Intriguing Photoelectricity from 2D Bismuth sheet Grown Directly on Si substrates

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Atomic sheet of bismuth, bismuthene, is expected to offer a host of exotic electrical, thermal and mechanical properties[1] beyond graphene or phosphorene for innovative nanoelectronics[2]. Despite recent success in growth on SiC[3] and physical forming[4], there is still a lack of device study on bismuthene. Given our previous results in direct growth on Si(111) substrate and dry delamination transfer of bismuthene, here we explore experimental realization and characterization of a bismuthene phototransistor and reveal original interesting results.

This work reveals unique electrical properties, which is affected by intrinsic nature such as thickness and phase (atomic arrangement), of bismuthene directly grown on Si(111) substrate. In theory, pristine bismuthene has bandgap varying from 0.1-0.8 eV and mobility ~1000 $cm^2/V\text{-}s^1$. Unlike graphene, MoS_2 or phosphorene, the first 4-7 monolayers (ML) of bismuthene prefer buckled rather than hexagonal arrangement for thicker layers (Figure 1a). This thickness dependent microstructure provides tool to engineer the bandgap, but has been underestimated. We emphasize this concept in realizing a phototransistor observing 3 orders of magnitude drain current in bismuthene with laser excitation compared to bare substrate (Figure 1b). Bismuthene phototransistors can operate under different gate bias in saturation or depletion modes, and can work as a unipolar device with 100× gate modulation at RT (Figure 2). It is worth noting that bismuthene provide more flexibility in bandgap tuning, enriched topological phases[5] and decent stability compared to other Xenes (IVA/VA family)[6], such as silicene and phosphorene, capable of 2D quantum spin hall and topological new device configurations. The photoelectrical property of bismuthene is a result of unique details in band structure such as bandgap, SOC and VB splitting (Figure 3a), again is a function of thickness (# of layers) as mentioned above. Figure 3b records the photo response path of a 12ML bismuthene device, starting from a sharp increase of photocurrent to a gradual saturation, and it has a strong hysteresis in I_d-V_d sweep with laser pulse ON and OFF, indicating annihilation of current carriers at retrieving negative drain bias. To better understand the photo current mechanism in bismuthene, dichronic photocurrent in bismuthene is under investigation.

This work will demonstrate that bismuthene represents a great opportunity for novel photoelectric concepts, e.g. topological bits and phototransistors on rigid and flexible substrates.

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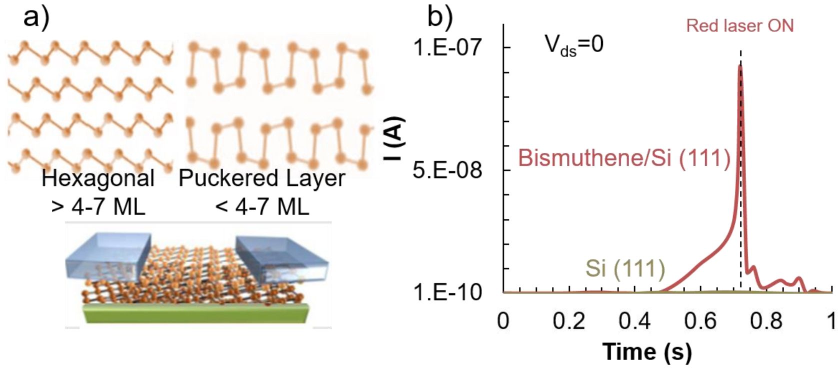

Figure 1. *Bismuthene phototransistor:* a) thickness dependent (from puckered to hexagonal) layer structure of bismuth atoms arrangement and a phototransistor device exhibiting b) strong photo current effect (10^3).

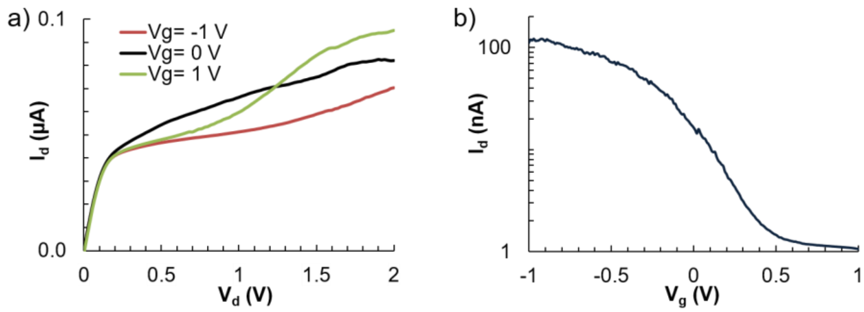

Figure 2. *Electrostatic measurement of bismuthene phototransistors*: a) drain current-voltage I_d-V_d under different gate bias and b) unipolar drain current versus gate voltage, I_d-V_g curve with $100\times$ gate modulation.

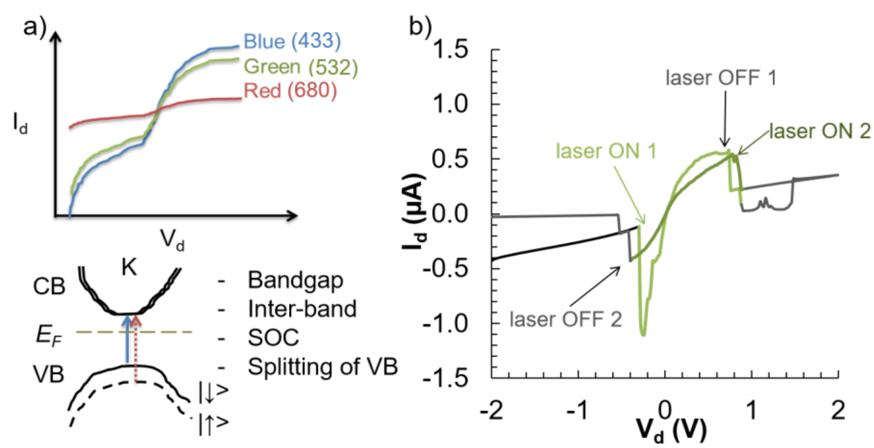

Figure 3. *Photo-electronic effect of bismuthene device:* a) photo current effect of incident laser with varied wavelength/energy, which could probe band structure such as VB splitting, b) response time of channel current to photo stimulation.