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Nano-mechanical switching at 1 ns and 1 V using an in-plane dynamic switching technique

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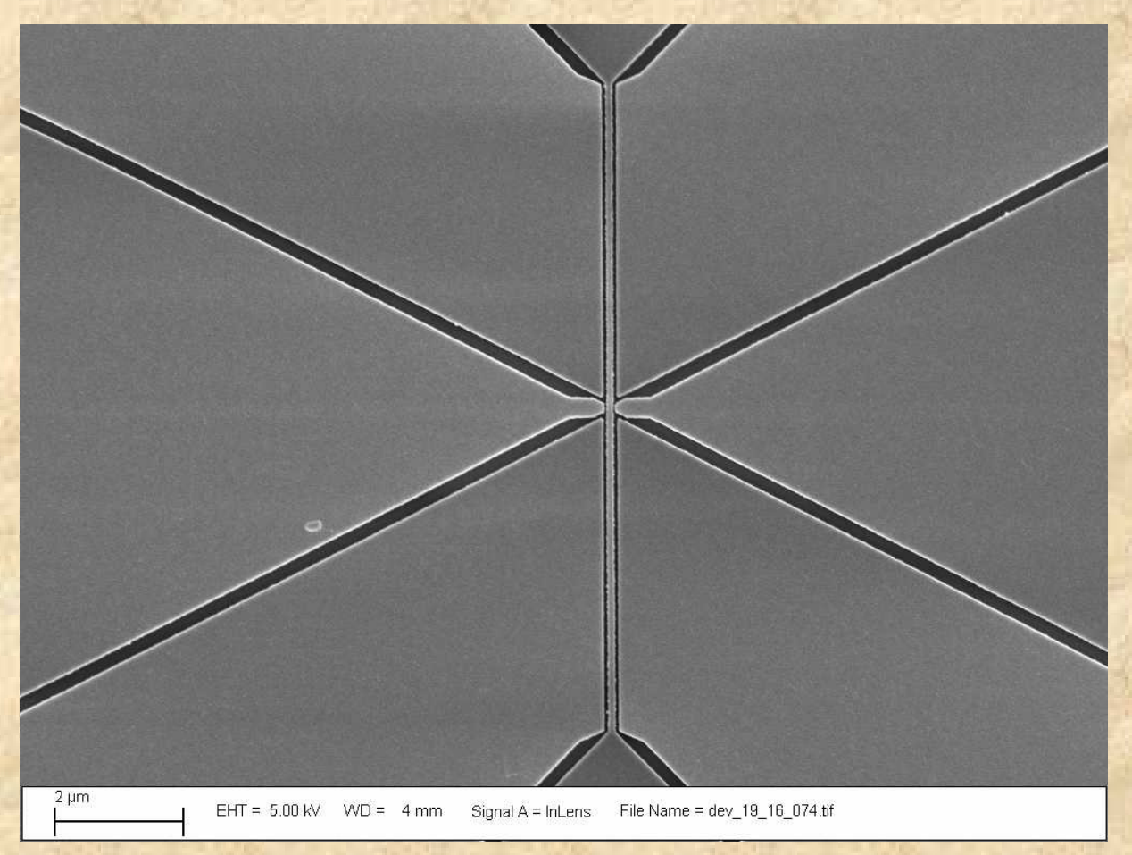
INTRODUCTION

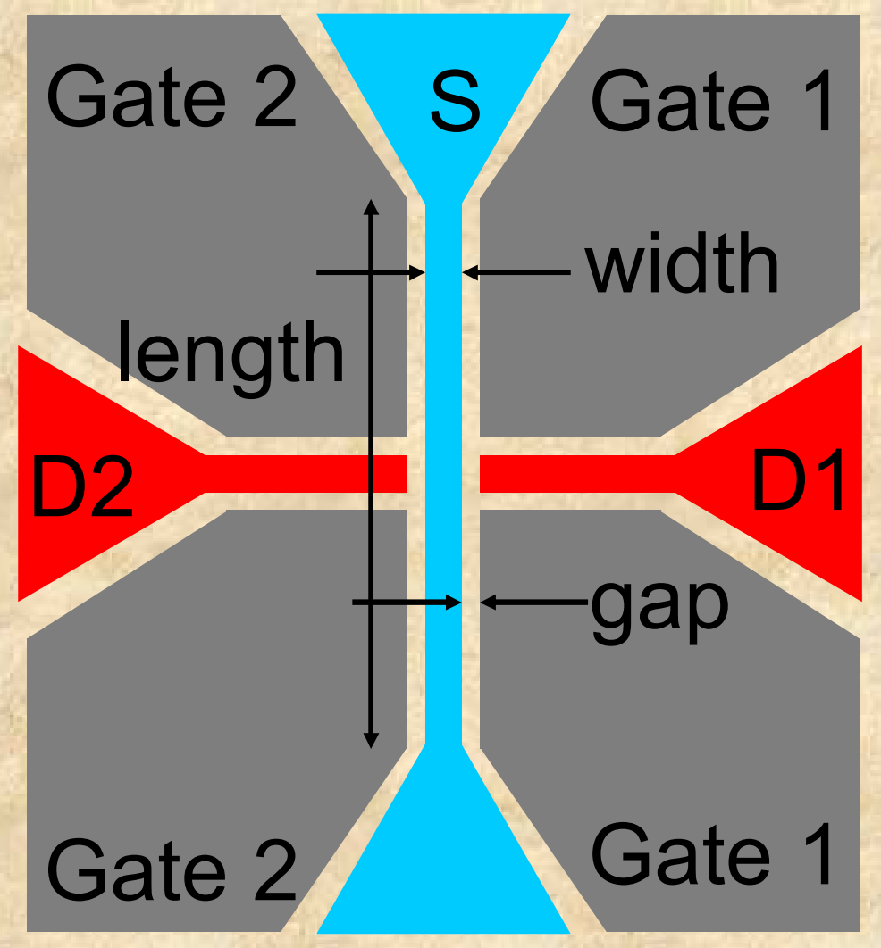
Micro- and Nano-electro-mechanical systems (MEMS / NEMS), specifically, ohmic metal contacting switches, could impact a wide variety of application fields such as medical, automotive, cellular phones, computing and RADAR.

Specifically, NEMS switches provide improvements in power consumption and radiation hardness over FET switches.

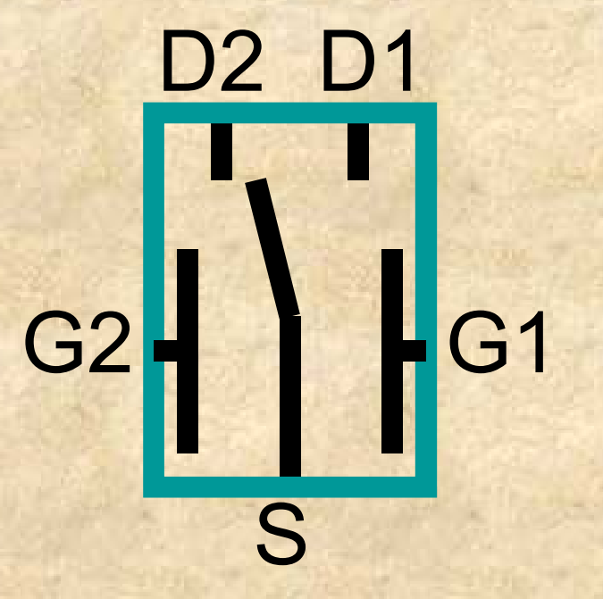
Goal: **To create NEMS switches with 1 V actuation and 1 ns switching times**

Switch Model

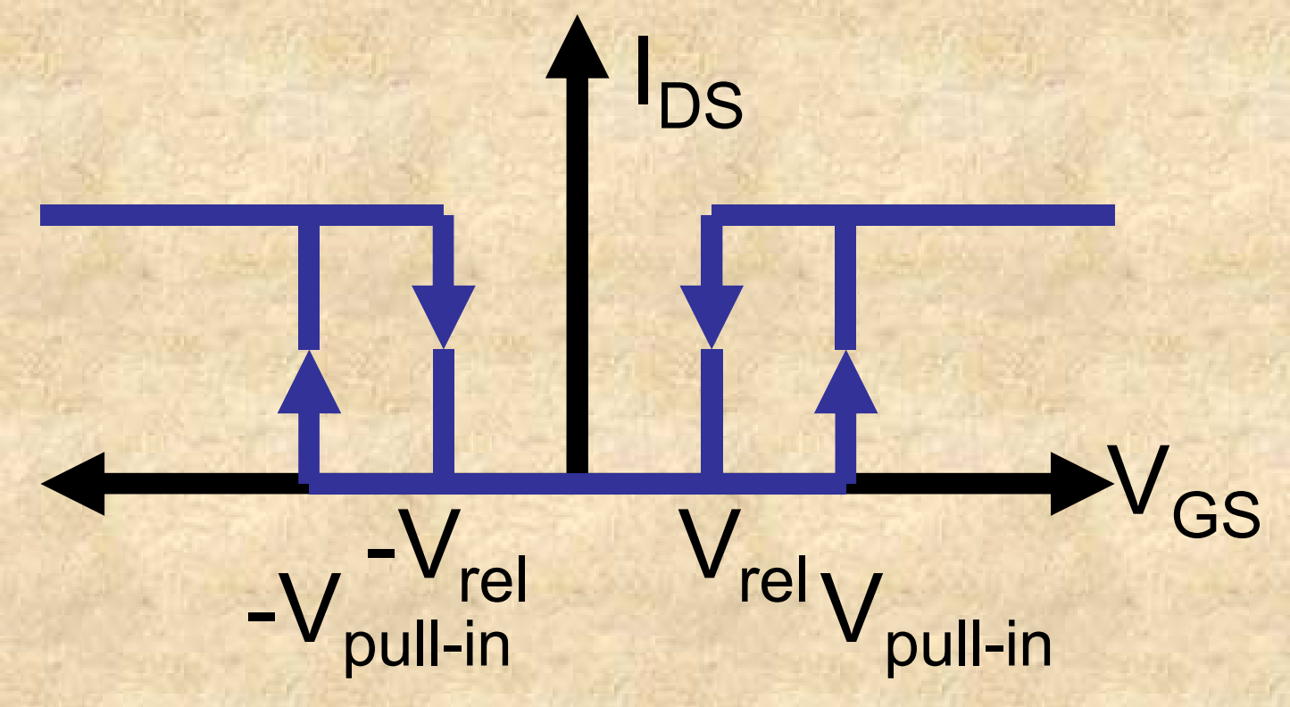




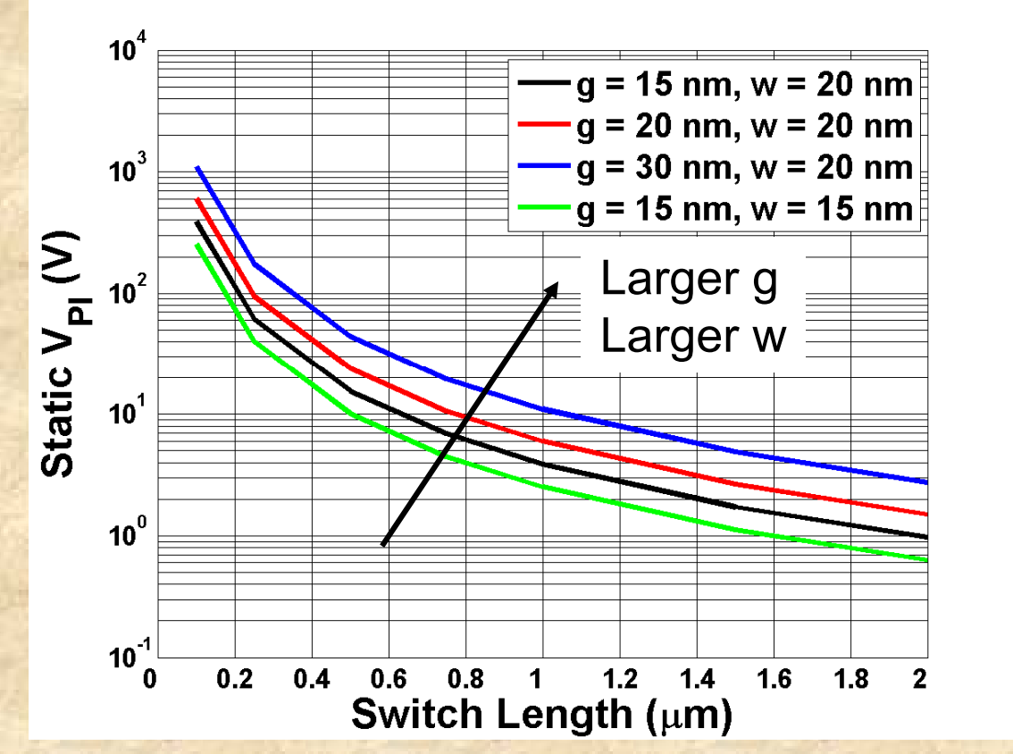
Equivalent Circuit

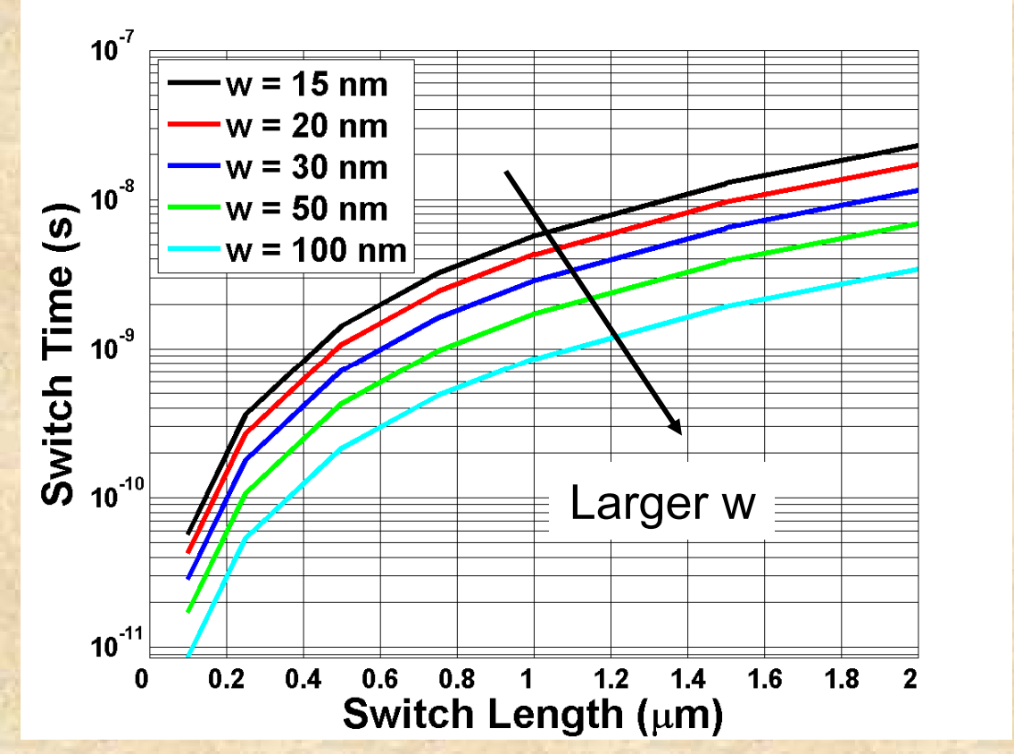


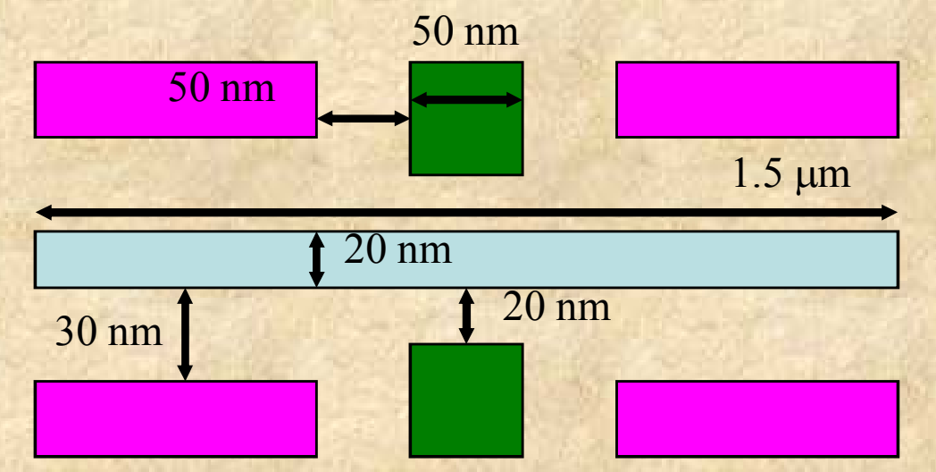
Transfer Function

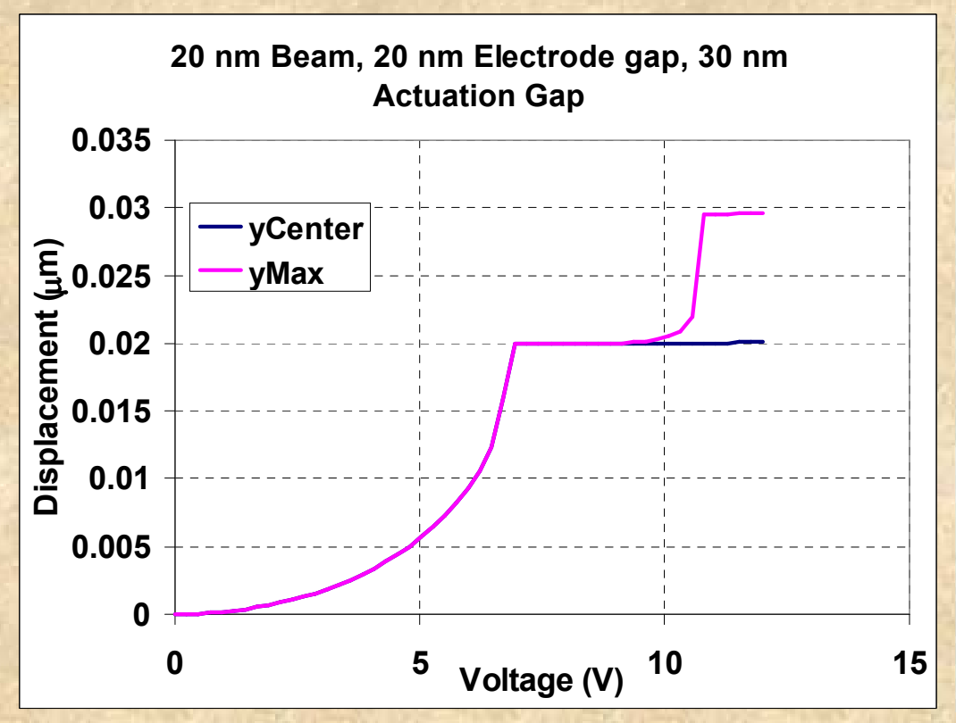


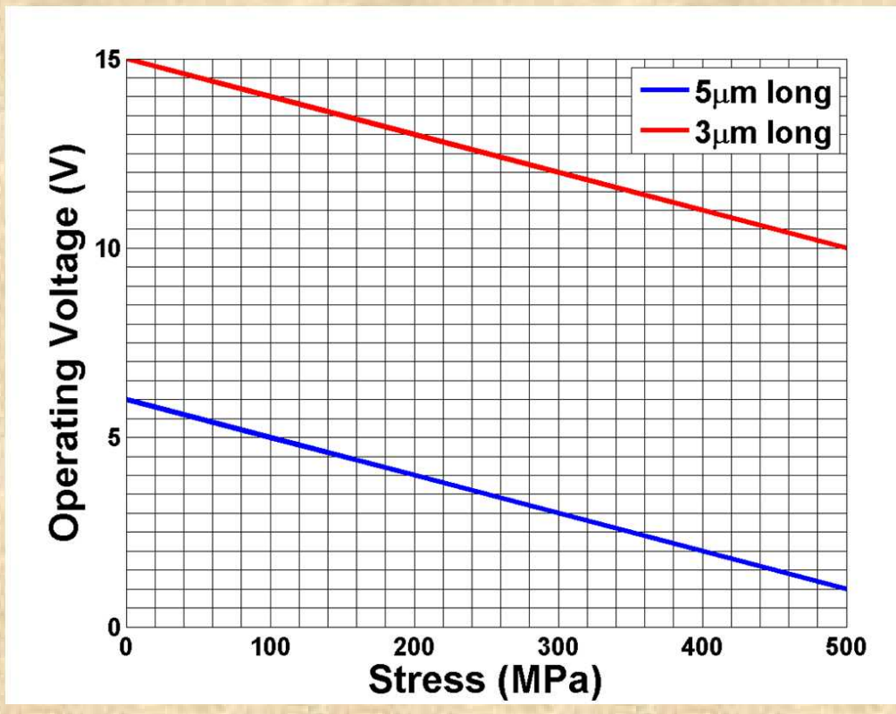
Finite Element Analysis





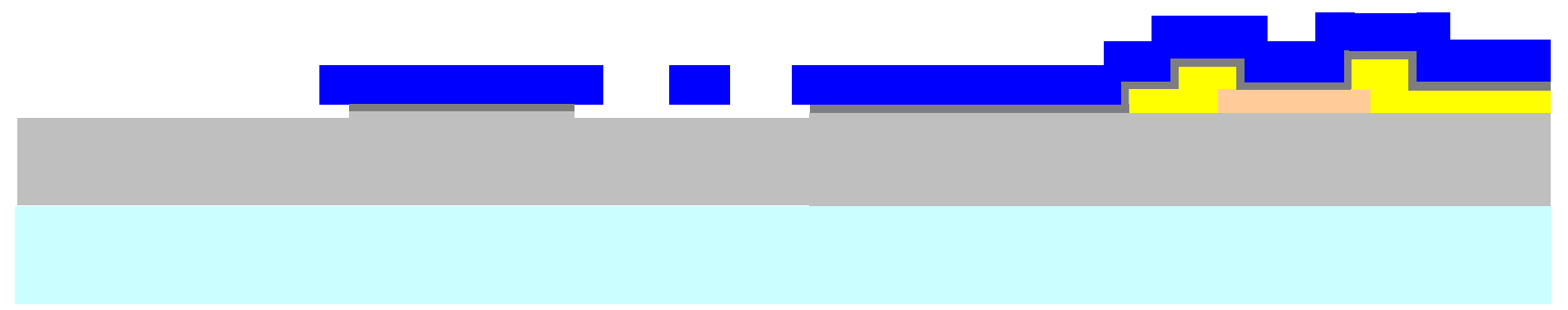






EXPERIMENTAL APPROACH

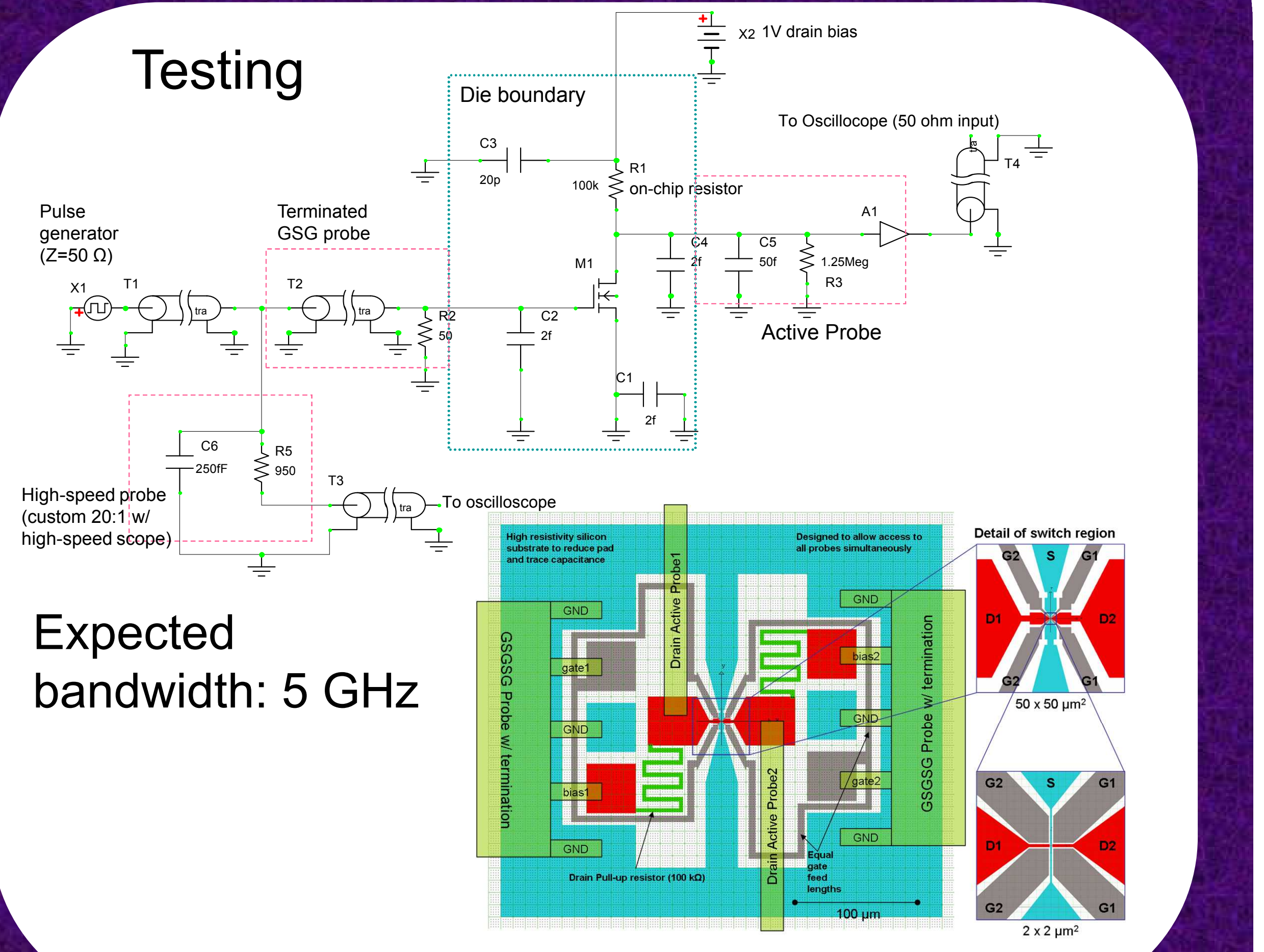
Fabrication



1. Start with high resistivity silicon substrate
2. 0.5 µm thermal silicon dioxide growth
3. TaN lift-off for 100kW resistor formation
4. Silicon nitride passivation
5. Etch via and opening for switch definition
6. Ru sputter deposition
7. PECVD SiO_2 hard mask deposition
8. Etch hard mask with optical contact lithography pattern
9. Etch hard mask with ebeam lithography pattern
10. Anisotropic etch using ICP HDP to define Ru switch
11. Wet release of the switch and remove oxide hard mask

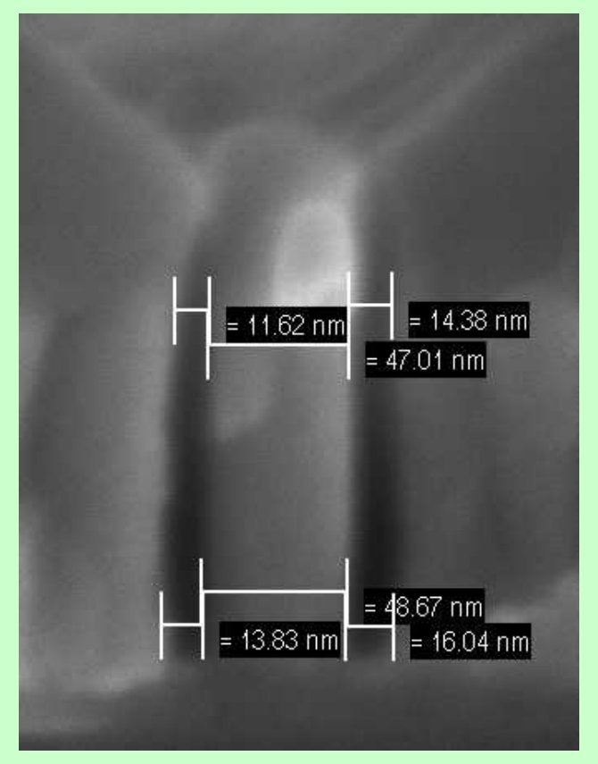
🟦 Si
⬜ SiO_2
🟧 TaN
🟨 SiN_x
🟦 Ru

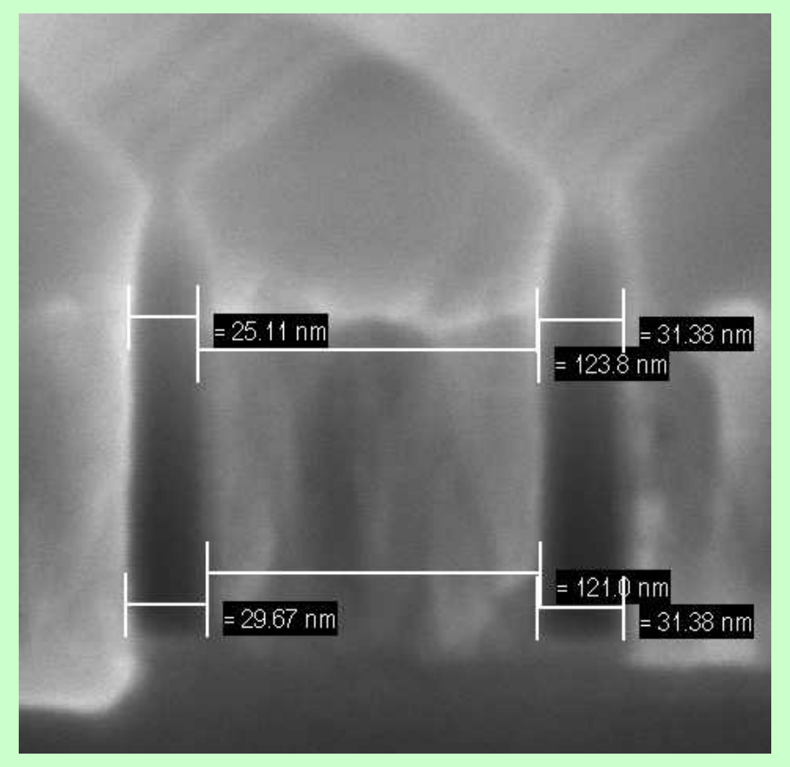
Testing



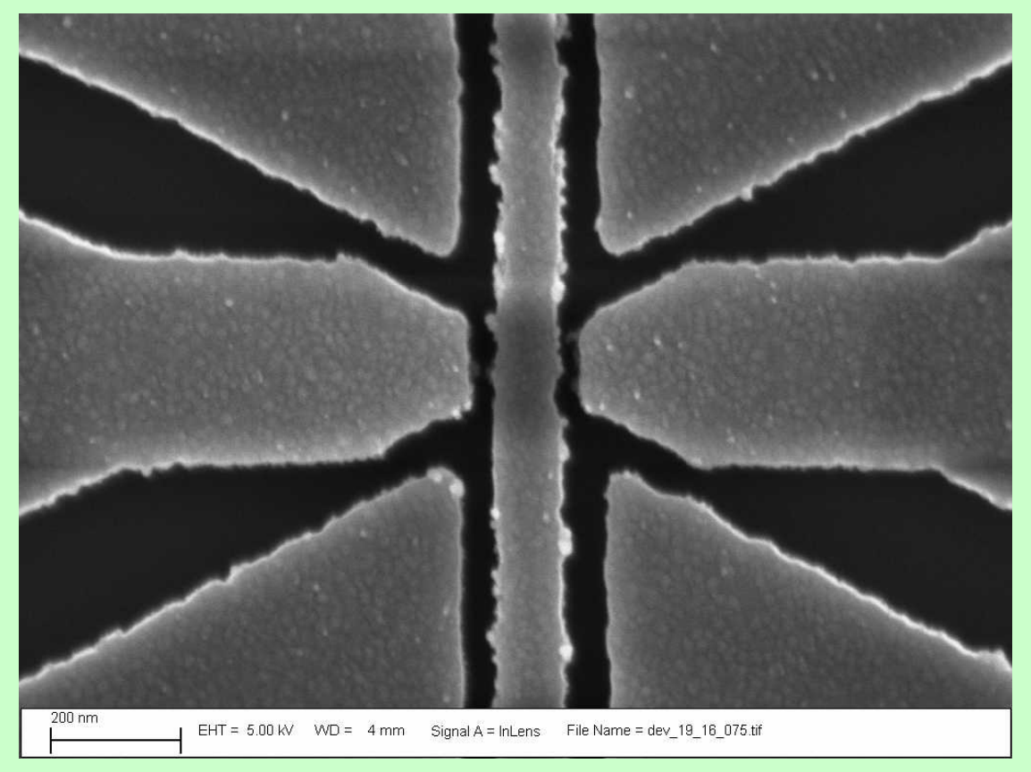
Expected bandwidth: 5 GHz

RESULTS

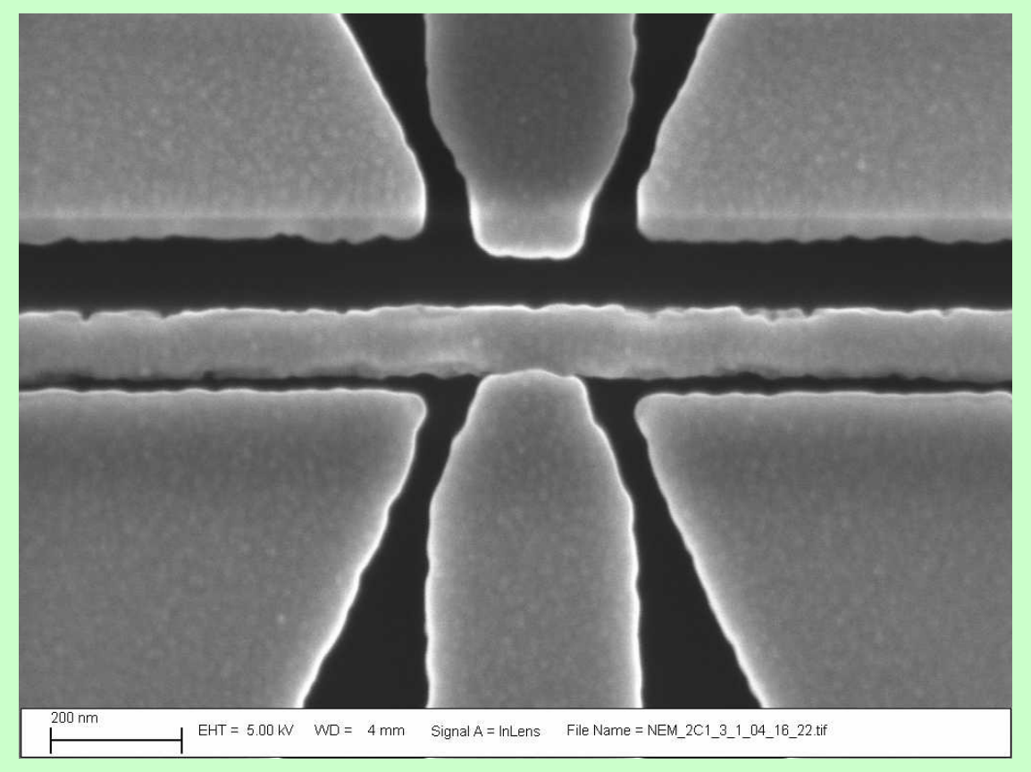




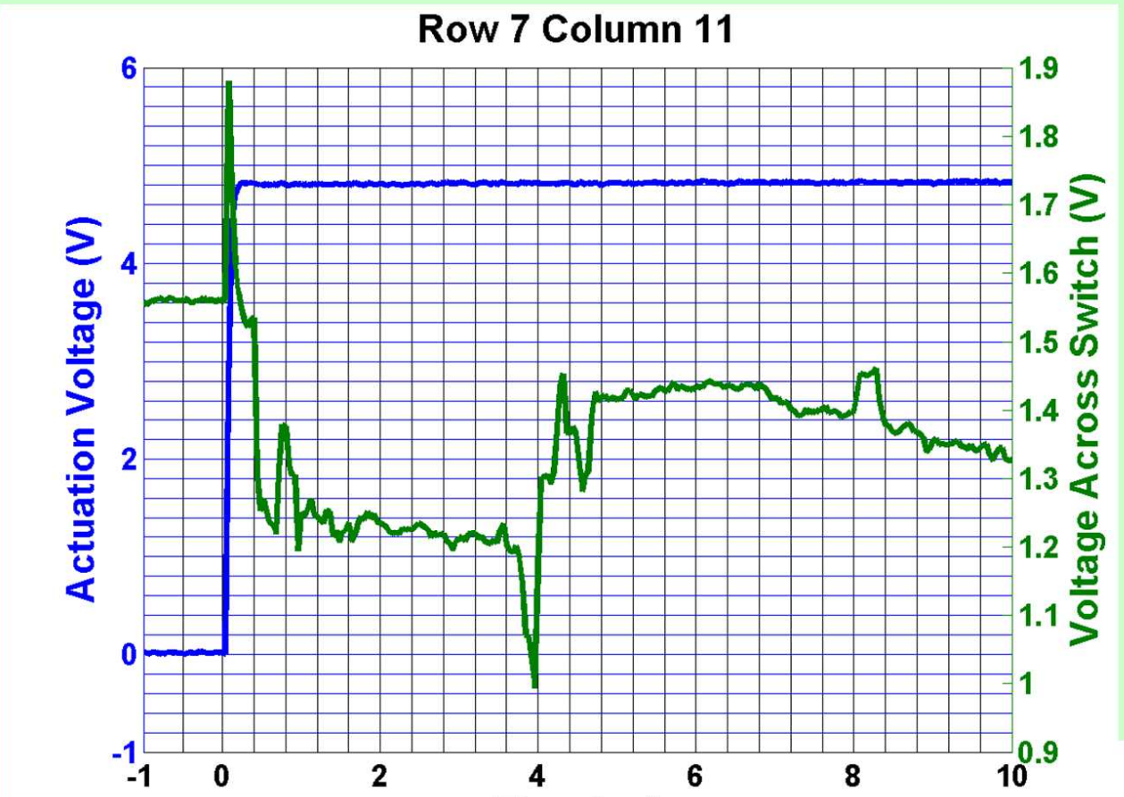
- Pattern transferred between oxide hard mask and Ru mechanical layer
- Gaps as small as 12 nm were realized

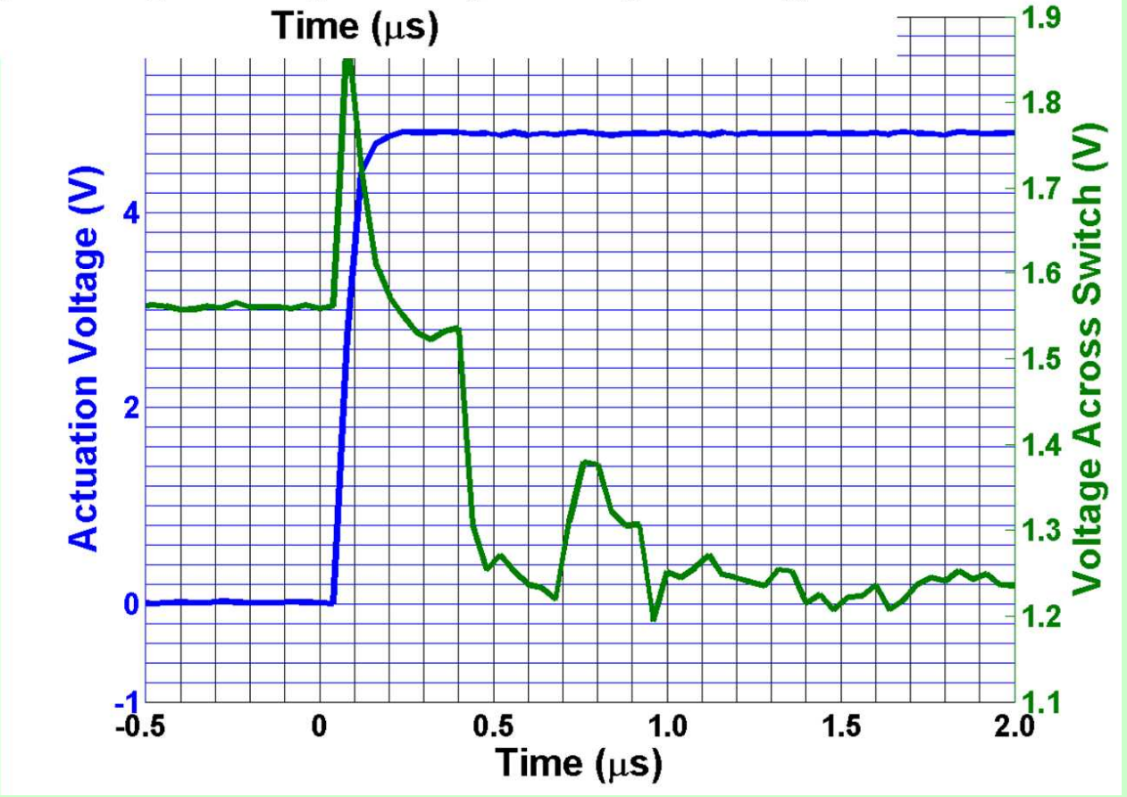


- Extended drain contacts
- Large line edge roughness
- Film uniform over small length scales

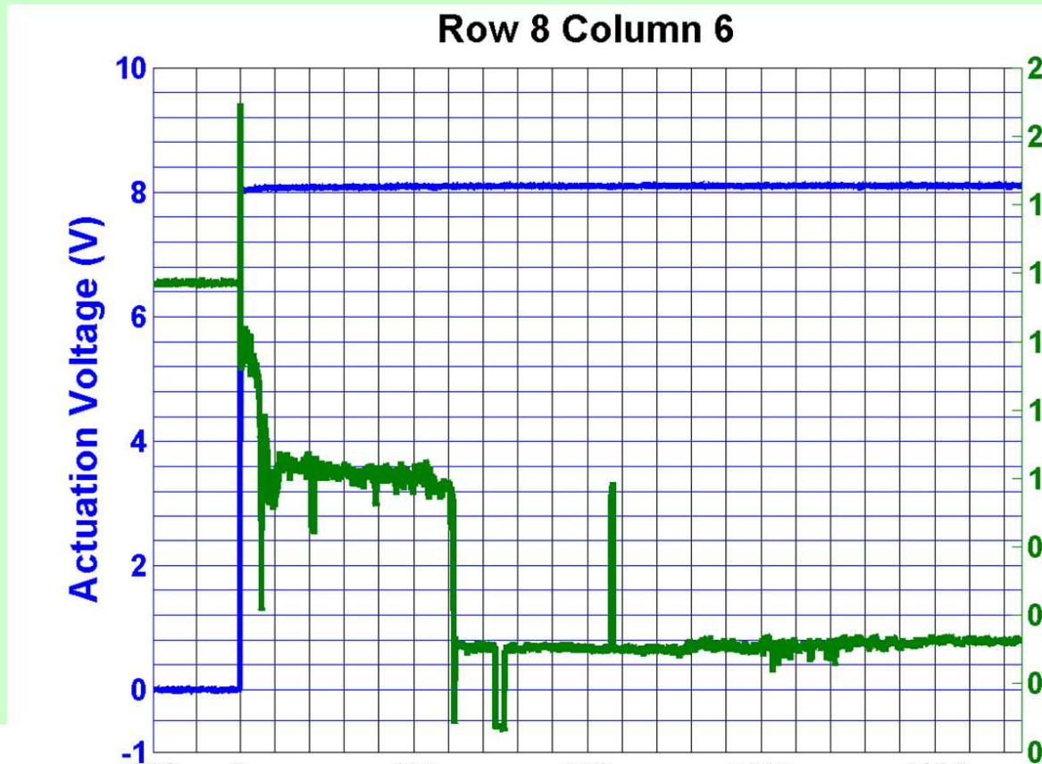


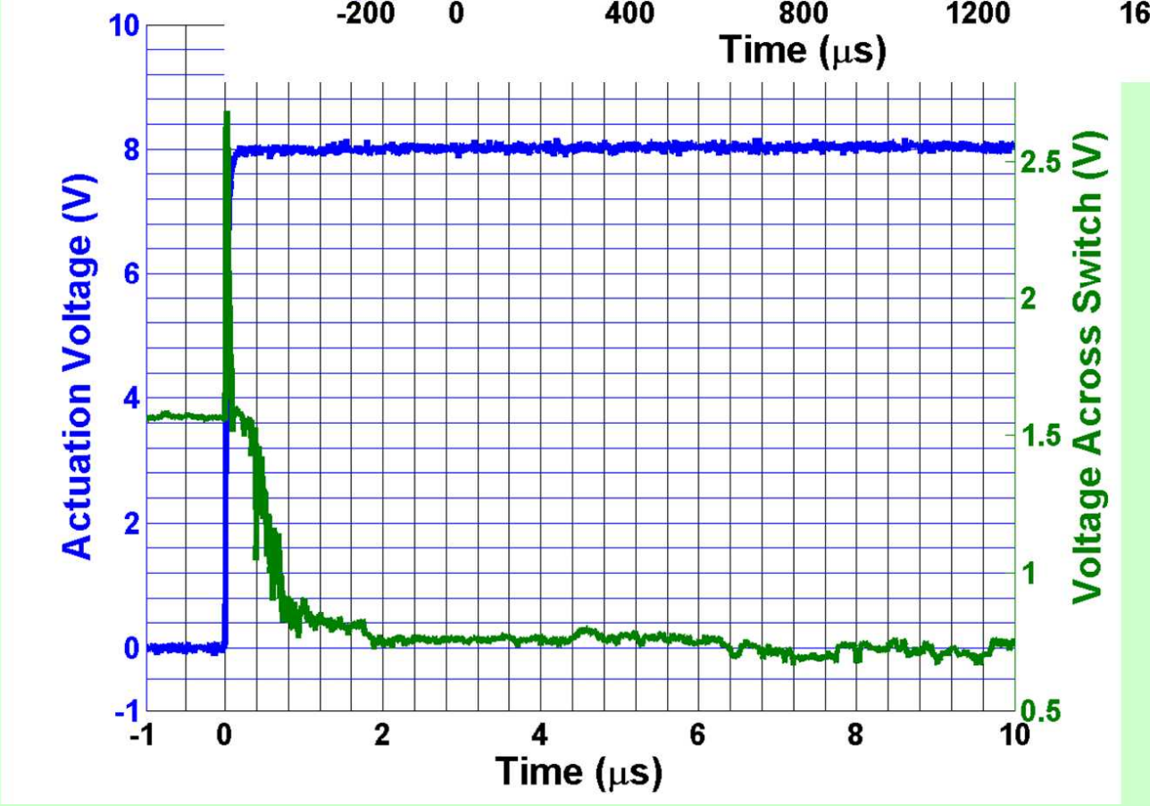
- Stuck shut device
- Gap still exists between drain and gate electrode



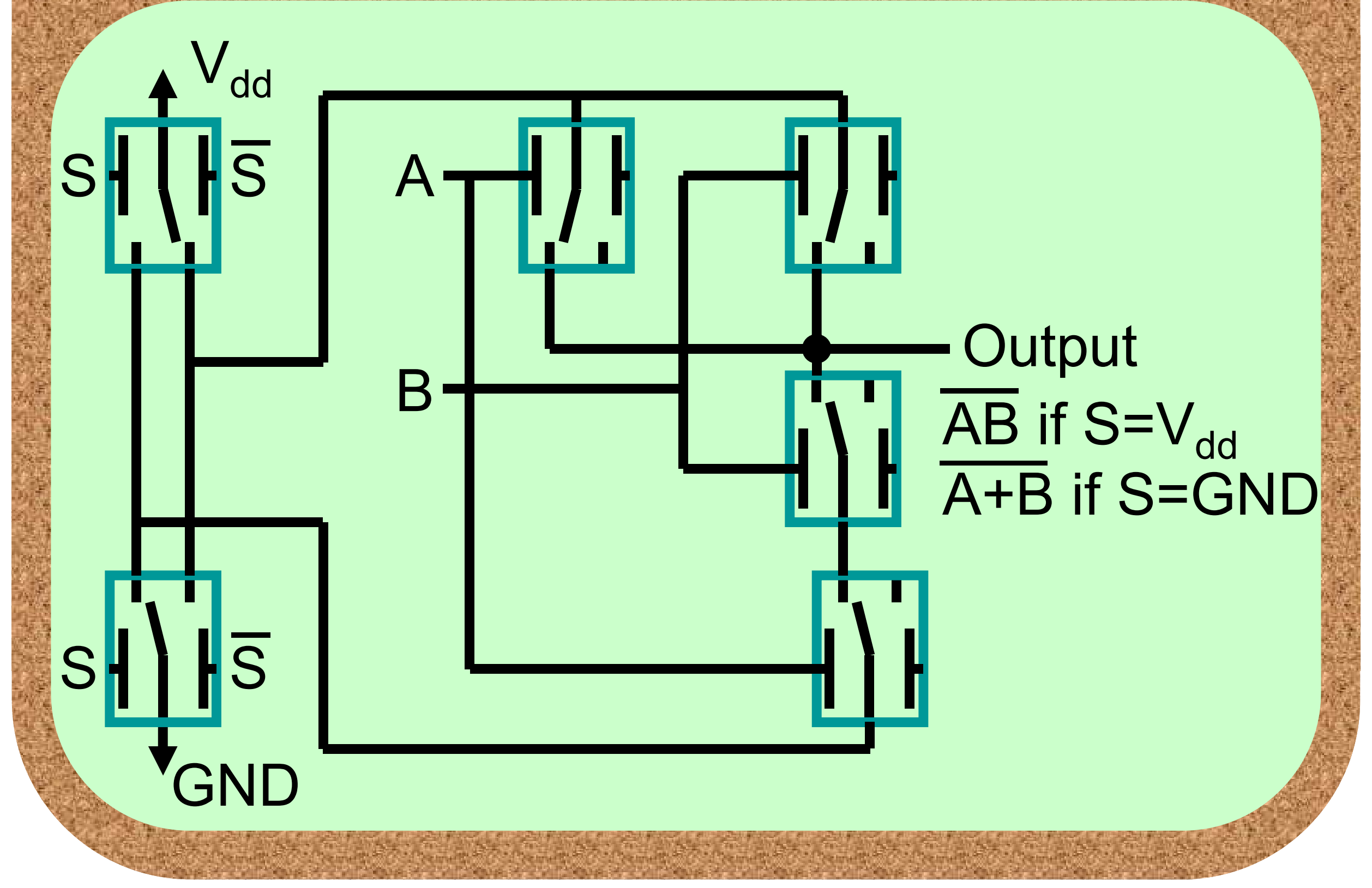


- 250 ns switching time
- 5 V actuation
- Asperity contact possibly causing changes in resistance over time
- Fast switching times are not reproducible
- Surface cleaning may improve performance





LOGIC ELEMENTS



CONCLUSIONS

- Measured switching times of ~250 ns at 5 V
- Switch lifetimes were measured in excess of 1M cycles
- Several switch designs were successfully measured with actuation voltages of 4 to 17 V
- Switching times were not consistent with predicted resonant frequency of the structures and were not reproducible
- The switching speed issues suggest surface contamination problems

FUTURE WORK

- **Utilize cleaning methods to passivate contact surfaces to improve performance**
- **Incorporate optimized deposition conditions to produce near zero residual stress in the Ruthenium mechanical layer after all thermal processing cycles**
- **Use cold developer to improve the edge roughness of the electron beam resist**
- **Realize logic NAND and NOR elements using 4 switch configurations**
- **Realize ring oscillator structures to measure the switching speeds of multiple connected switches**

ACKNOWLEDGEMENTS

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