# Investigating 2D semiconductor contacts for Cooper-pair light-emitting diode applications


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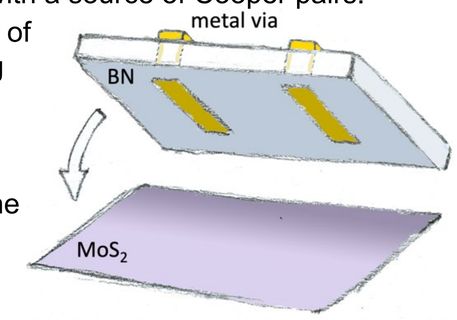
## Abstract


Future quantum technologies will require high-efficiency, on-demand sources of entangled photons. A possible route to building such light sources employs two-dimensional (2D) semiconductors interfaced with a source of Cooper pairs.

To investigate the possibility of such devices, we are testing methods to make high transparency transferred metal contacts to 2D semiconductors, following the pioneering work of Liu et al. [1]

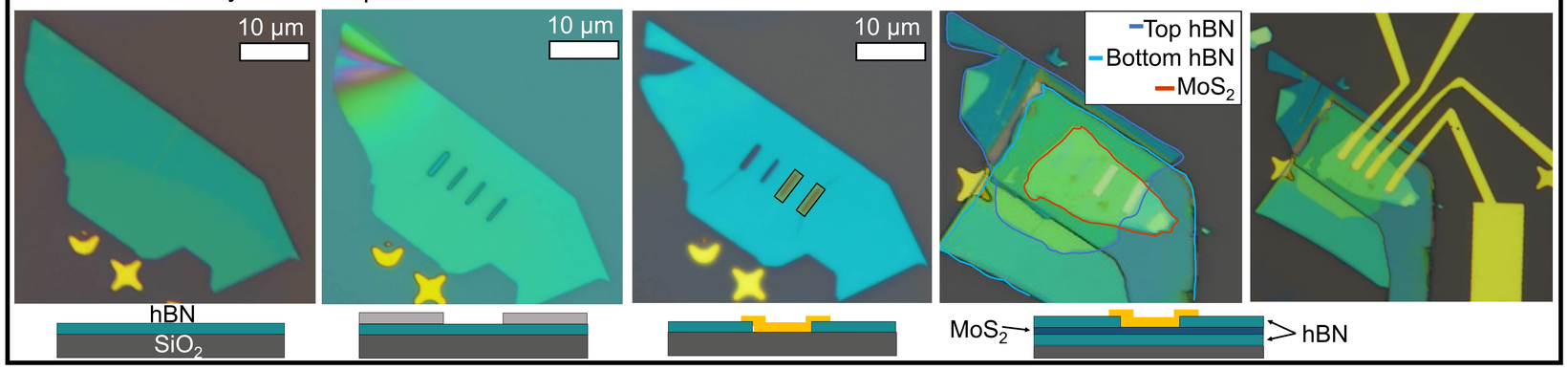




## Background

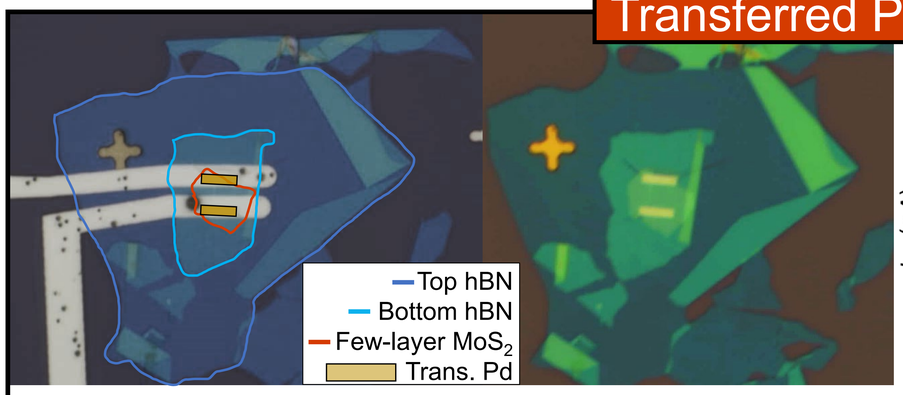
- The “second quantum revolution,” a new era of technology with more secure communication networks, better quantum sensors, and universal quantum computers, relies on controllable quantum entanglement [2]
- Theoretical proposals: Entangled pairs of electrons in a superconductor can be converted into entangled pairs of photons by interfacing a superconductor layer with a semiconductor layer [3], [4]
- This approach needs high-quality n-type and p-type contacts to a 2D semiconductor that work at cryogenic temperatures; transferred metal VIA contacts have been shown to satisfy these requirements [1]

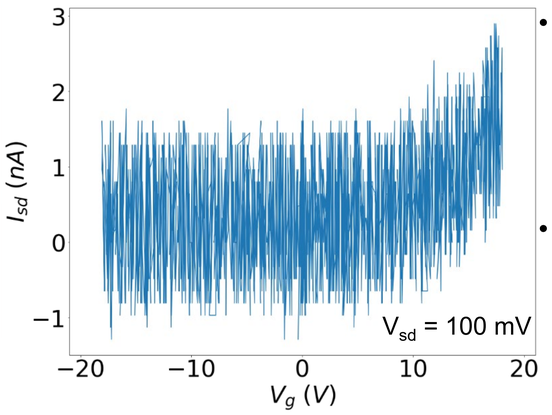
## VIA Fabrication

1. Exfoliate hBN, identify ~30 nm flake by color
2. EBL: Print etch pattern in PMMA
3. Etch hBN/evaporate metal†
4. Encapsulate $MoS_2$ with VIA-contact hBN
5. Evaporate onto VIA contacts



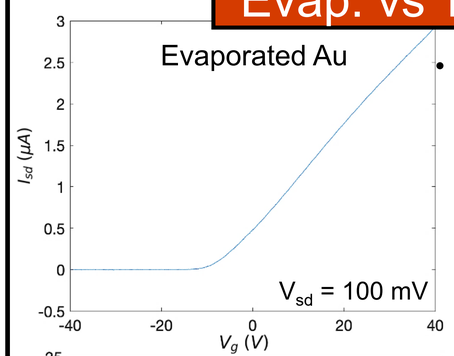

## Transferred Pd



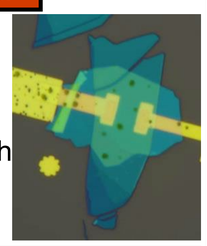



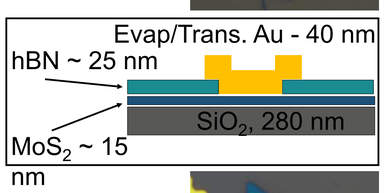

- Palladium (Pd) VIA contacts transferred to multilayer $MoS_2$
- Expected p-type contact
- Bad n-type contact, possibly due to open-air fabrication
- Next steps: Try fabricating in glovebox

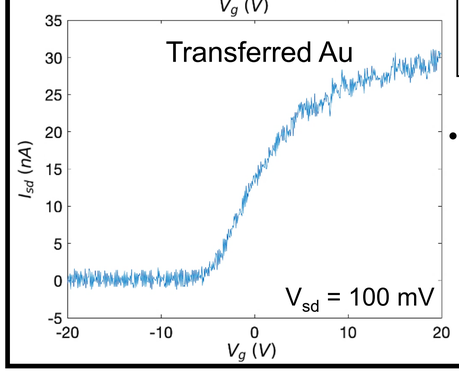
## Evap. vs Trans. Au



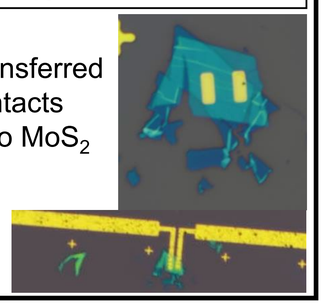

- Evaporated contacts directly onto $MoS_2$ through holes in hBN



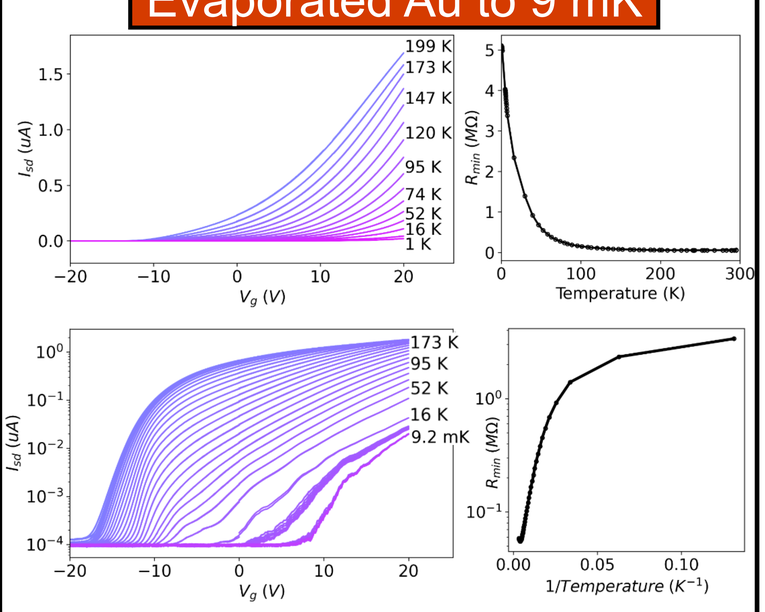



- Transferred contacts onto $MoS_2$

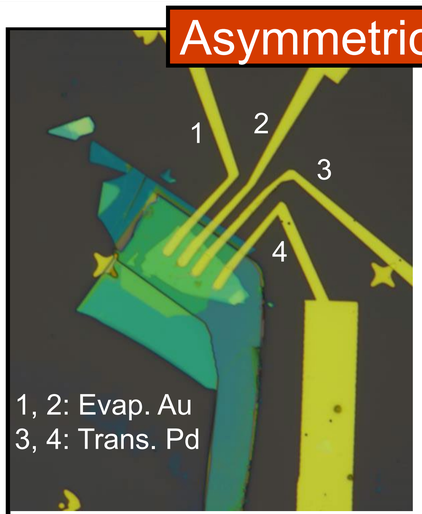


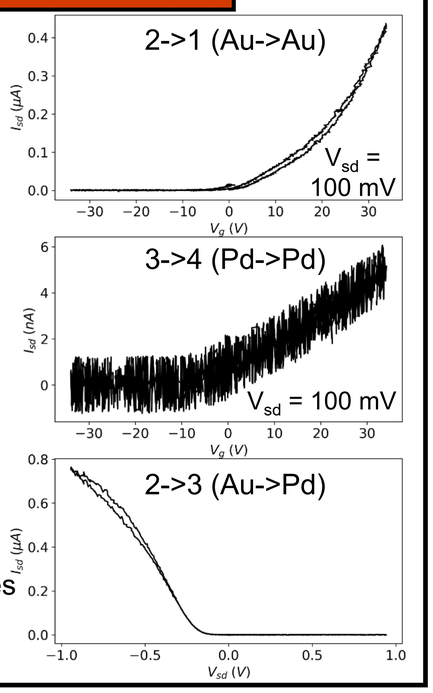
## Evaporated Au to 9 mK




- $V_{thres}$ and $R_{min}$ increase at lower T, as in [1], due to decreasing carrier concentration [5]

## Asymmetric Contacts




- Evap. Au-Au are good n-type
- Trans. Pd-Pd are bad n-type - Same as other transferred Pd and evaporated Au devices
- Au-Pd shows rectifying behavor with $V_{thres}$ = 0.2 V


[1] Liu, Y., Guo, J., Zhu, E. *et al. Nature* **557,** 696–700 (2018). doi.org/10.1038/s41586-018-0129-8

[2] “Quantum Manifesto: A New Era of Technology,” (2016). [Online]. https://qt.eu/engage/resources/

[3] I. Suemune *et al.*, *Japanese J. Appl. Physics,* **45**, 12, 9264–9271, (2006), doi: doi.org/10.1143/JJAP.45.9264

[4] A. Hayat, H. Y. Kee, K. S. Burch, and A. M. Steinberg, *Phys. Rev. B* **89**, 9, p. 094508, (2014), doi.org/10.1103/PhysRevB.89.094508.

[5] Liu, X., He, J., Liu, Q. *et al*. J. Appl. Phys. **118,** 124506 (2015), https://doi.org/10.1063/1.4931617


† The metal pads are made 0.5 μm larger than the etch holes to ensure they are transferred with the hBN. Etch parameters: $CHF_3$:O2 40:4 sccm with 60 W RF power and 60 mTorr gas pressure