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Contact-controlled transistors: Device characteristics and modelling challenges

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The Royal Academy of Engineering

EPSRC Engineering and Physical Sciences Research Council

Motivation for this talk

Printed and flexible electronics activities growing, on a continuum

EPSRC Fellowship

2021-2026

TCAD	Manufacturability and variability	Hybrid integration	User-centric design

Outline

1. Overview and motivation

2. Contact controlled transistors
   - The Source-Gated Transistor – SGT
   - The Multimodal Transistor - MMT

3. Device fabrication and characteristics
   - The modelling challenge

Contact-controlled transistors
Background

In many TFT technologies, reducing contact effects is a challenge.

Contact effects reduce current density, transconductance, on-off ratio, cut-off frequency.

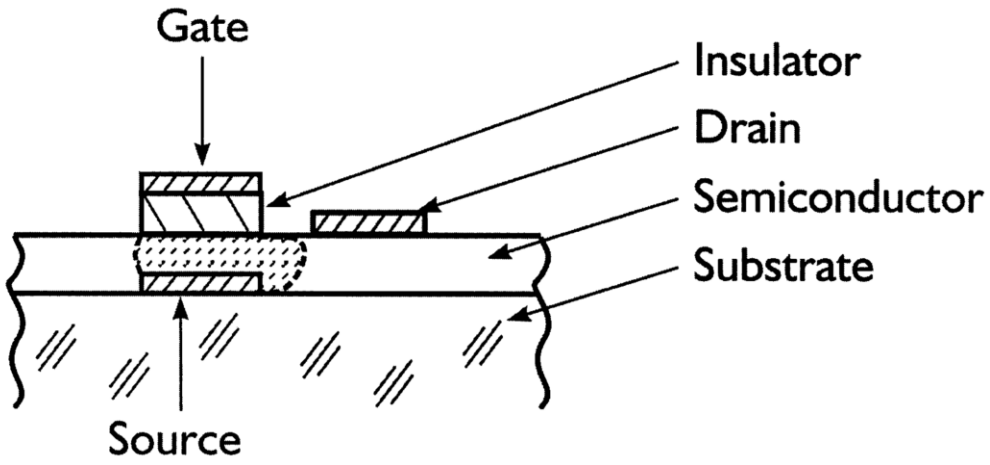
But contact effects can also be used constructively.

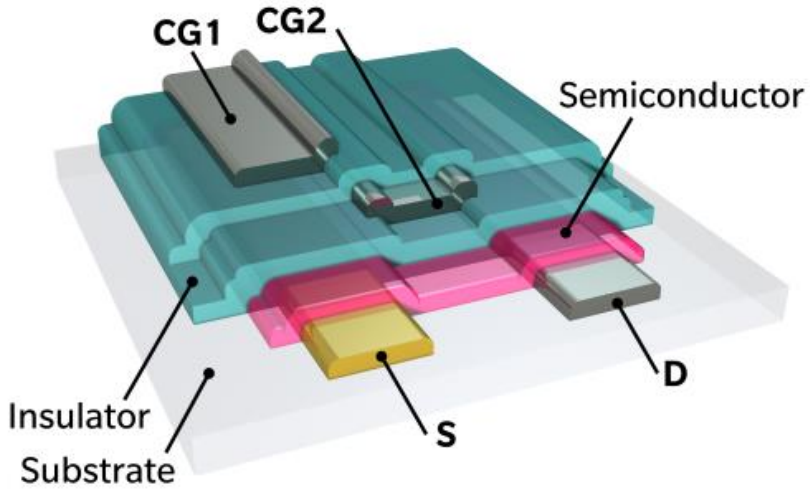
15+ years of heritage in contact-controlled transistors:

- **Source-Gated Transistor (SGT)**
- **Shannon, Gerstner, Balon, Guo (2003+)**
- **Sporea (2007+)**
- **Performance trade-offs**

The new multimodal transistor (MMT):

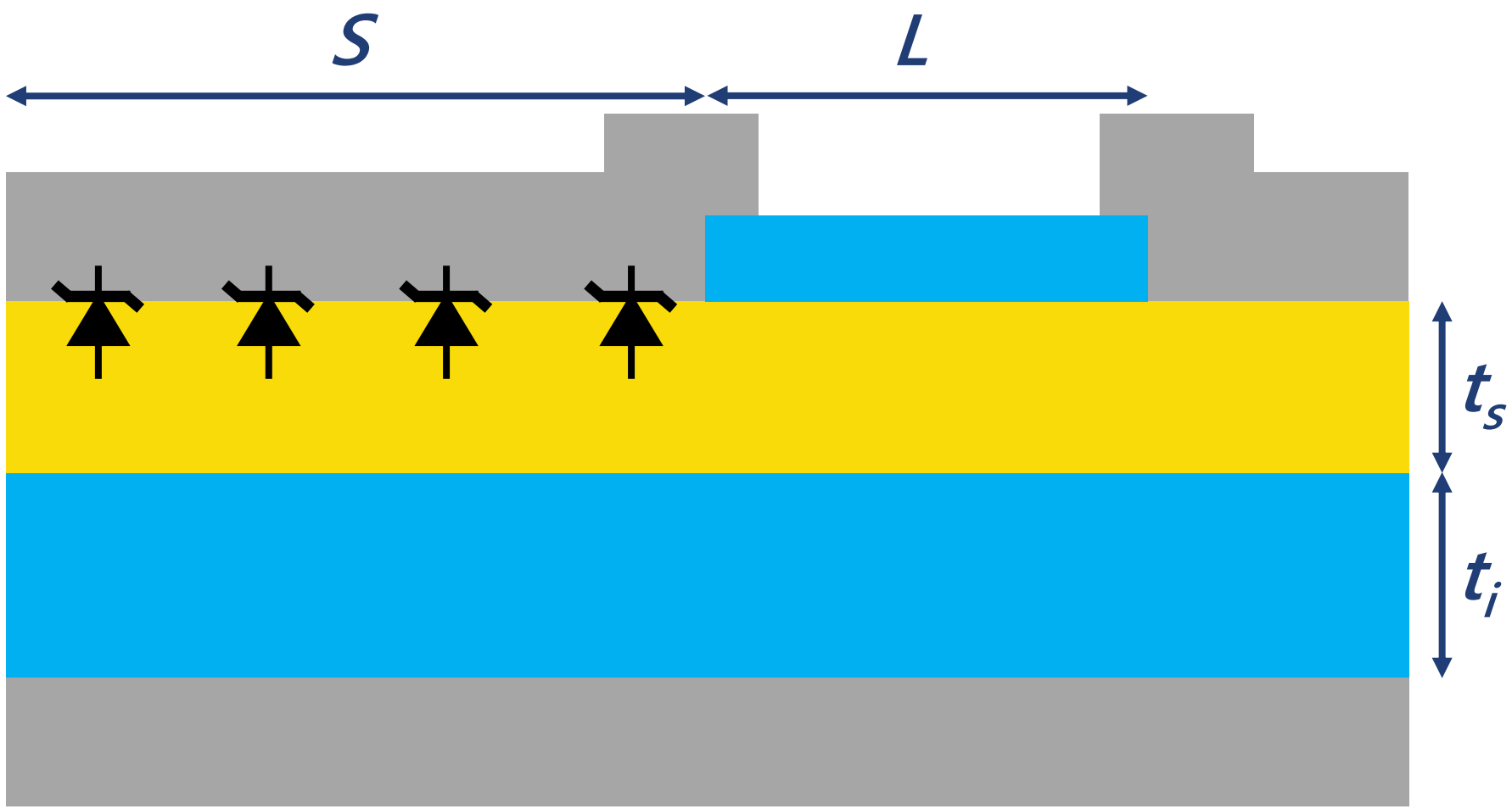
- **Sporea and Bestelink (2017+)**
- **Refines the philosophy**
- **Higher level of abstraction**





Source-gated transistor (SGT) structure

J. M. Shannon and E. G. Gerstner, "Source-Gated Thin-Film Transistors," *IEEE Electron Device Lett.*, vol. 24, no. 6, pp. 405–407, 2003.



Source-gated transistor (SGT) operation

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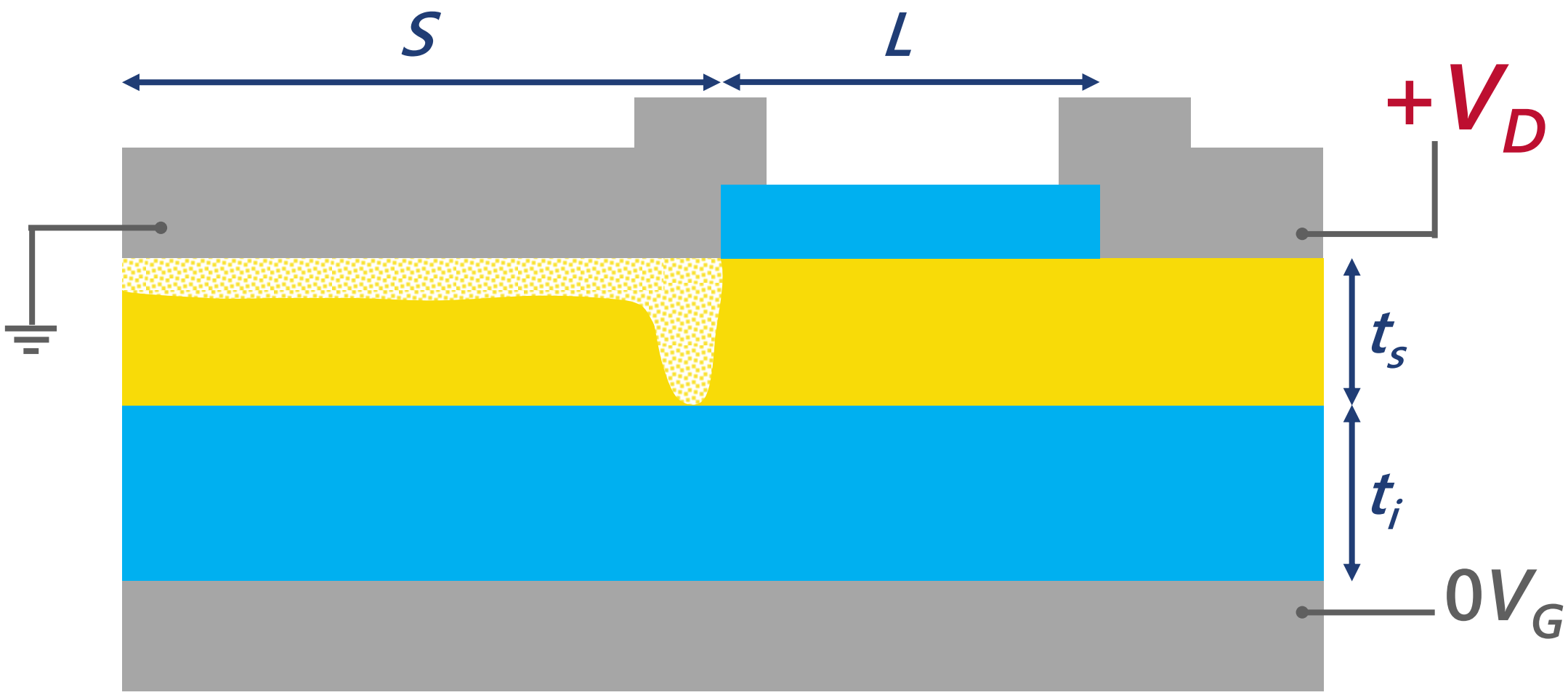

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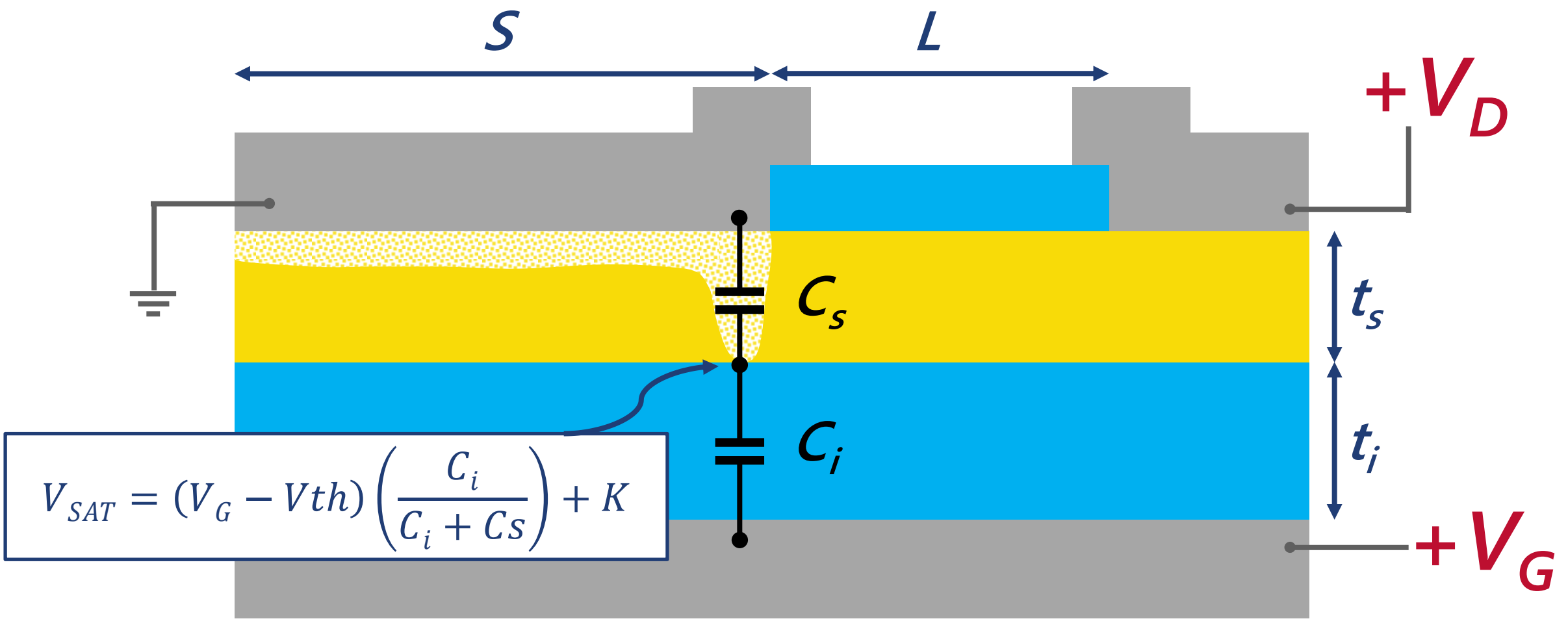
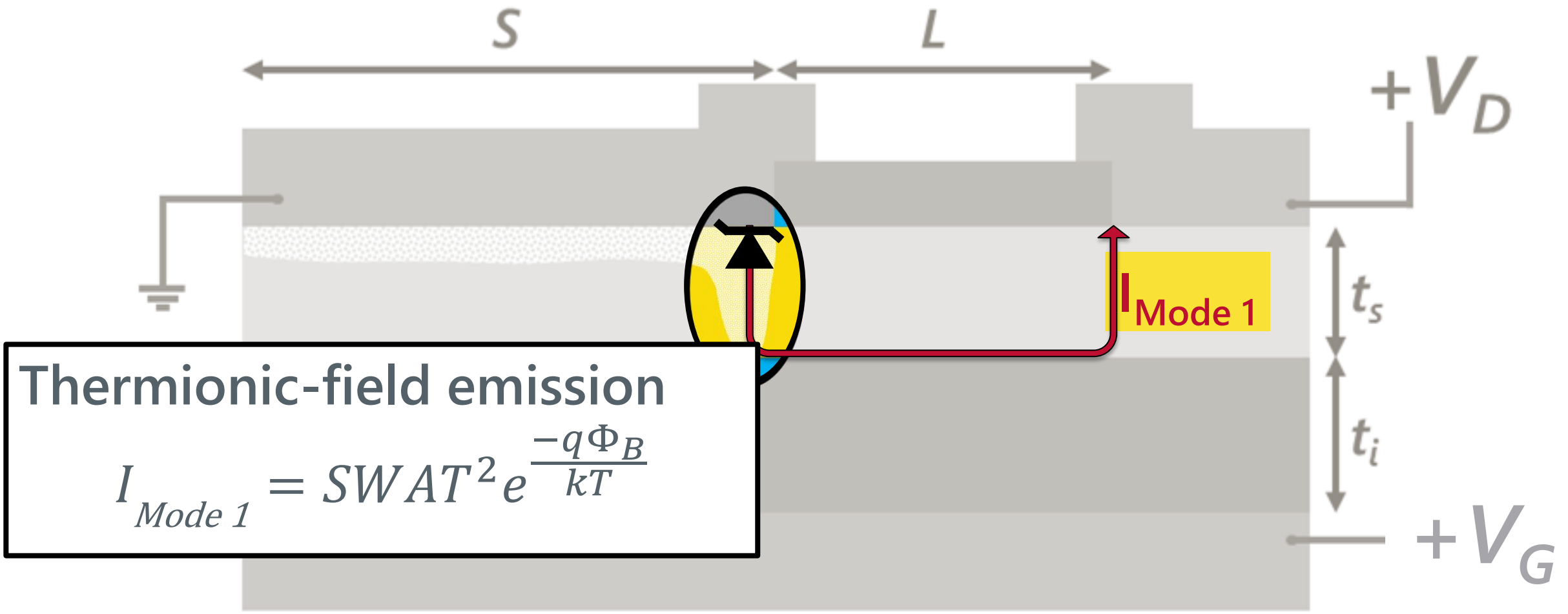


$$V_{SAT} = (V_G - Vth)\left(\frac{C_i}{C_i + Cs}\right) + K$$

Source-gated transistor (SGT) operation

J. M. Shannon, R. A. Sporea, S. Georgakopoulos, M. Shkunov, and S. R. P. Silva, "Low-Field Behavior of Source-Gated Transistors," *IEEE Trans. Electron Devices*, vol. 60, no. 8, pp. 2444–2449, 2013.



Thermionic-field emission

$$I_{Mode\ 1} = SWAT^2 e^{\frac{-q\Phi_B}{kT}}$$

Source-gated transistor (SGT) operation

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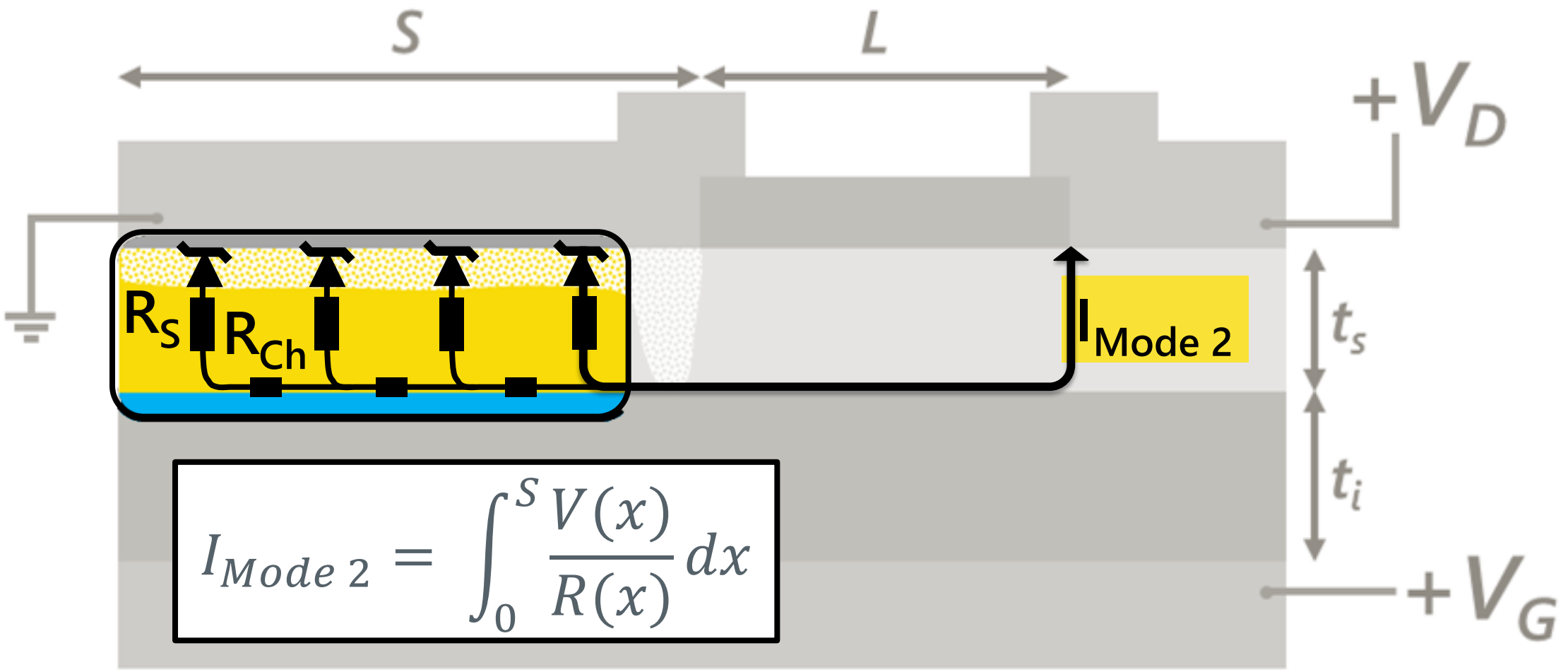
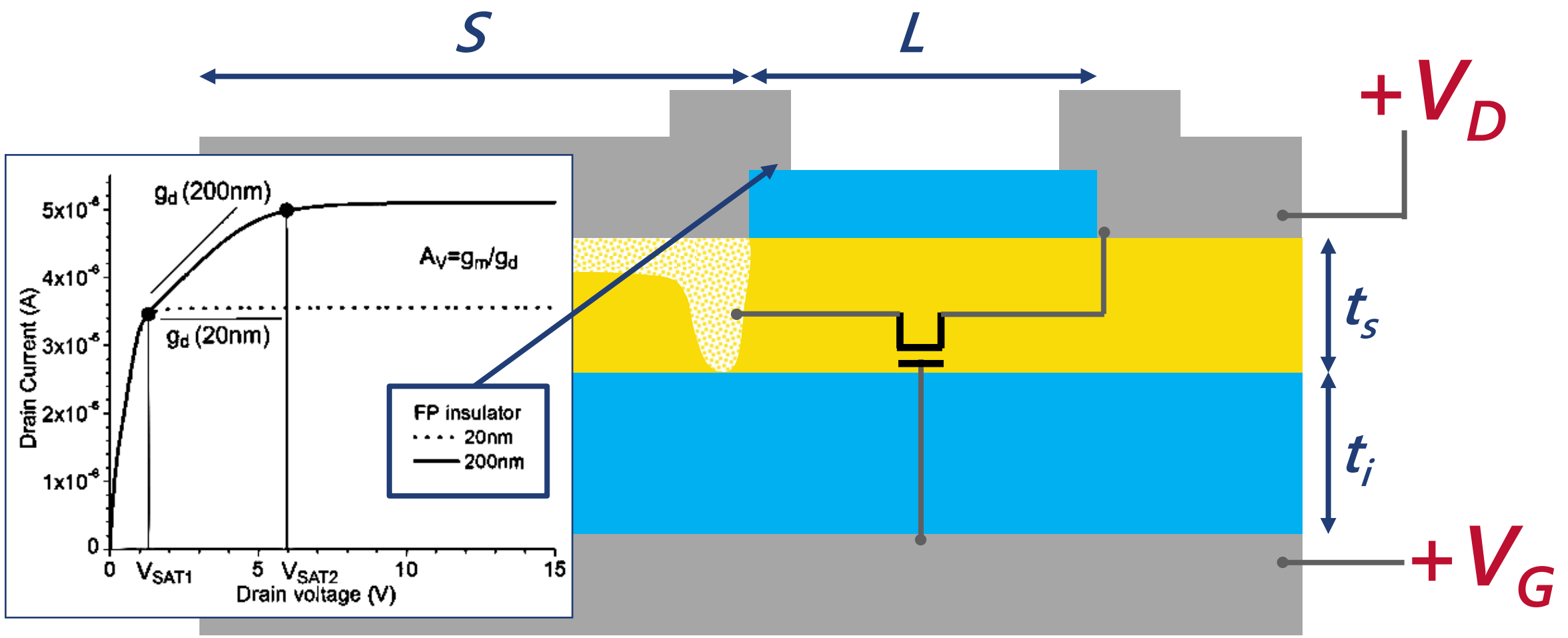


$$I_{Mode\,2} = \int_0^S \frac{V(x)}{R(x)}\,dx$$

Source-gated transistor (SGT) operation

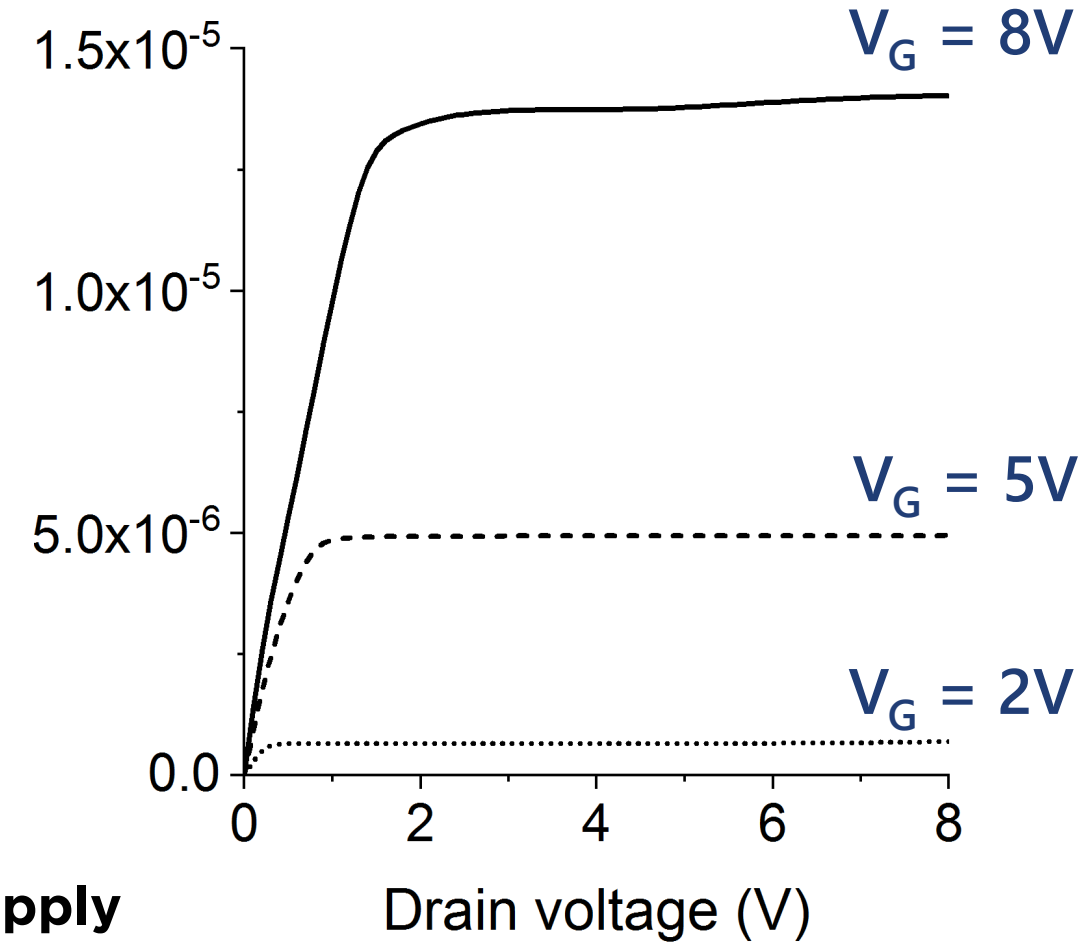
R. A. Sporea, M. J. Trainor, N. D. Young, J. M. Shannon, and S. R. P. Silva, "Source-gated transistors for order-of-magnitude performance improvements in thin-film digital circuits," *Sci. Rep.*, vol. 4, pp. 1–7, 2014.



Source-gated transistor (SGT) electrical characteristics

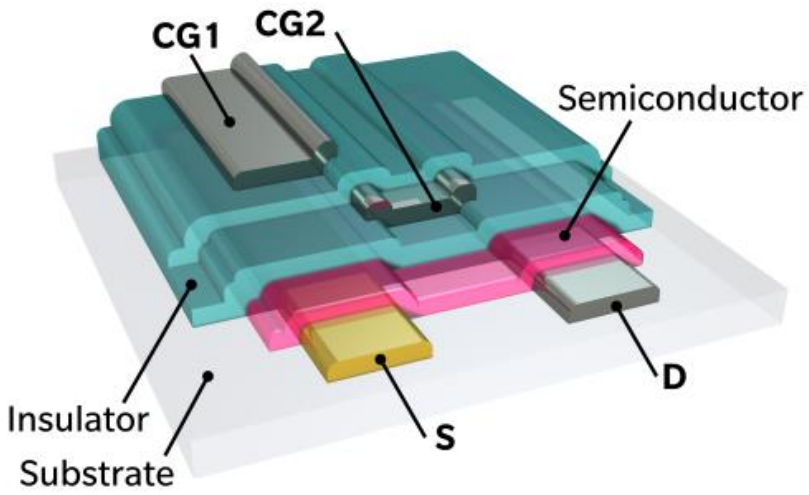
Compared to conventional TFTs:

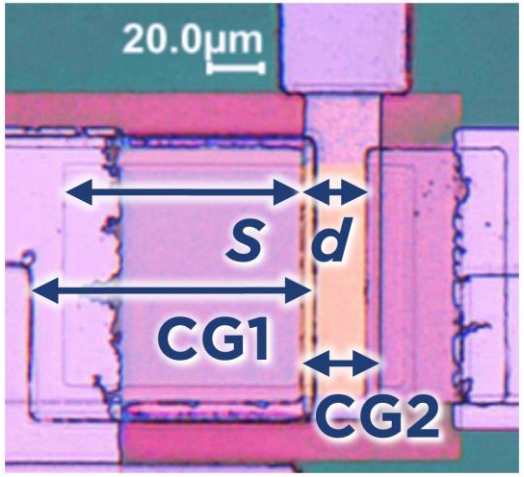
- **Low saturation voltage**
- **Flat output characteristics**
- **On-current is lower for the same geometry**
- **Generally independent of source-drain gap (L)**
- **Temperature dependence varies with source length (S)**
- **Field effect mobility cannot be extracted meaningfully because the transport equation is different**



As such, conventional TFT/FET models do not apply

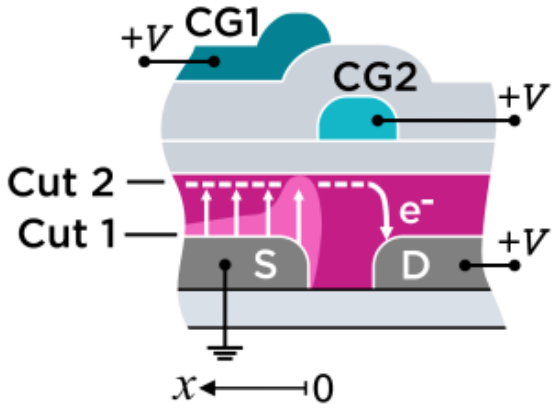
The Multimodal Transistor (MMT)
Operation





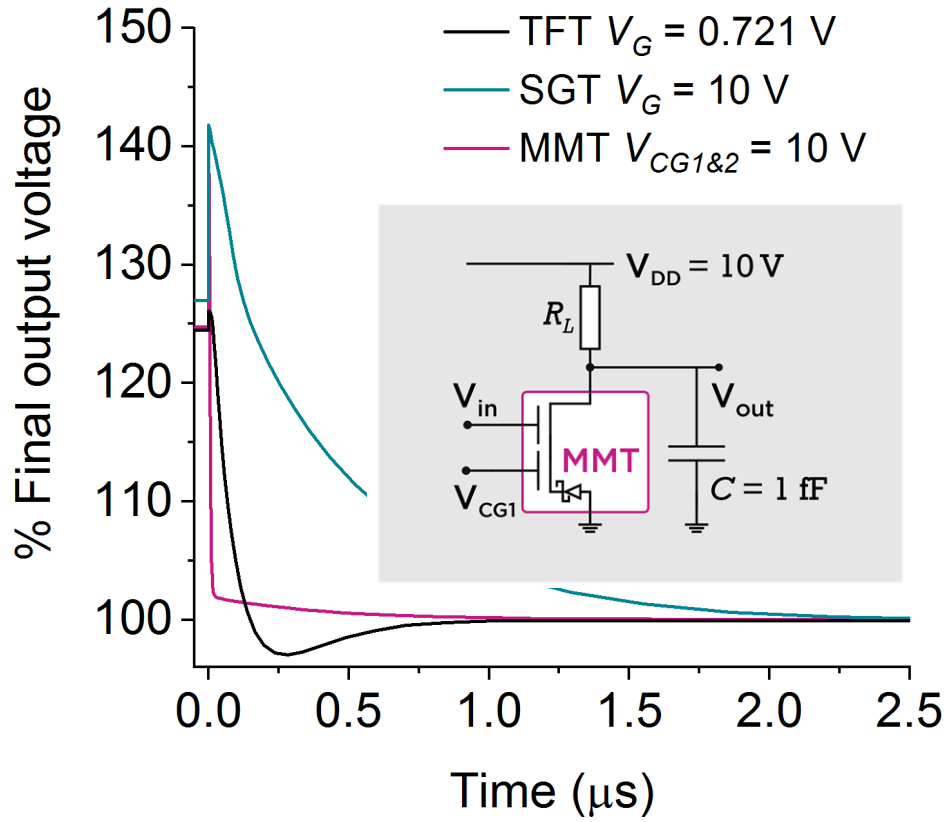
The Multimodal Transistor (MMT)
Operation

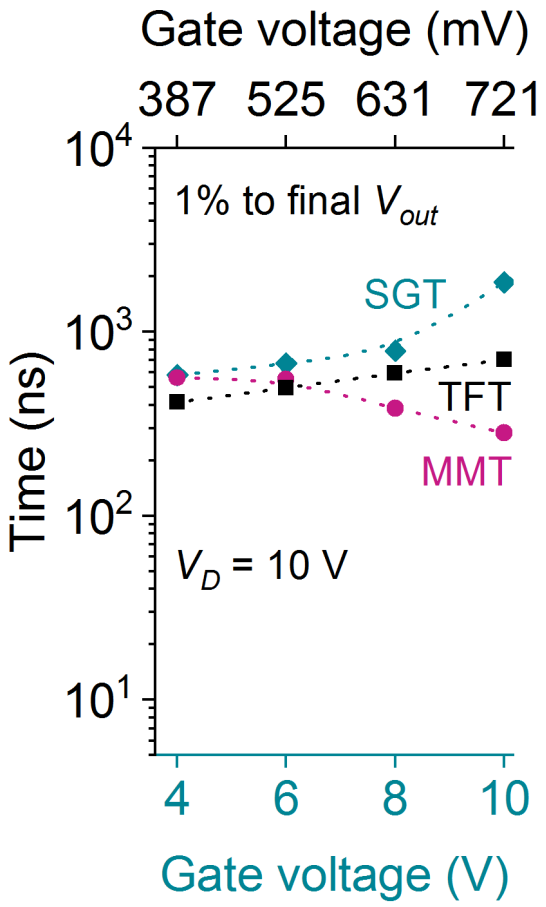
Output and transfer characteristics

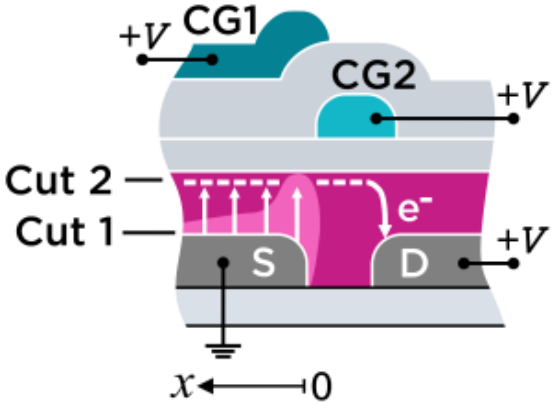


The Multimodal Transistor (MMT)
Operation

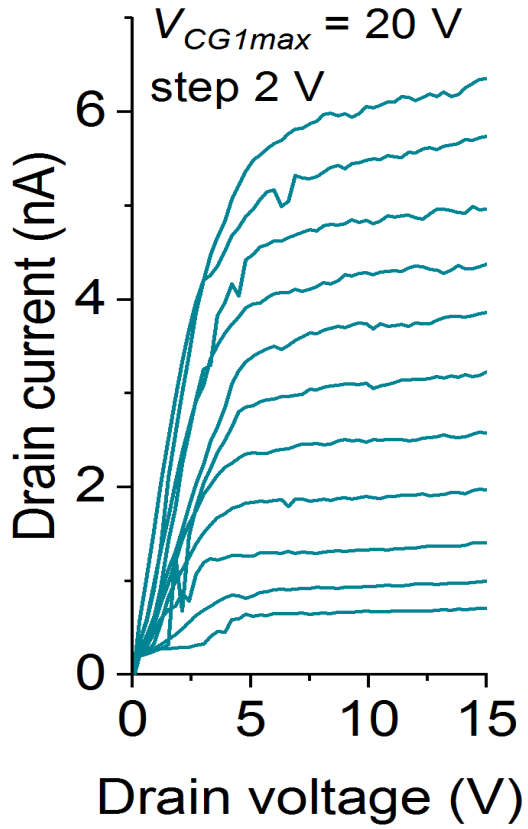
Switching speed







Constant transconductance *in saturation*

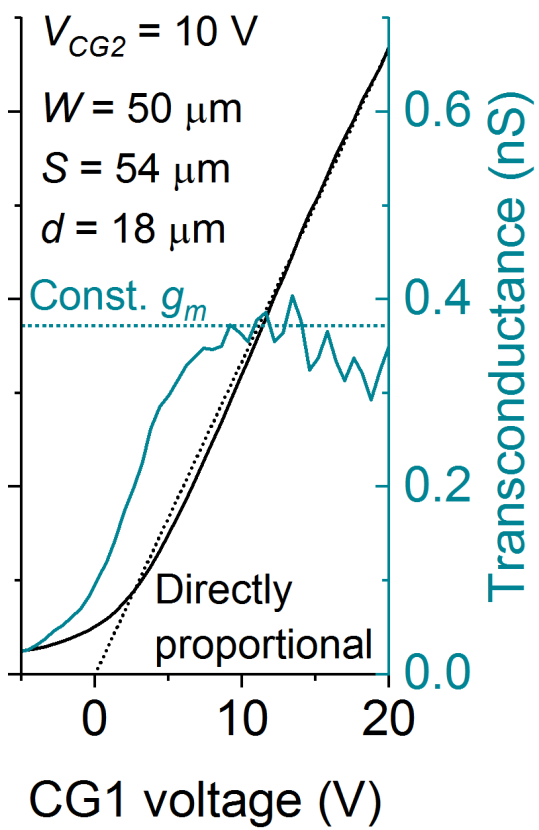


Ohmic (linear): $V_{GS} > V_t$ $V_{DS} < V_{GS} - V_t$

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[V_{DS}\left(V_{GS} - V_t\right) - \frac{V_{DS}^2}{2}\right]$$

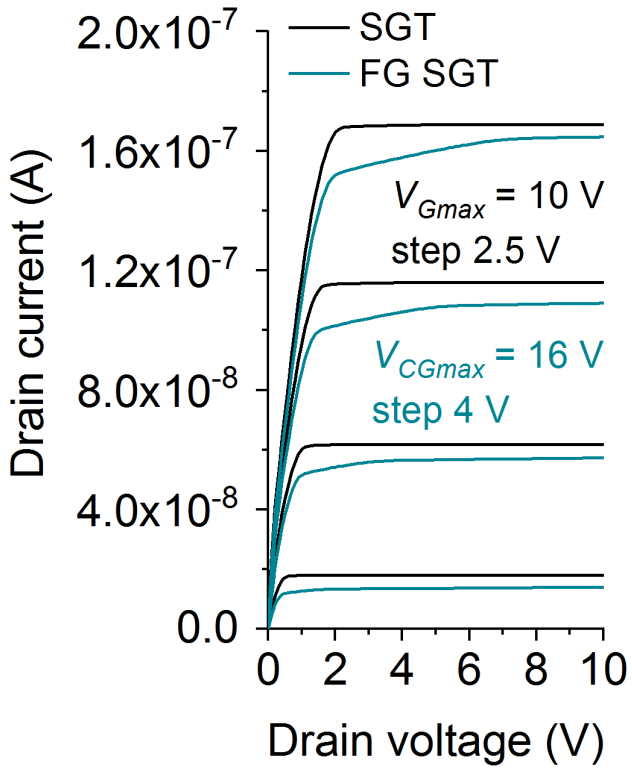
Saturation: $V_{GS} > V_t$ $V_{DS} > V_{GS} - V_t$

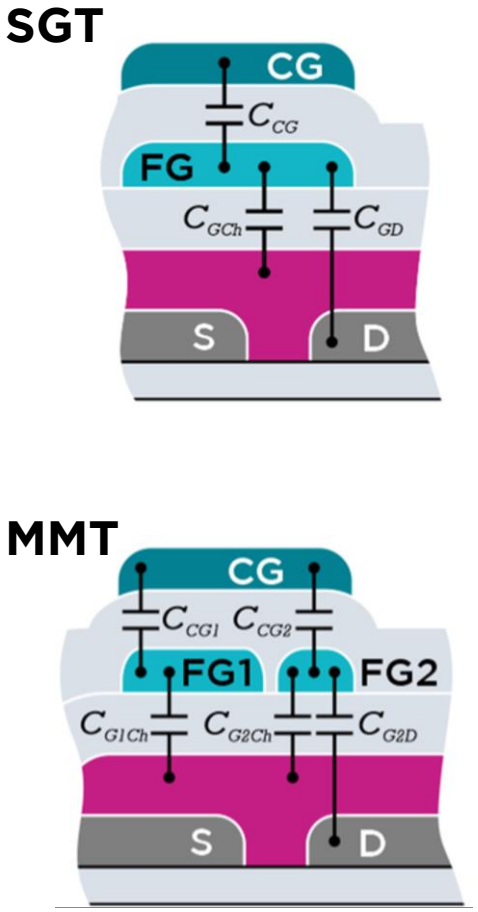
$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_t\right)^2$$

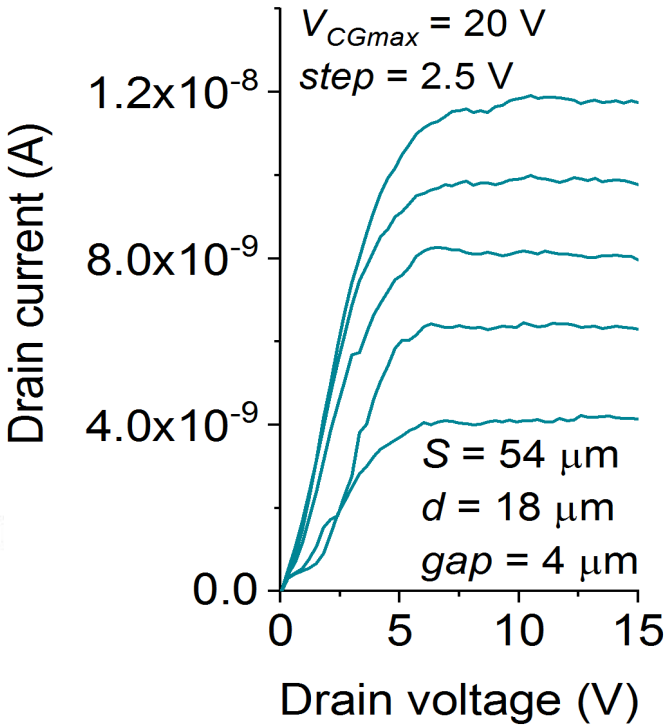


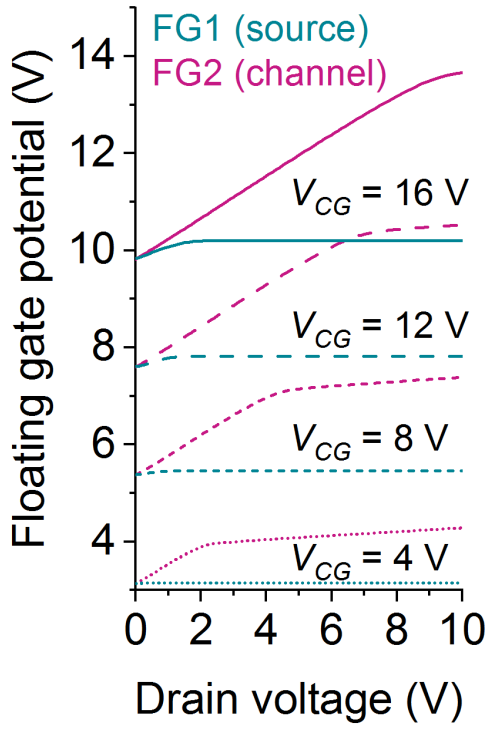
The Multimodal Transistor (MMT)
Operation

Total gain recovery in floating gate configuration









Contact-controlled transistors
The modelling challenge

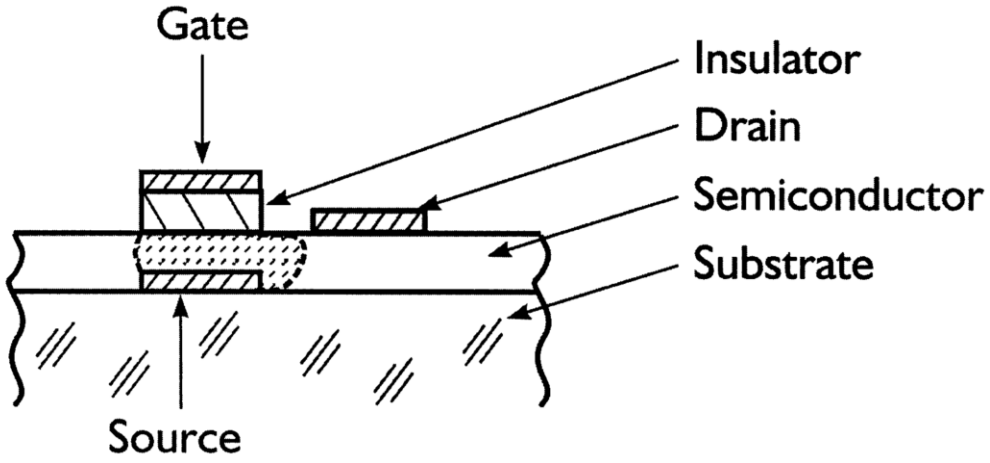
The manufacturing challenge has been lowered:

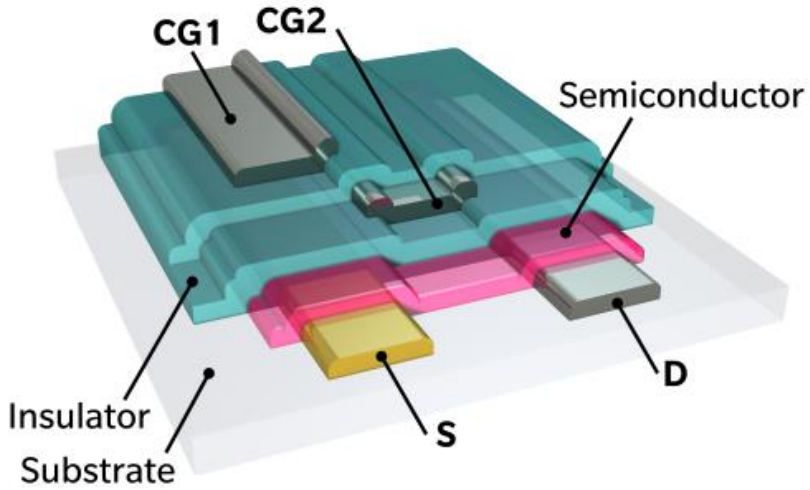
- ✓ **Staggered electrodes**
- ✓ **Rectifying contacts**

Conventional models do not apply directly

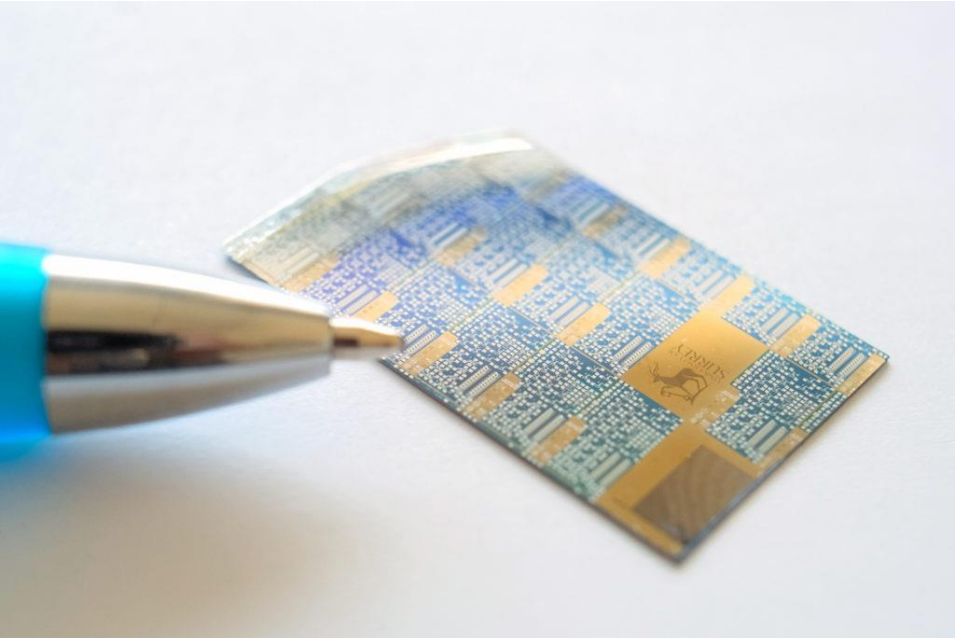
Without realistic models, it is hard for designers to adopt these new technologies.

Next: overview of the potential applications





The Multimodal Transistor (MMT)
first publication



COMMUNICATION

28 October 2020

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Versatile Thin-Film Transistor with Independent Control of Charge Injection and Transport for Mixed Signal and Analog Computation

*Eva Bestelink, Olivier de Sagazan, Lea Motte, Max Bateson, Benedikt Schultes, S. Ravi P. Silva, and Radu A. Sporea**

Microcrystalline silicon
+ Silvaco TCAD

EPSRC Fellowship – Project ALPACA

A new Low-complexity Paradigm for Analogue Computation and hArdware learning

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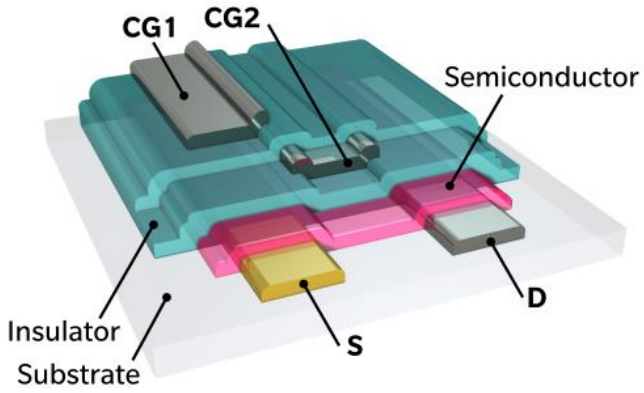
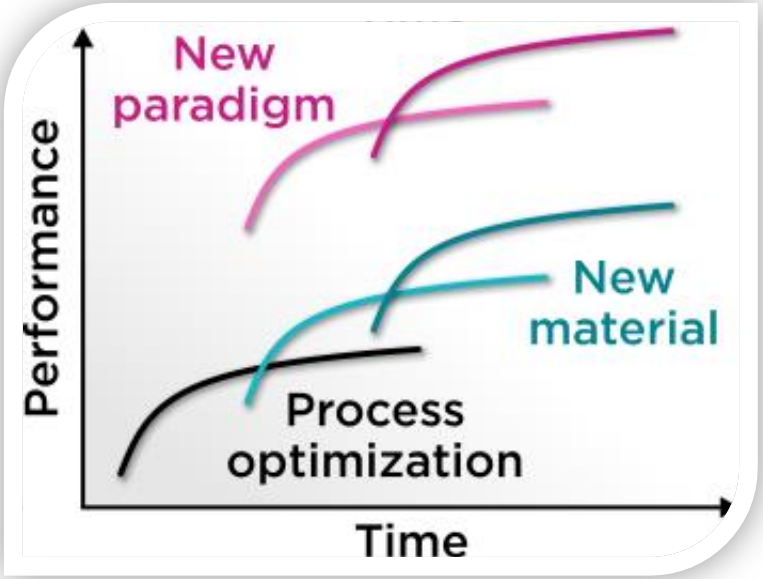
Silvaco	University of Cambridge	Yamagata University

+ U. Stuttgart, U. Sussex, SYSU, KHU

EP/V002759/1
£1.12M form EPSRC
2021-2026





Operation and applications of the multimodal transistor

What next?

Let's talk!

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EP/R028559/1
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