Contribution ID: **136** Type: **Invited Talk**

Overcoming of “Boltzmann tyranny” in MOSTET with the “cold metal” source

Friday, 17 November 2023 09:30 (30 minutes)

The subthreshold swing S is a fundamental characteristic of MOSFET transistors [1]. It shows how many times the gate voltage Vg must be increased in the subthreshold range in order to achieve an increase in the drain current Id by an order of magnitude: $S \equiv \ln(10)\frac{dV_g}{d\ln(Id)}$.At room temperature in a high-quality transistor with a large value of sub-gate capacitance, the threshold value of this parameter is equal to $S \equiv \ln(10)\frac{kT}{e} \approx$ 60 mV/decade, where e is the electron charge, k is the Boltzmann constant, and T is the temperature in Kelvins.

The importance of this parameter lies in the fact that its smallest threshold value determines the minimum possible operating voltage of the transistor supply (on the figure the curve with $S_2 < S_1$ corresponds to lower $V_{dd}^{(2)} < V_{dd}^{(1)}$). Therefore, a decrease in S below the fundamental limit, called in many sources as ‘Boltzmann tyranny,’ would theoretically open up great prospects for further reducing power consumption and scaling transistors.

For this purpose, in particular, it was previously proposed [2-4] to use the effect of negative capacitance in a ferroelectric that forms the gate dielectric layer. However, the futility of such attempts has been proven on the basis of fundamental thermodynamic principles and numerical calculations of real systems in [5].

Therefore, another, much more physical way to overcome the fundamental limit was proposed: to use a cold metal source for electron injection into the MOSFET channel, where, due to the small width of the valence band, the electrons injected into the channel no longer have a “hot” Boltzmann “tail” in their energy distribution. Transistors with a monolayer sub-10-nanometer MoS2 channel and drain and source on the basis of NbS2 and TaS2 with a subthreshold swing below the fundamental limit have already been realized experimentally [6, 7]. However, a visual analytical model that would allow us to estimate the magnitude of the expected effect has not yet been created.

Within the framework of the Landauer-Datta-Lundstrom formalism [8], we have derived in [9] an analytical expression for the subthreshold swing S, which implies that S is generally somewhat smaller than the fundamental limit, and the degree of its decrease is determined by the ratio of the energy kT (26 meV at room temperature) to the value of the energy interval between ΔE, the top of the valence band of the source material, and the value of the surface potential in the transistor channel. Under the limit $\Delta E \gg kT$, this expression leads to a standard value $S(300\,\mathrm{K}) = 60$ mV/decade. The formula can be used to estimate the magnitude of the effect under study in real state-of-the-art electronics systems.

1. S.M. Sze. Physics of Semiconductor Devices. 2nd Edition. John Wiley & Sons: New York, Chichester, Brisbane, Toronto, Singapore (1981).
2. R. Landauer. Can capacitance be negative? Collect. Phenom., 2, 167-170 (1976).
3. Michael Hoffmann, Stefan Slesazek, Thomas Mikolajick. Progress and future prospects of negative capacitance electronics: A materials perspective. APL Mater. 9, 020902 (2021).
4. S. Salahuddin, S.Datta. The era of hyper-scaling in electronics. Nat. Electron. 1, 442-450 (2018).
5. E.A. Eliseev, A.N. Morozovska, L.P. Yurchenko, M.V. Strikha. Could the negative capacitance effect be used in field-effect transistors with a ferroelectric gate? Physics and Chemistry of Solid State 23(4), 705–713 (2022)
6. Yiheng Yin, Zhaofu Zhang, Chen Shao, John Robertson and Yuzheng Guo. Computational study of transition metal dichalcogenide cold source MOSFETs with sub-60 mV per decade and negative differential resistance effect. NPJ 2D Materials and Applications 6, 55 (2022); https://doi.org/10.1038/s41699-022-00332-6
7. Kunyi Liu, Fei Lu, Yuan Li. Bias-Independent Subthreshold Swing in Nanoscale Cold-Source Field-Effect Transistors by Drain Density-of-States Engineering. arXiv:2211.02304 (2022).
8. Yu.Krugliak, M.Strikha. Landauer – Datta – Lundstrom generalized electron transport model for micro- and nanoelectronics. 2015 IEEE International Conference on Electronics and Nanotechnology (ELNANO). Conference Proceedings. Kyiv: NTUU “KPI”, 70-74 (2015).
9. М.В.Стріха, К.О.Корж. Аналітична модель для підпорогового розкиду в MOSFET з витоком на основі холодного металу. Сенсорна електроніка і мікросистемні технології. 20, № 3, 30 – 37 (2023).

Topics

Contact Email address

Primary author: Prof. STRIKHA, Maksym (Taras Shevchenko National University of Kyiv, V.Lashkariov Institute of Semiconductor Physics, NAS Ukraine.)

Presenter: Prof. STRIKHA, Maksym (Taras Shevchenko National University of Kyiv, V.Lashkariov Institute of Semiconductor Physics, NAS Ukraine.)

Session Classification: Plenary