Si electron nano-aspirator en-route for energy-efficient hydro-electronic devices.

Shizuoka Univ.[1], Hokkaido Univ.[2], NTT Basic Research Lab.[3]
Manjakavahoaka Razanoelina[1], Himma Firdaus[1], Tokinobu Watanabe[1], Masahiro Hori[1], Daniel Moraru[1], Yasuo Takahashi[2], Akira Fujiwara[3], Yukinori Ono[1]

E-mail : razanoelina.manjakavahoaka@shizuoka.ac.jp

Hydrodynamic effects in semiconductors are phenomena induced by electron-electron (e-e) scattering, bearing similarity with fluid dynamics governed by inter-particle collisions [1]. However, the e-e scattering which is an energy and momentum conserving process, has less influence on the mobility of a transistor and its effects have mostly been ignored for real applications. In fact, the fundamental limit of a MOSFET drivability is the source injection current hindered by the momentum non-conserving scattering [2]. Recently, we proposed to overcome this fundamental limit with the silicon electron nano-aspirator which is a silicon on insulator (SOI) T-shaped MOS device, as shown Fig 1a. [3]. The underlying physics behind the electron aspirator operation is the electrostatic equivalence of the Bernoulli pumping effects in non-viscous fluid [3]. The device includes an exchangeable emitter and collector, and a fixed base terminal. The emitter and the collector have their own gate to control the energy of the injected electrons and the current flowing into the collector. We performed the measurements at 8 K.

In Fig 1b, low energy electrons are injected ($|eV_E| \simeq$ 0.3 meV) from the emitter terminal in a constant current injection (emitter current I_E = -10 nA) and with the base and collector terminals grounded. These low energy electrons enter the T-branch and flow to the base (not shown in the figure) and to collector with almost the same amount. Here, the device is in the diffuse regime as sketched the figure next to the measurement data.

When high energy electrons ($|eV_E| \simeq$ 1eV) are injected from the emitter terminal, these energetic electrons collide with the cold electrons in the T-branch region and transfer energy and forward momentum to the secondary electrons. These electrons flow to the collector, leaving "holes" (empty states in the conduction band) behind. The hole accumulation drops the voltage in the T-branch and induces an electrons flow from the base. This net flow between two grounded terminals is the *aspirator mode* of the device. As a consequence, the collector current is enhanced as shown Fig 1c, and more importantly *without requiring additional power*. In Fig. 1c, the collector current exceeds the emitter current by a factor of 2.4.

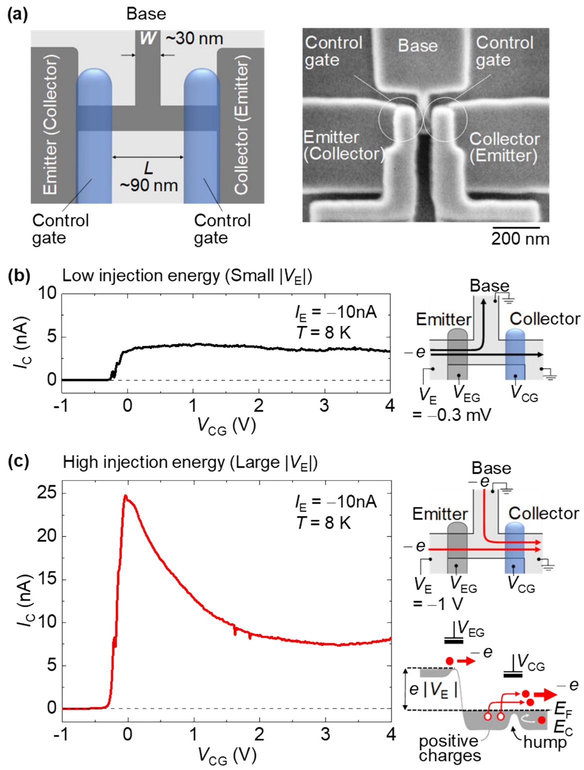

Figure 1 (a) schematic top view and SEM image of the device. The SOI top silicon layer thickness is about 20 nm. (b) Collector current I_C in function of the collector gate voltage V_{CG} for constant emitter current in low energy injection. (c) Collector current I_C in function of the collector gate voltage V_{CG} for constant emitter current in high energy injection.

Here, it is important to note that the kinetic energy gained by the lateral electric field is inevitably dissipated in conventional MOS transistors. In the electron aspirator, the energy gained is transferred to the cold electrons by e-e scattering and therefore enhance the output current. Put in other way, the aspirator efficiently uses the energy that is usually wasted to thermalize the transistor. In this context, the aspirator is not only a strong candidate for an energy-efficient device but also opens the possibility of breaking the fundamental limit of transistor drivability.

[1] A. O. Govorov & J. J. Heremans, *Phys. Rev. Lett.* **92**, 026803 (2004).
[2] M. Lundstrom, *IEEE Electron. Dev. Lett.* **18**, 361 (1997).
[3] H. Firdaus et *al.*, *Nat. commun.* **9**, 4813 (2018).

Acknowledgments: JSPS KAKENHI (JP15H01706, JP16H04339, JP16H02339, JP16H06087, JP17H06211, JP18H05258 and JP18K13803)