gel films, between the channel and top gate metal, as the reference electrode.

**Measurements and characterizations:** Raman and photoluminescence spectra were collected in NT-MDT confocal Raman microscopic system (laser wavelength: 473 nm; laser power: 1 mW; spot size: ≈ 1 µm). The spectra taken from samples were calibrated against a Si peak at 520 cm$^{-1}$. The AFM images were performed in a Veeco Dimension-Icon system. All electrical characterizations were performed using a semiconductor parameter analyzer (Agilent E5270) in a shield probe station inside a N$_2$-filled glovebox. Impedance measurements were performed using a frequency response analyzer (a Solartron 1252A frequency response analyzer with a Solartron 1296 dielectric interface controlled by ZPlot and ZView software), and the frequency range was set to $10^{-3}$–$10^5$ Hz with an AC voltage amplitude of 5 mV.

*Figure S1.* (a) AFM measurement of a typical CVD WSe$_2$ monolayer film. (b) The height profile of WSe$_2$, giving an average thickness of ~0.72 nm.
**Figure S2.** AFM measurement of a gold-doped WSe_2 monolayer film (20 s). The 20 sec Au deposition appears as film-like on WSe_2.

![AFM image of Au 20s/WSe_2](image)

**Figure S3.** (a) AFM image of the WSe_2 triangular flake after immersed in a AuCl_4 solution (5 mM). For these samples, the AuCl_4 immersing time was 20 seconds and rinsed with DI water Au deposition. (b) Raman spectra of the WSe_2 flakes before and after Au nanoparticles decoration.

![AFM image of WSe_2 and Raman spectra](image)