The concept of electrostatic doping and related devices

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The concept of "electrostatic doping", also defined as gate-induced charge, is a unique feature of nano-sized structures such as fully-depleted silicon-on-insulator (FD-SOI), nanowires, nanotubes, and 2D materials. In an ultrathin device, a positive gate bias induces an electron population that spreads over the entire body (volume inversion or accumulation). This effect is very different from the charge-sheet interface layer formed in bulk semiconductors or in thick SOI. The thinner the film, the more uniform the volume carrier distribution. The original undoped body suddenly behaves as an *n*-doped region. Changing the polarity of the gate bias turns the body into a *p*-type region.

Electrostatic doping can be contemplated as the last chance to form junctions and contacts in disparate technologies where ion implantation is not applicable; examples of CNT, 2D, and NW devices will be discussed. A less cynical view is to take advantage of the fascinating doping metamorphosis, which offers unrivalled flexibility for conceiving novel and reconfigurable devices. For example, band-modulation devices (field-effect diode, Z^2-FET, Z^3-FET) consist of successive *n*- and *p*-regions that are electrostatically doped to emulate a thyristor *npnp*. Other examples include the ultrathin extended drain MOSFET with a fully depleted drift region that cannot drive current unless the virtual doping of the drain extension is tuned via a ground plane and the gate-driven NMOS that features 5 doped regions out of which two have adjustable electrostatic doping for achieving good ESD protection. The operation of such sharp-switching devices like tunneling FET (TFET), I-MOS and electron-hole bilayer TFET also relies on electrostatic doping.

Another interesting device is the virtual (or Hocus-Pocus) diode that can be emulated in ultrathin FD-SOI films by appropriately biasing the front and back gates. Adjacent electron and hole populations form a virtual *pn* junction. The current-voltage characteristics reveal similarities and major differences with those of conventional *pn* diodes with ion-implanted doping. The lateral electric field from the anode combines with the gate-induced vertical field and leads to unusual 2D effects. A distinct merit of the virtual diode is the possibility to adjust the concentrations of electrostatic doping via the gates. The reverse current, forward current and depletion depth become gate-controlled. By modifying the type of electrostatic doping, the virtual diode can be reconfigured into 8 types devices, including semi-virtual diodes, *pin* diodes, TFETs and band-modulation FETs.

We will discuss in detail the device physics, architecture, and applications for the most promising devices enabled by electrostatic doping.