

Learning MOSFET Models from I–V Data: A Neural Surrogate Approach Validated on the Open SKY130 Process

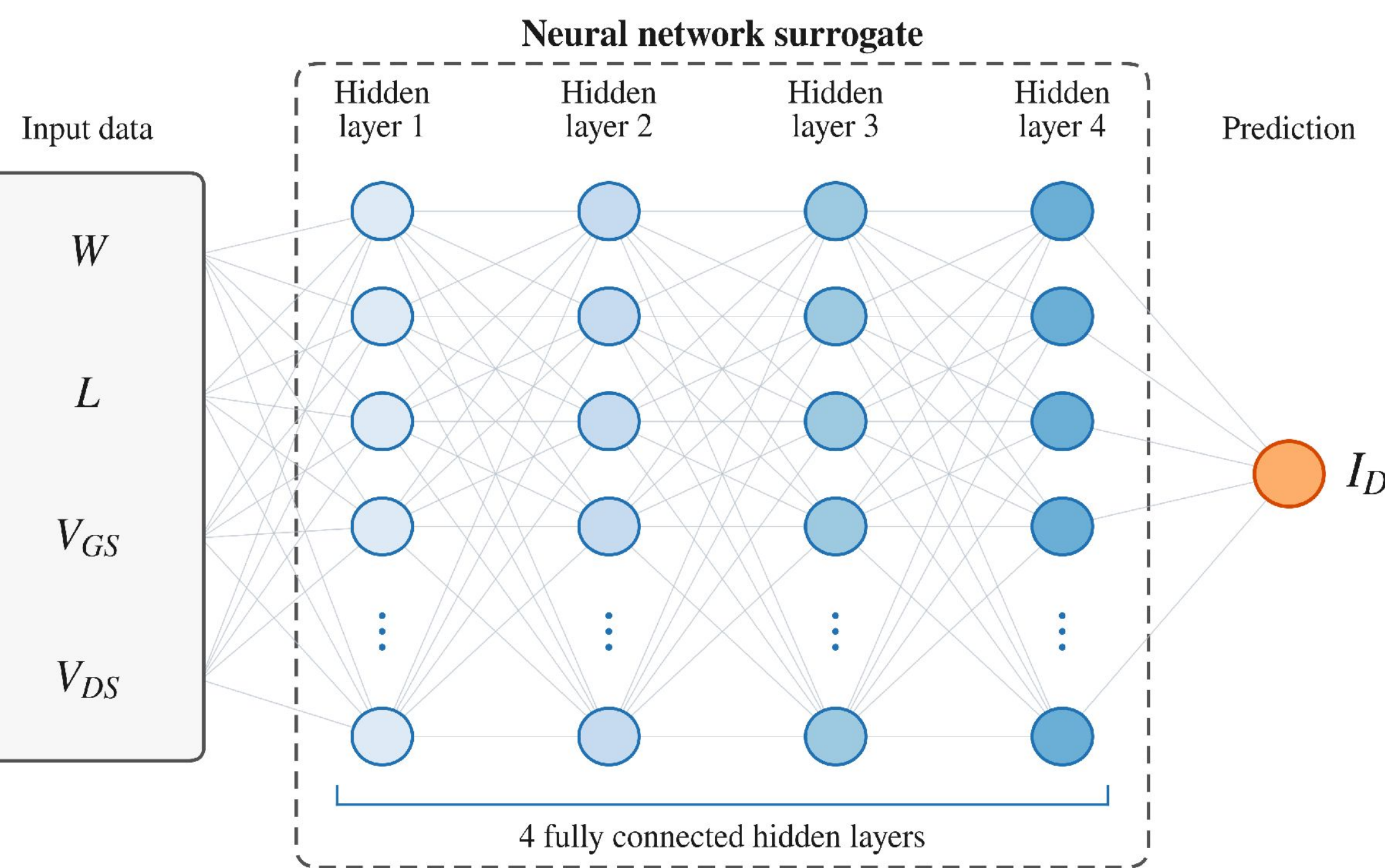
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Introduction

- Many particle detectors use readout chips that run cold.
- Chip design needs accurate transistor models.
- Foundry models are made at room temperature.
- Refitting them for the cold is slow and difficult.
- We train a neural network to learn transistors from I–V data.
- We test it first at room temperature on SKY130.

Method

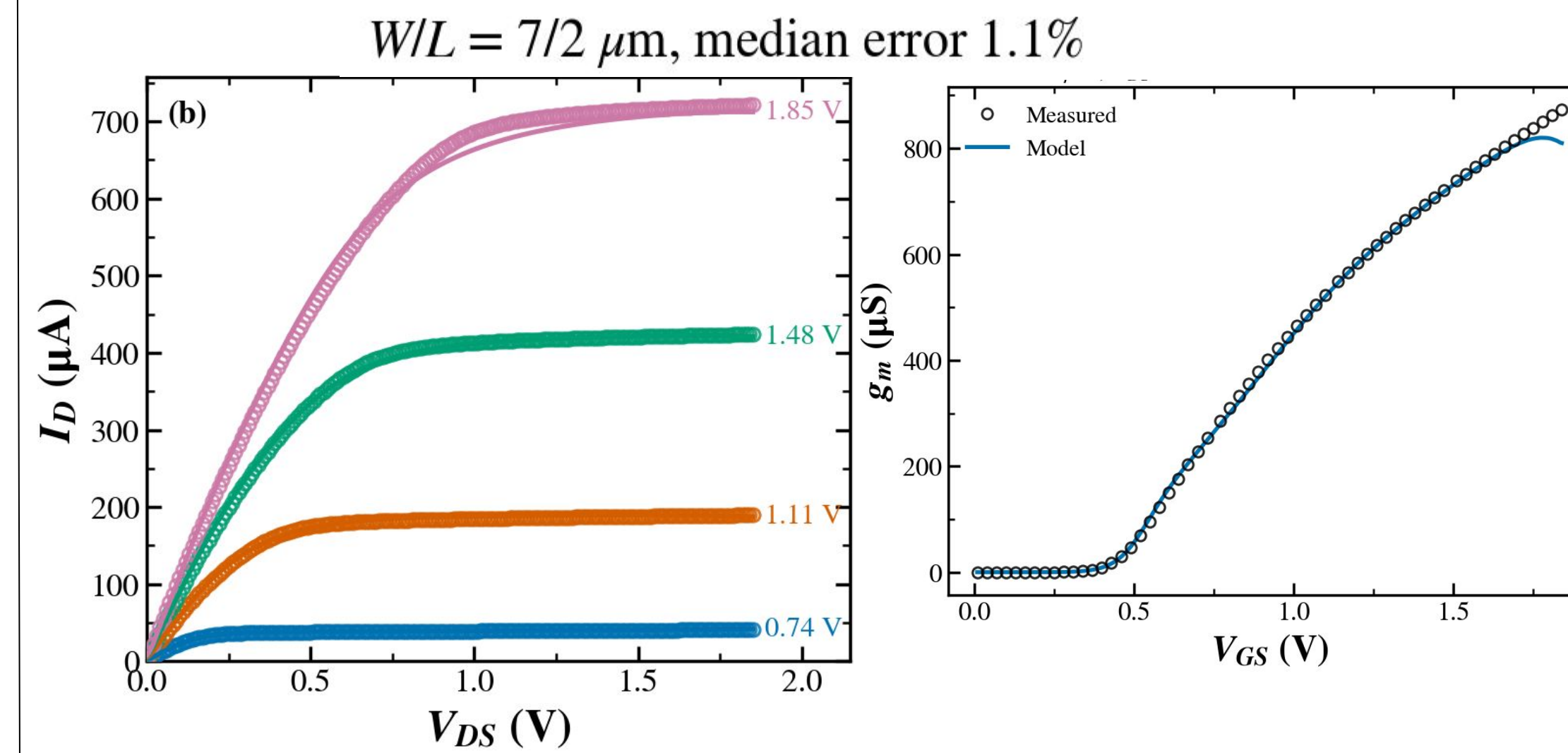


- We generated I–V data from SKY130 PDK simulations at room temperature.
- The network takes W , L , V_{GS} and V_{DS} and predicts the drain current I_D .
- It has 4 fully connected hidden layers.
- It learns $\log_{10} I_D$, so small and large currents are treated on equal footing.
- Test devices are kept out of training.
- We repeated this for transistors measured in our lab

Results

Simulated devices (SKY130 PDK)

- Model vs. SPICE for a device never seen in training.
- Dots are SPICE, lines are the model.
- The fit holds from the off-state, through turn-on, to full current.



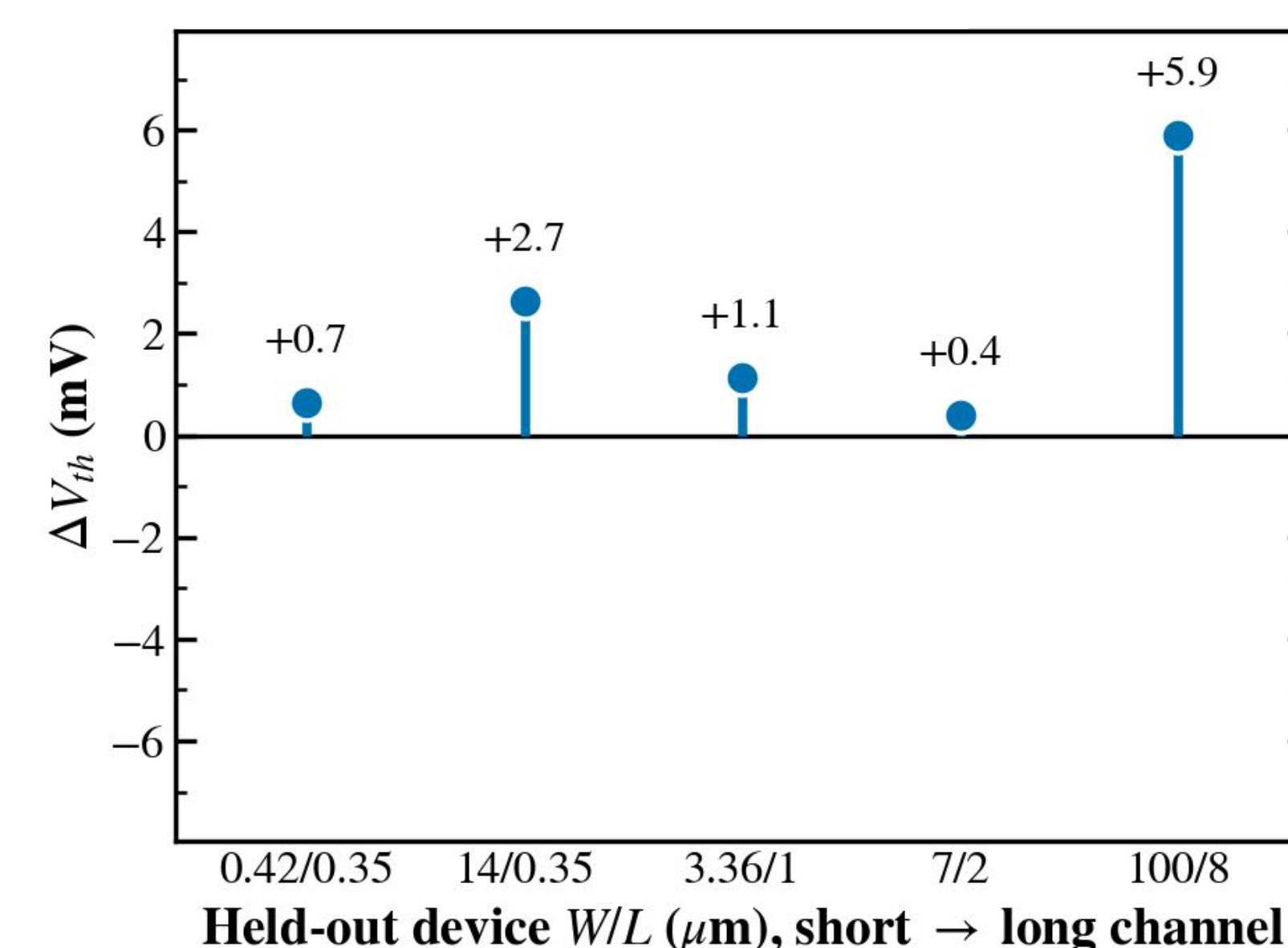
Current error on unseen devices

- All five devices within 6% median current error.

W (μm)	L (μm)	NRMSE	RRMS	Median rel. error (%)
7	2	0.0067	0.0233	1.1
3.36	1	0.0121	0.0412	1.9
100	8	0.0137	0.0487	4.9
14	0.35	0.0207	0.0666	2.5
0.42	0.35	0.0422	0.1373	5.9

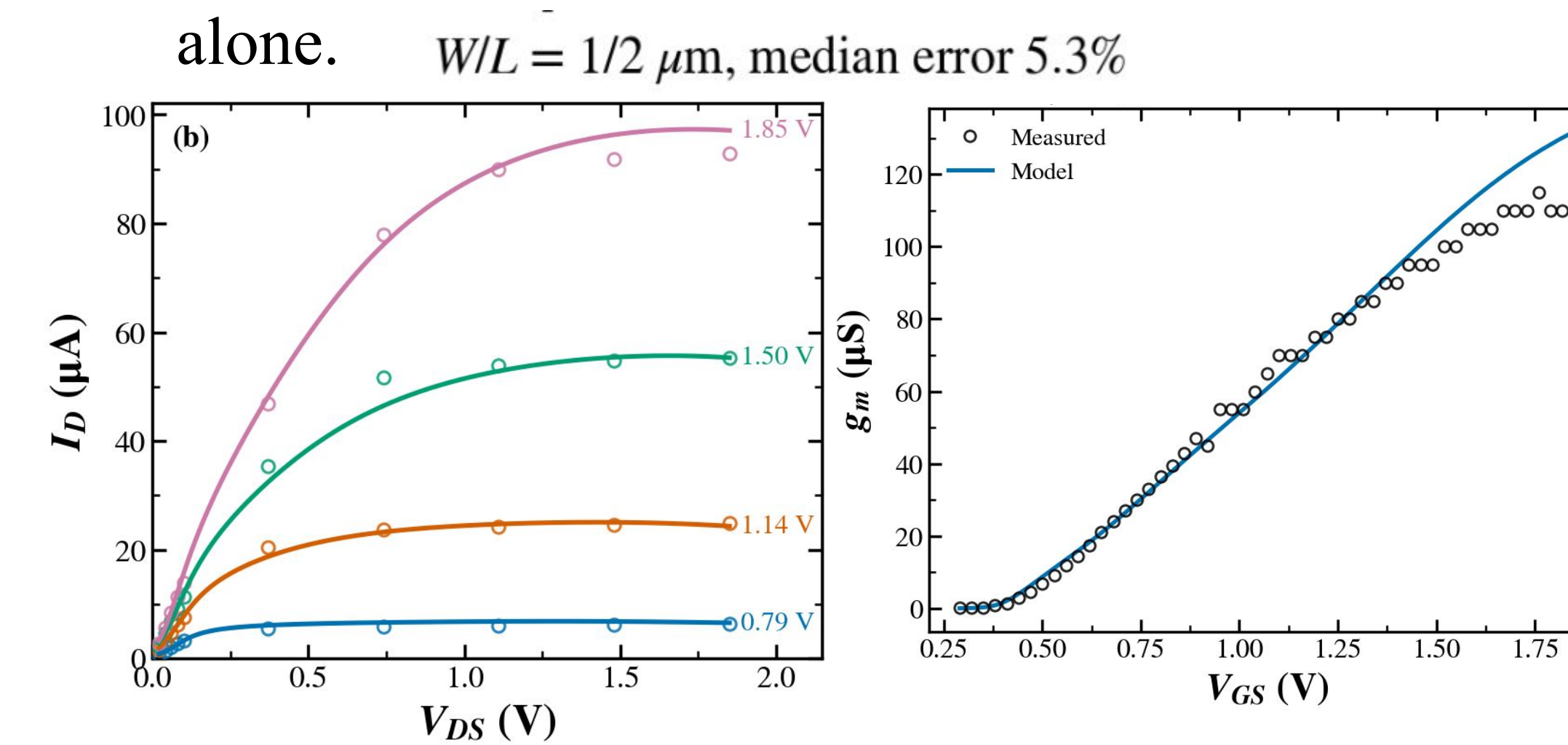
Threshold-voltage error on unseen devices

- $\Delta V_{th} = V_{th}^{\text{model}} - V_{th}^{\text{PDK}}$ is how far the model's threshold voltage is from the SKY130 PDK simulation.
- All five unseen devices are within 6 mV



Measured devices (room temperature)

- Model vs. measurement for a transistor never seen in training.
- Dots are measured data, lines are the model.
- The model follows the real device using I–V data alone.



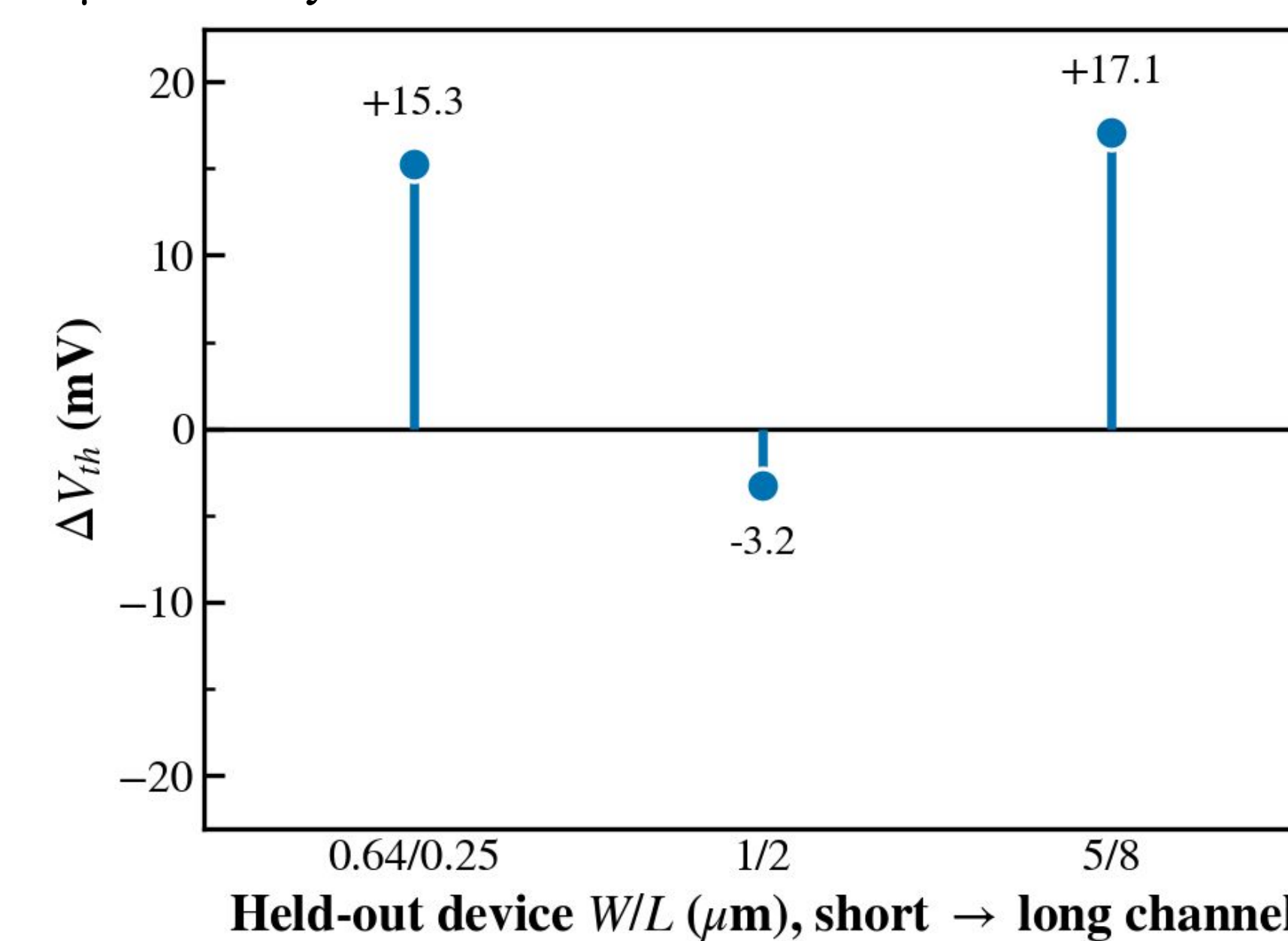
Current error on unseen devices

- Two devices stay near 5–6%, while the 5/8 μm device is harder, at about 25%.
- Few similar sizes were measured near 5/8 μm , which limits accuracy there.

W (μm)	L (μm)	NRMSE	RRMS	Median rel. error (%)
1	2	0.0129	0.0762	5.3
0.64	0.25	0.0145	0.0809	5.6
5	8	0.0973	0.5852	24.5

Threshold-voltage error on unseen devices

- $\Delta V_{th} = V_{th}^{\text{model}} - V_{th}^{\text{meas}}$ is how far the model's threshold voltage is from the lab measurement.
- Only the 1/2 μm device is within 4 mV; 0.64/0.25 and 5/8 μm miss by 15–17 mV



Limitations

- Only 28 device sizes were measured, with large gaps between some.
- Real measurements contain noise, especially at very small currents.
- Room temperature only; 77 K not yet tested

Conclusion

- The network predicts current for transistors it never saw.
- Simulated devices: within 6% current error and 6 mV for threshold voltage error.
- On real lab data, two of three test devices fall within about 6%.
- No foundry model parameters are needed.
- More measured device sizes should improve accuracy further.

Future Work

- Train and test on our 77 K measurements.
- Measure more device sizes to fill coverage gaps
- Export the model for use in circuit simulators (SPICE)

References

- SkyWater SKY130 open-source PDK, github.com/google/skywater-pdk
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- J. Wang *et al.*, "Artificial neural network-based compact modeling methodology for advanced transistors," *IEEE Trans. Electron Devices* 68, 1318 (2021).
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