(Invited) Intriguing Prospects of 2D Atomic Sheets for Innovative Nanoelectronics

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Two-dimensional (2D) atomic sheets have collective properties of mechanical flexibility and tunable bandgap[1], holding great promise for novel nanoelectronics. This talk will summarize our recent research progresses along this line from flat graphene to buckled 2D sheets: silicene and phosphorene. Graphene, the first 2D material, has drawn a widespread interest in nanoelectronics over past decade, whereas high-performance flexible graphene devices have been rarely achieved. We have developed large-area high-quality vapor synthesized graphene and conformal dielectrics that enable high-speed flexible RF nanoelectronics. Most recently, we achieved short channel graphene transistors on flexible glass with a intrinsic cut-off frequency, f_T=95 GHz (Fig. 1) after standard de-embedding[3], which is 280% higher compared to f_T=25 GHz from our previous GFET on polyimide plastics[2]. The saturation velocity of our GFET on flexible glass is the highest among any flexible transistors reported so far.

Silicene, IVA family cousin of graphene, is predicted to offer a host of exotic electrical properties[4] depending on its material phase, interface and external fields. Our recent effort addressed long-lasting air-stability and portability issues, allowing silicene transistor to make its debut[5], corroborating theoretically predicted ambipolar transport indicating Dirac band structure. Electrostatic characterization on prototype silicene transistors observed carrier mobility ~100 cm^2/V-s and 10× gate modulation (Fig. 2) at RT. In theory, pristine free-standing silicene may offer intrinsic mobility over 1000 cm^2/V-s[6] without non-ideal limiting factors, e.g. phase boundary scattering and electron-phonon coupling. Further device optimization is under investigation to shed light on the upper mobility bound achievable and aging evolution of silicene devices. Phosphorene, phosphorus analog to graphene, is a contemporary semiconductor promising for 2D nanoelectronics[7, 8] due to its direct bandgap bridging between graphene and transitional metal dichalcogenides. For instance, our recent few-layer black phosphorus (BP) demonstrated high carrier mobility 310-1500 cm^2/Vs with gate modulation 10^3-10^5 (Fig. 3) on flexible polyimide substrate[9, 10]. We also reported the first phosphorene based flexible RF transistors with intrinsic f_T=20 GHz, sustaining under ex-situ bending test with tensile strain up to 1.5%. It has been integrated into a functioning circuit as phosphorene flexible audio receiver[9].

Aforementioned recent progresses on graphene, silicene and phosphorene represent a great opportunity for novel device concepts, e.g. topological bits, in flexible nanoelectronics applications.

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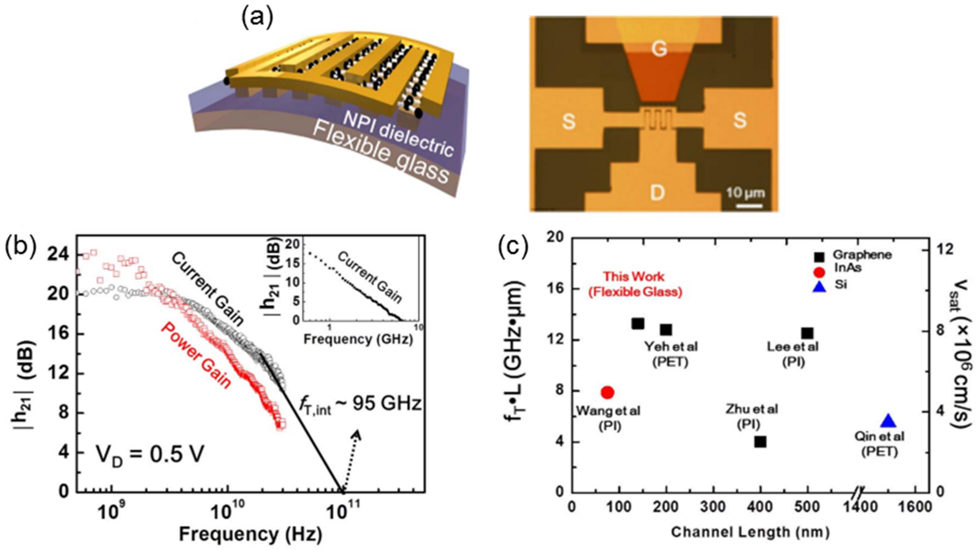

Figure 1. *High-performance flexible graphene field-effect transistors (GFET) on flexible glass.* (a) A sketch of GFET and microscope image on a real device with (b) an intrinsic cut-off frequency ~95 GHz and (c) bench marking compared to existing literature reports[3].

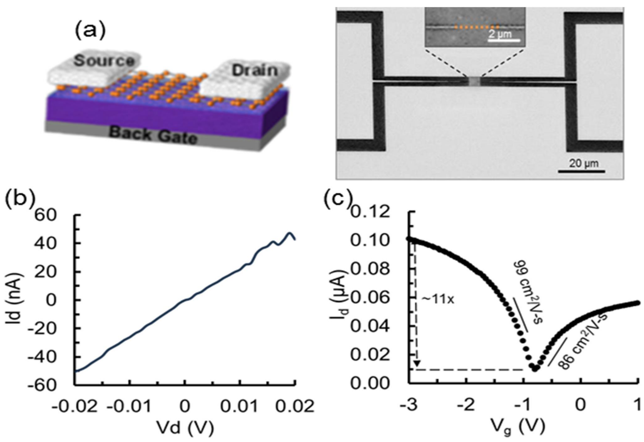

Figure 2. *Silicene field-effect transistors*. (a) A sketch and SEM image of silicene transistor device and (b) I_d-V_d , (c) I_d-V_g curve at RT showing ambipolar behavior with a Dirac point[5].

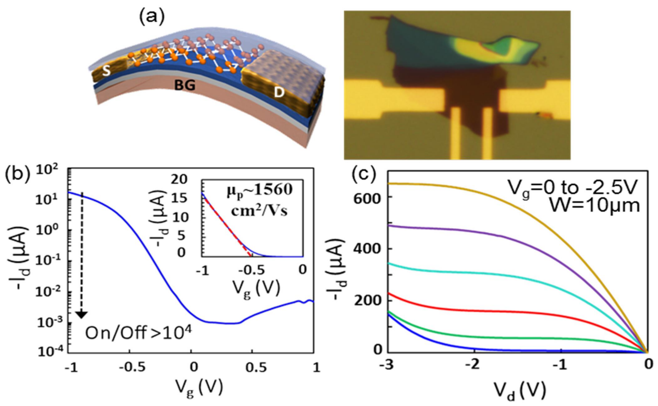

Figure 3. *Flexible phosphorene transistors.* (a) A sketch of device structure and optical image of real device with (b) transfer, (c) output characteristics[9] showing high mobility and current saturation.