Energy consumption, conversion, and transfer in nanometric Field-Effect-Transistors (FET) used in readout electronics at cryogenic temperatures

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1. Introduction

Cryogenic operation of Complementary-Metal-Oxide-Semiconductor (CMOS) Field-Effect-Transistor (FET) technologies is of crucial relevance for quantum computing. A commercial high-K metal-gate, 14 nm FinFet technology node is used as a test vehicle. Its nominal operation voltage is of 0.9 V, and the effective width over length geometry is W/L = 120 nm / 20 nm.

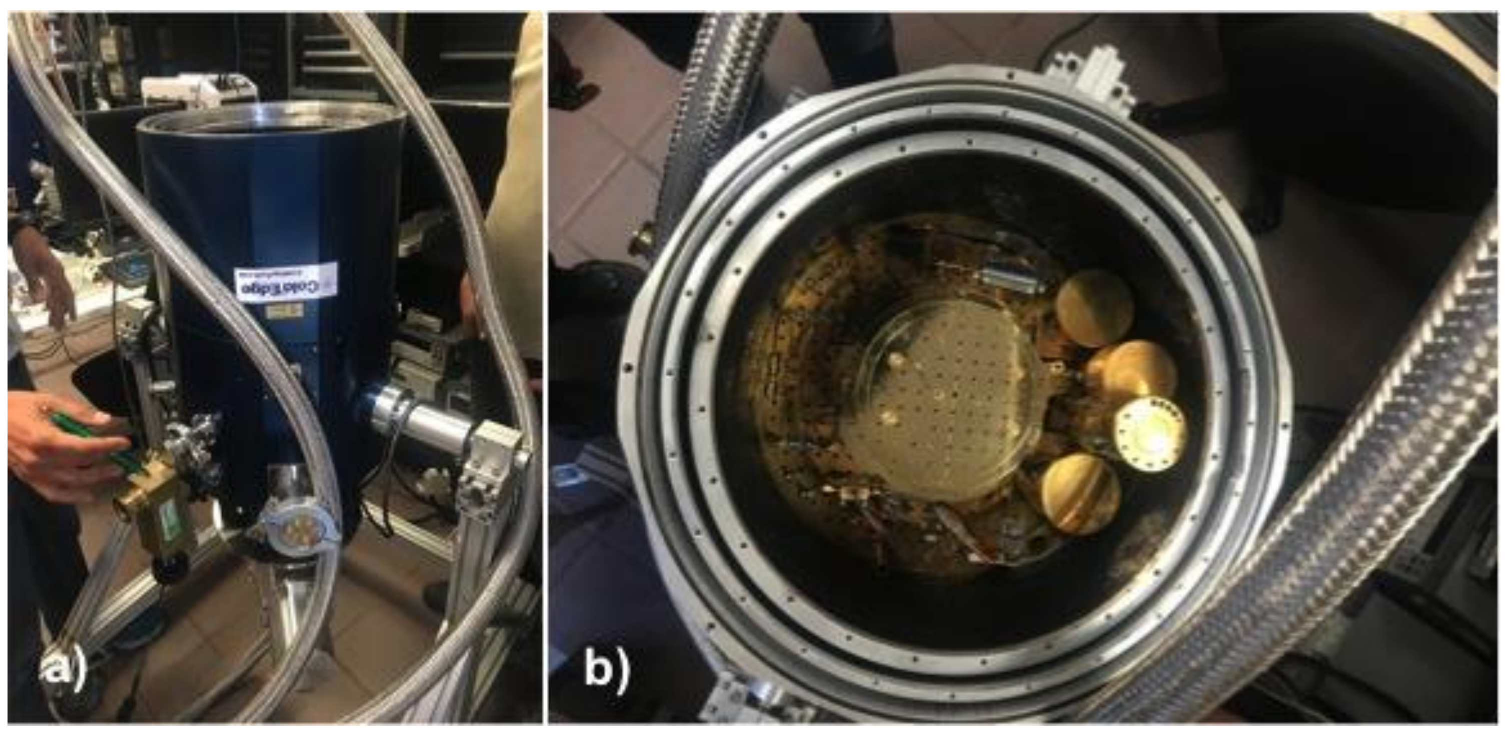

Fig. 1 250 mK closed-cycle He^3-He^4 based cryostat used for the characterization. *Left* is the general view, and *Right* the close view of the internal chamber.

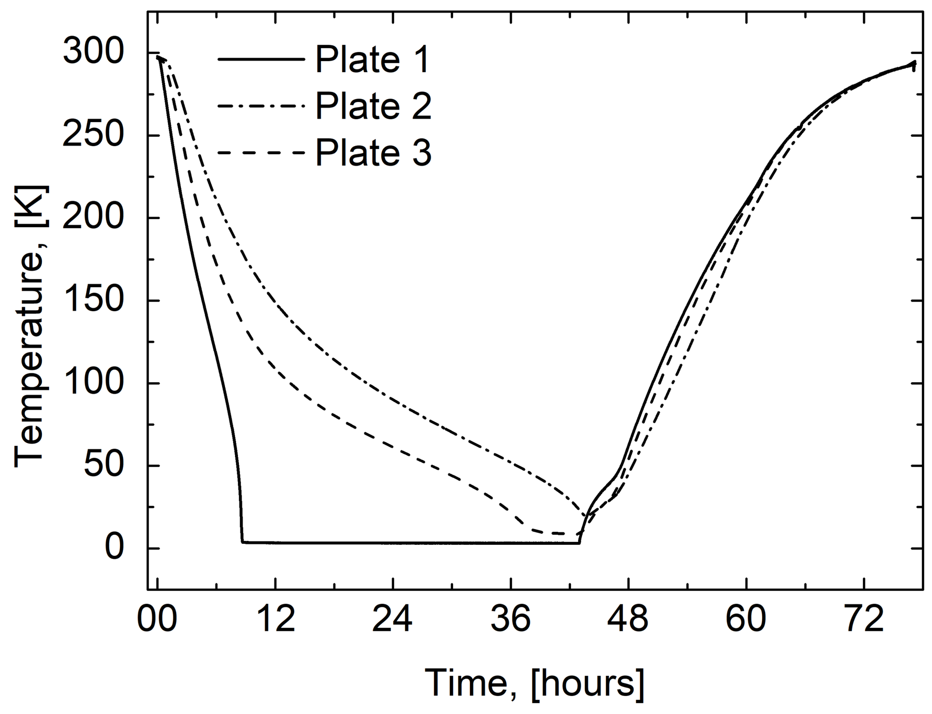

Fig. 2 Temperature-time profile (T-t) of the closed-cycle cryostat featuring three different cooling plates held at different distances from the cold finger.

2. Results and discussion

Inner energy of the FET device decreases with the reduction of the temperature, which leads to an increase of the threshold voltage V_T.

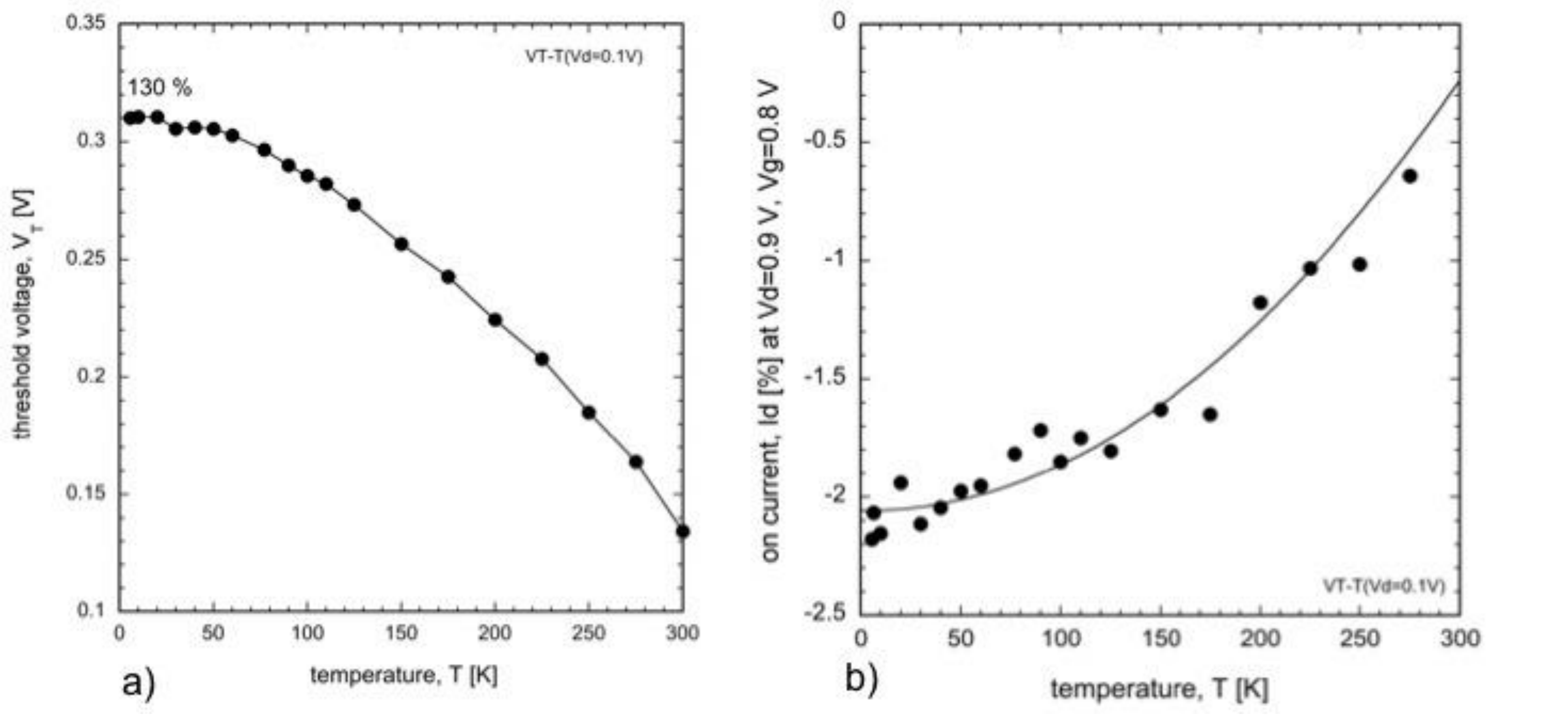

Fig. 3 a) Measured threshold voltage V_T (at Vd=0.1 V), and b) percentage variation of the on current I_{on} (at (Vd=0.9 V,Vg=0.8 V).

There is a monotonic increase of energy consumption with Vd @3.1K but a non-monotonic function in the whole 300K - 3.1K temperature range.

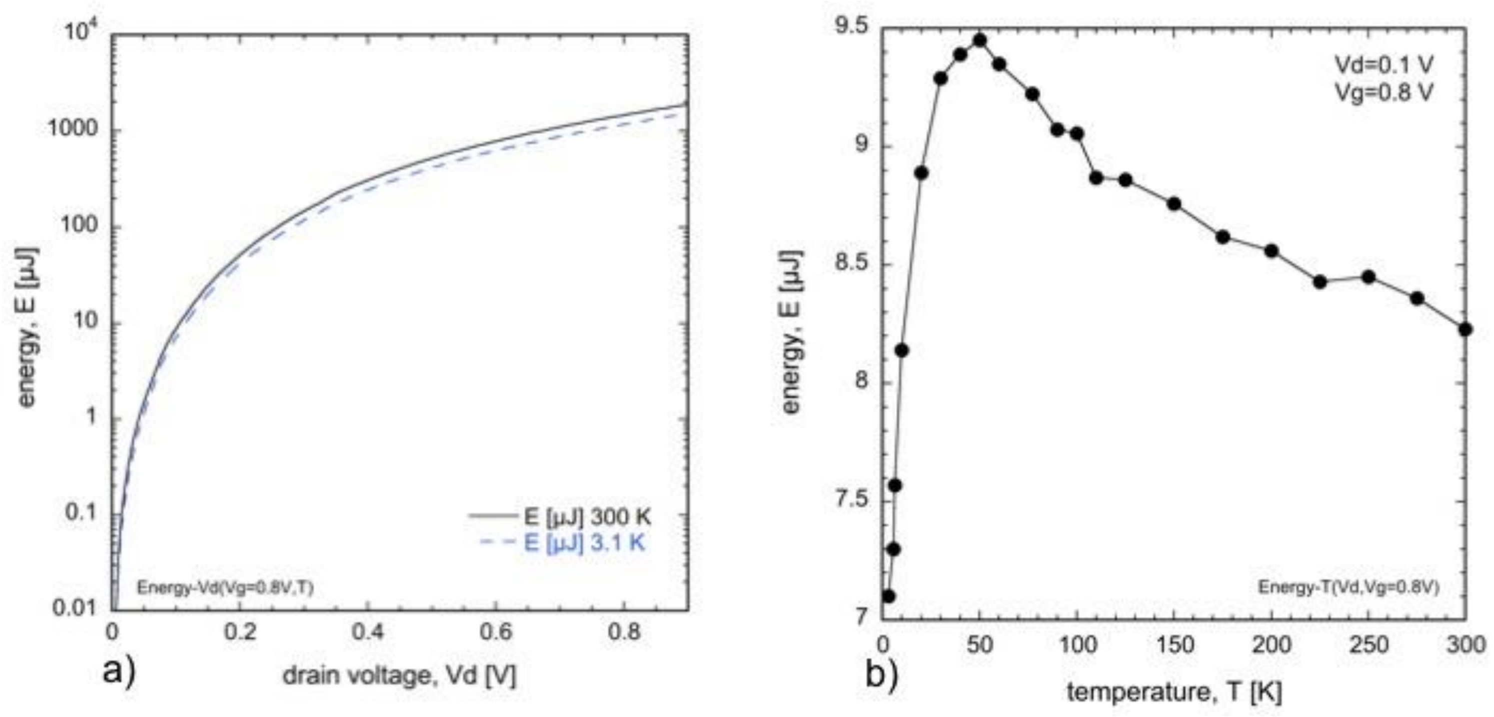

Fig. 6 a) Measured energy consumption at T=3.1 K as a function of V_d, with V_g=0.8 V; b) Measured energy consumption as a function of temperature for V_d = 0.1 V, at V_g=0.8 V.

Id and gm normalized for 0.1 and 0.4V show that this technology represents an excellent option for low-voltage cryogenic systems.

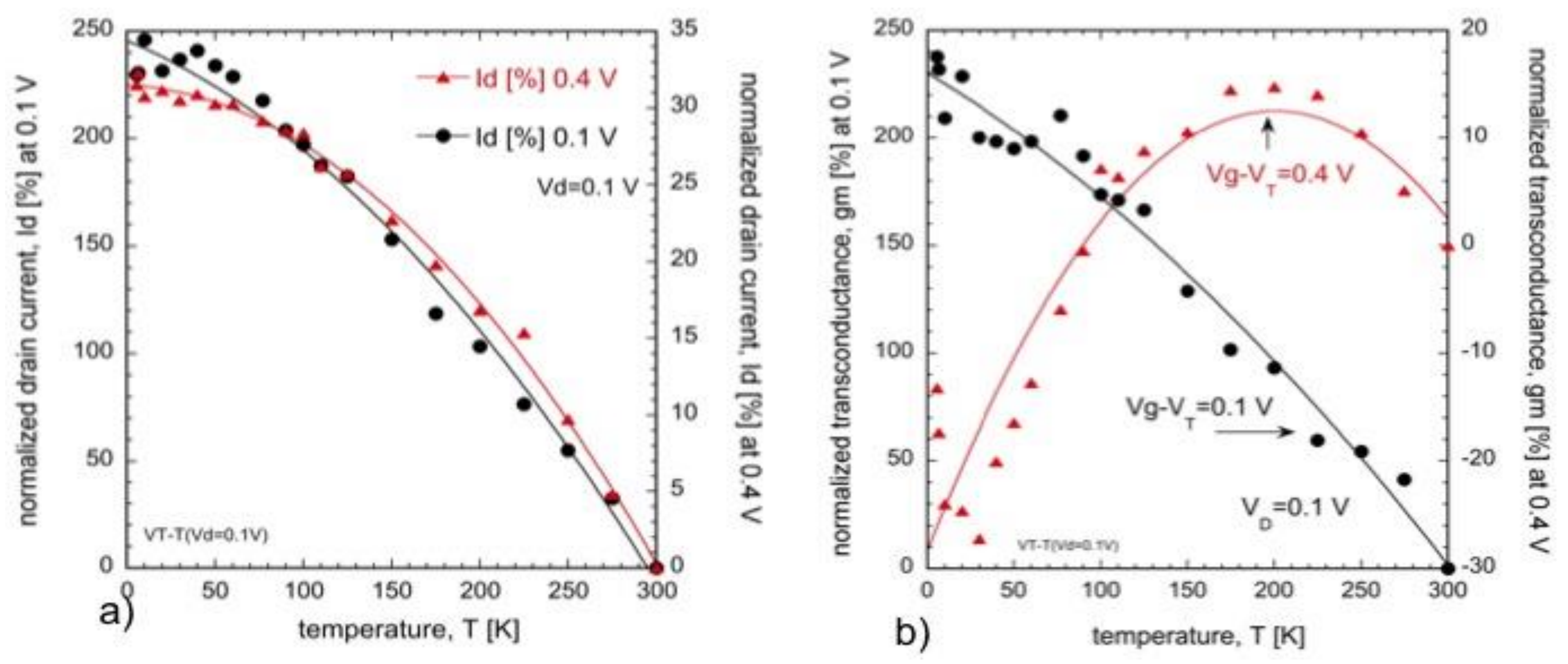

Fig. 4 a) Measured and normalized Id current increase, and b) percentage of increase of the transconductance for 0.1 and 0.4 V gate overdrive voltage.

Kink effect happens at the condition where the holes generated by impact ionization start changing the bulk potential which results in a decrease of the V_T voltage, and an increase of Id.

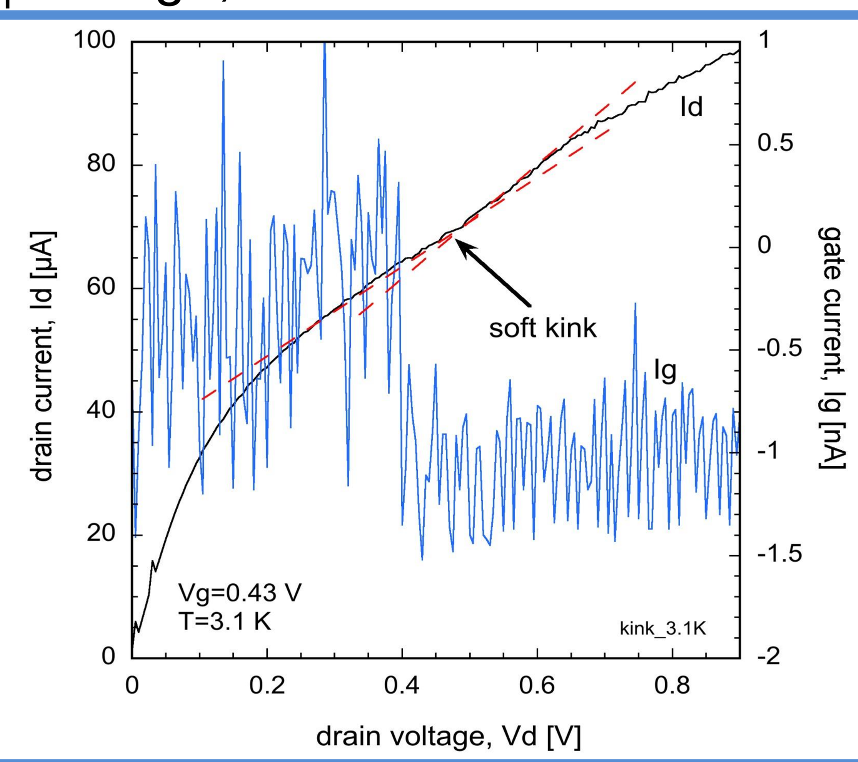

Fig. 7 Measured Id-Vd curve at Vg=0.43 V and T=3.1 K. The measured gate current (Ig) is on the right axis.

The electrical performance of the *p*-type FinFet shows a regular behavior.

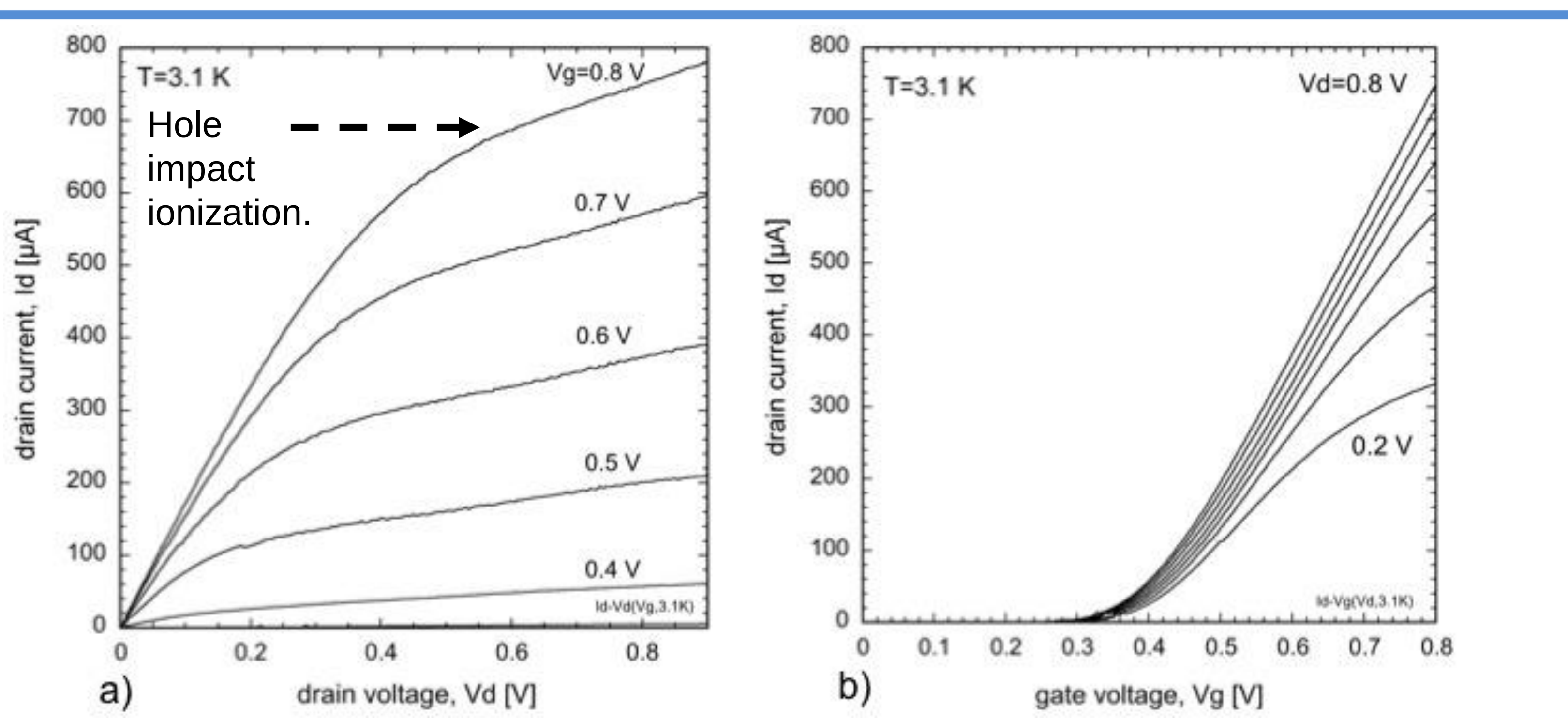

Fig. 5 Experimental results obtained at T=3.1 K: a) measured I_d-V_d characteristics, and b) I_d-V_g characteristics.

3. Conclusions

The 14 nm FinFet technology works well down to 3.1 K and has a superior energy efficiency, which proves this technology is an appropriate candidate for quantum computing applications.

References

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