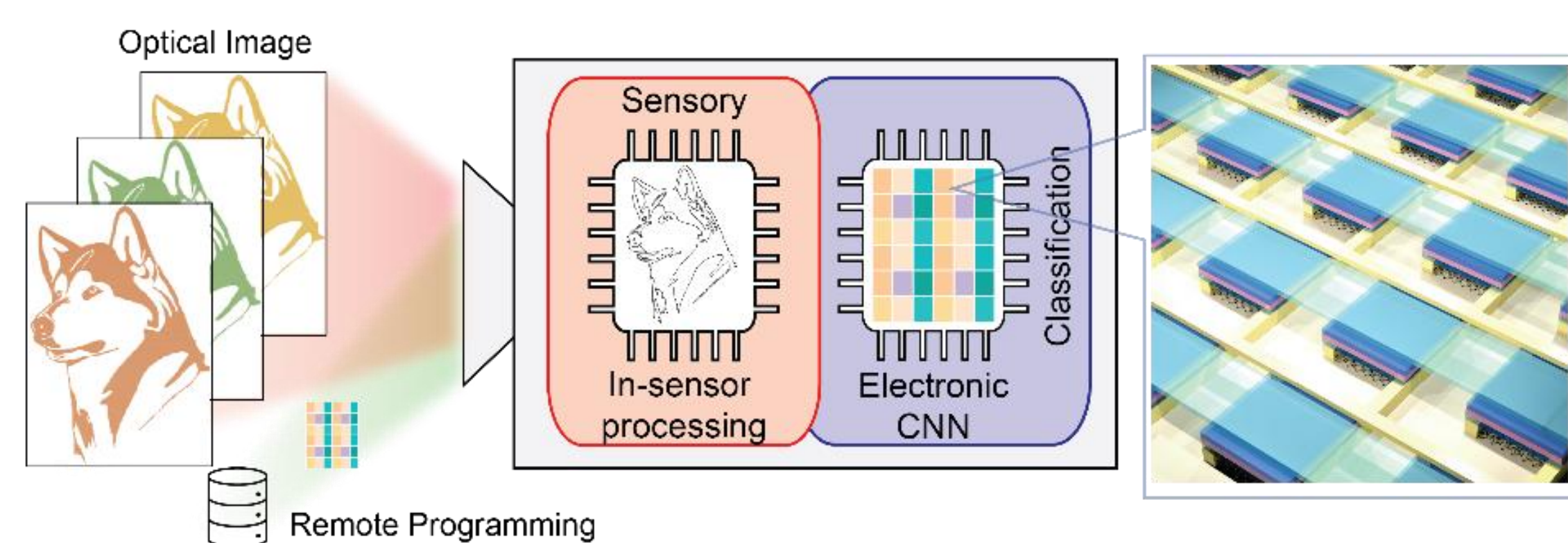


Programmable black phosphorus image sensor for broadband optoelectronic edge computing

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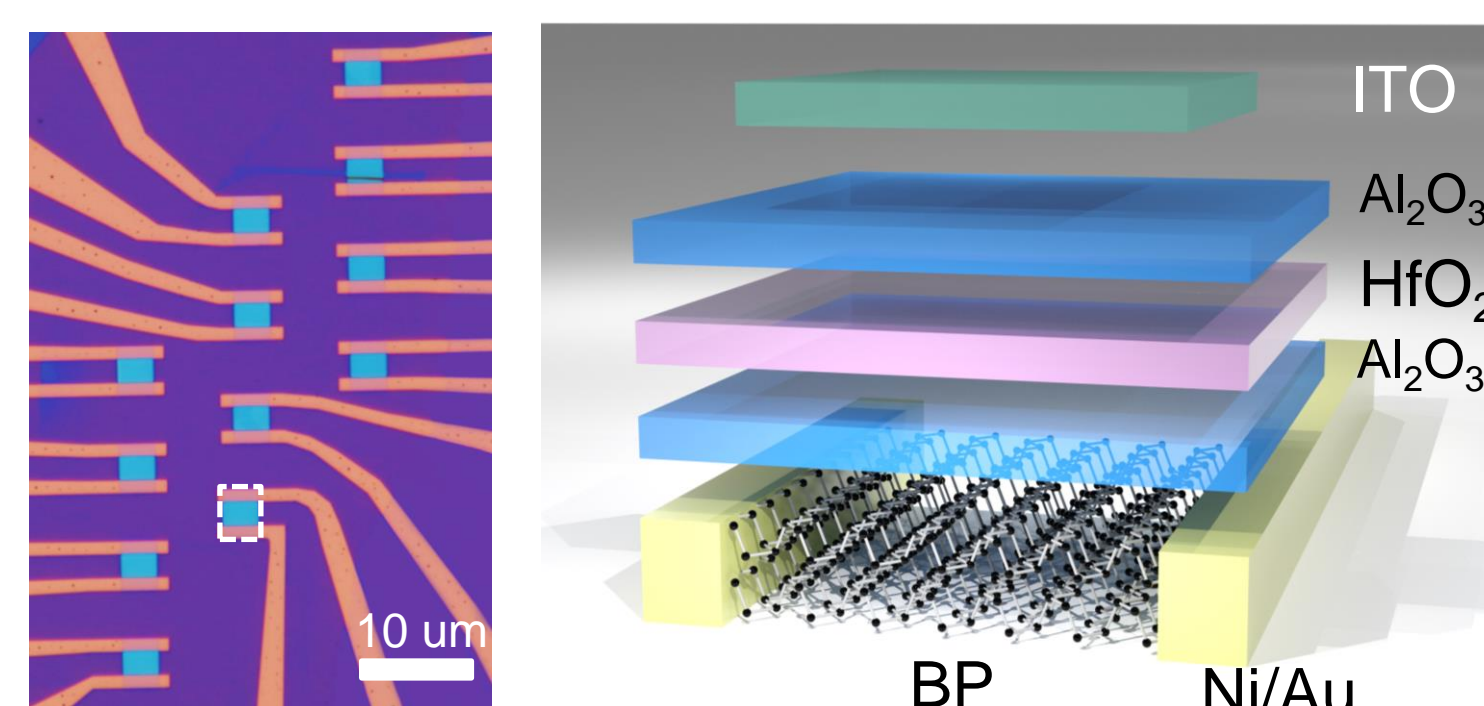
Introduction

- The conductivity of black phosphorus (bP) changes dramatically depending on the charge doping level, and so does the responsivity at wide wavelength ranges from visible to Mid-IR light [1].
- The doping level of the bP channel can be manipulated by concentration of local charges, which can be stored in non-volatile manner by engineering the stack of dielectric layers (AHA) [2].
- As bP-transistors are connected in an array, it can perform basic convolutional neural network tasks in a vision sensor, enabling edge computing [3].

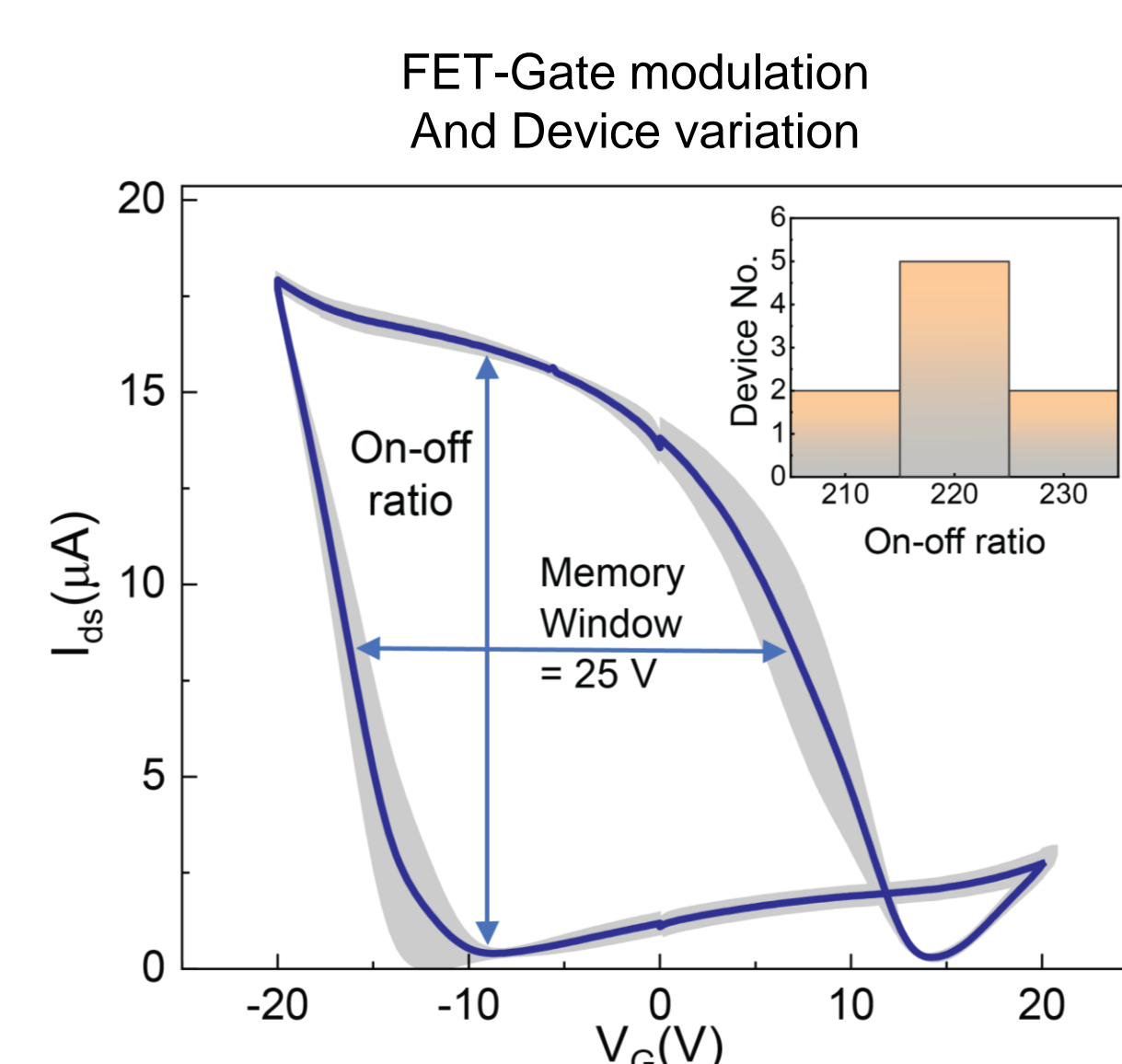
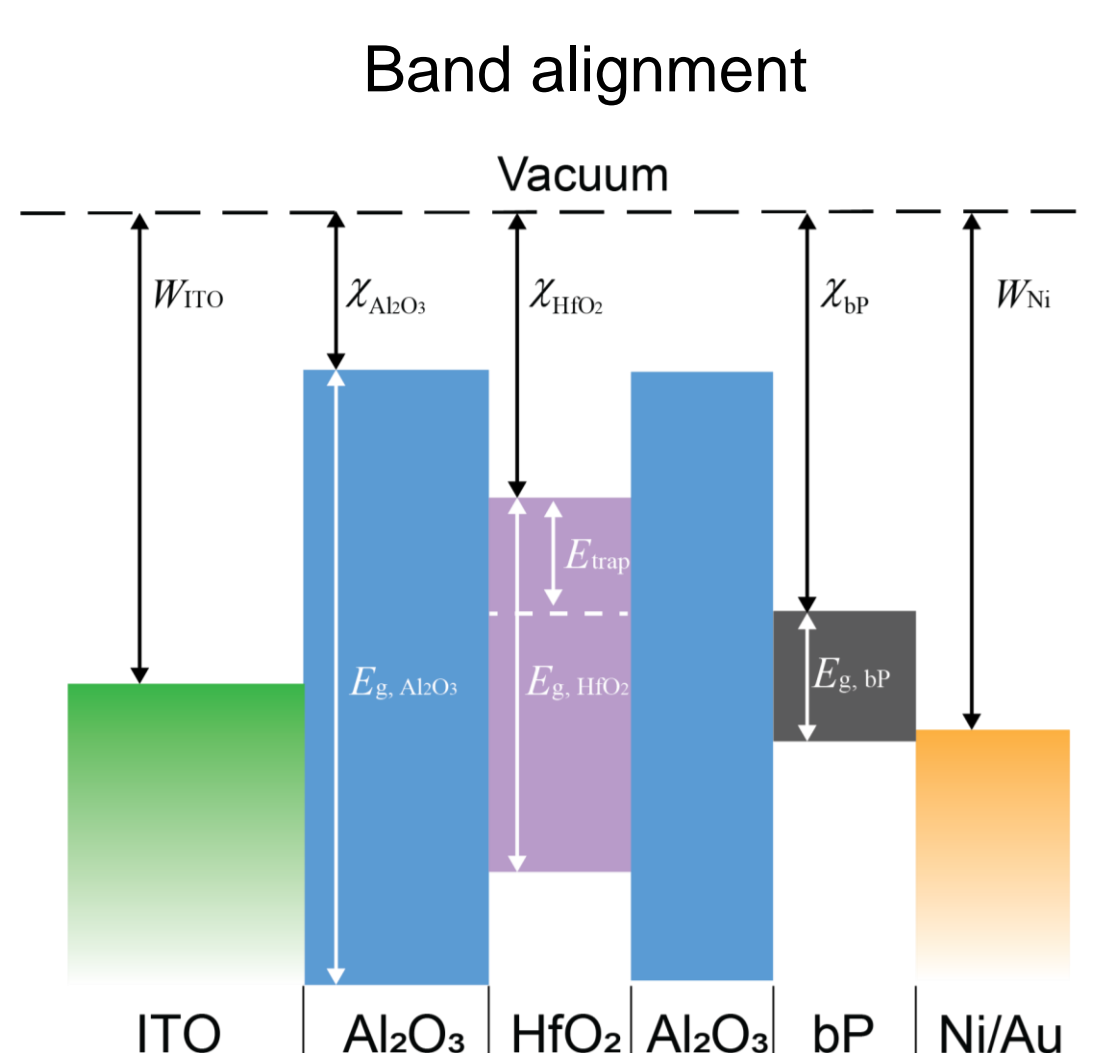


Black Phosphorus Phototransistor Design

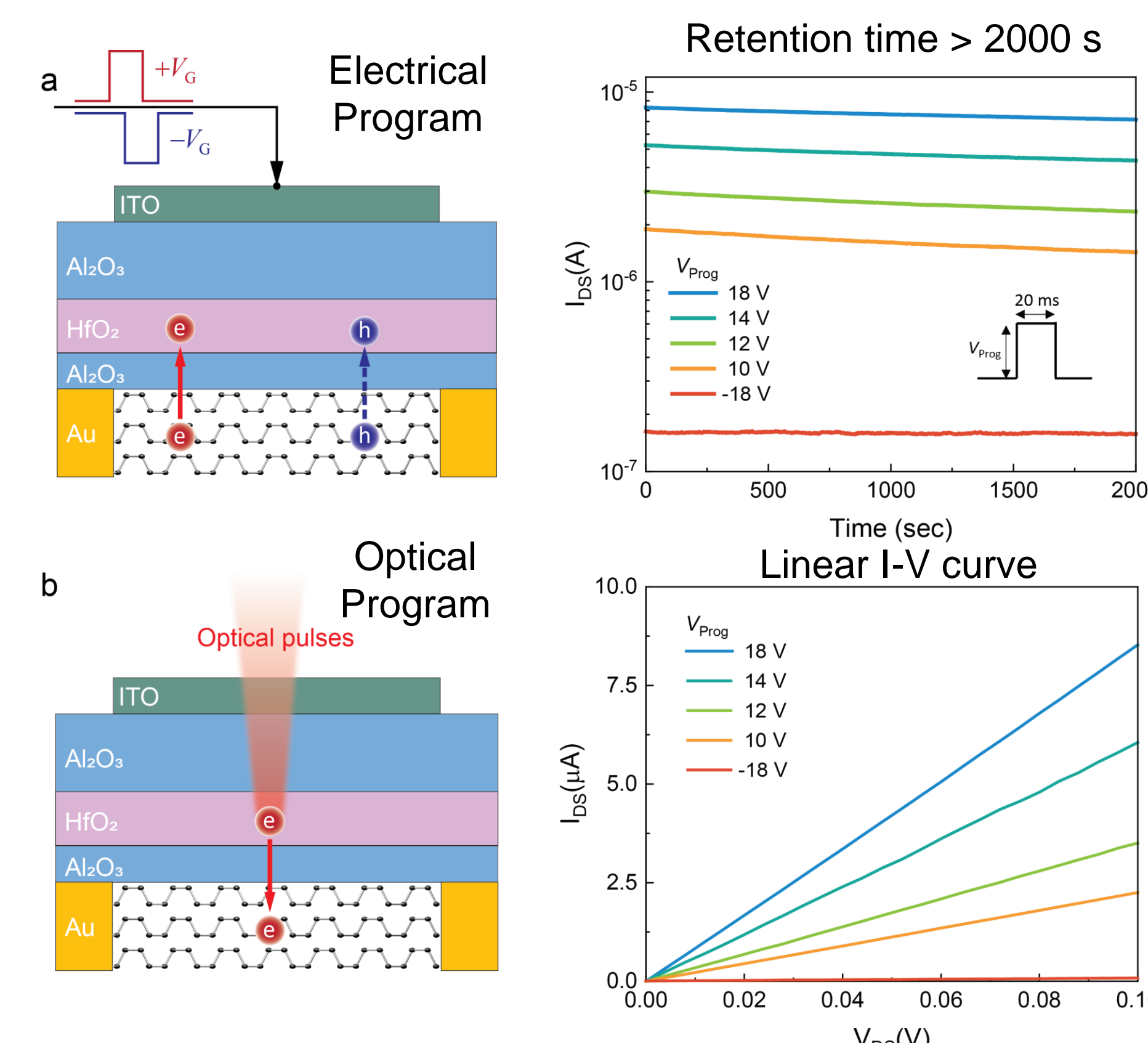
BP-Phototransistor structure and the Optical image



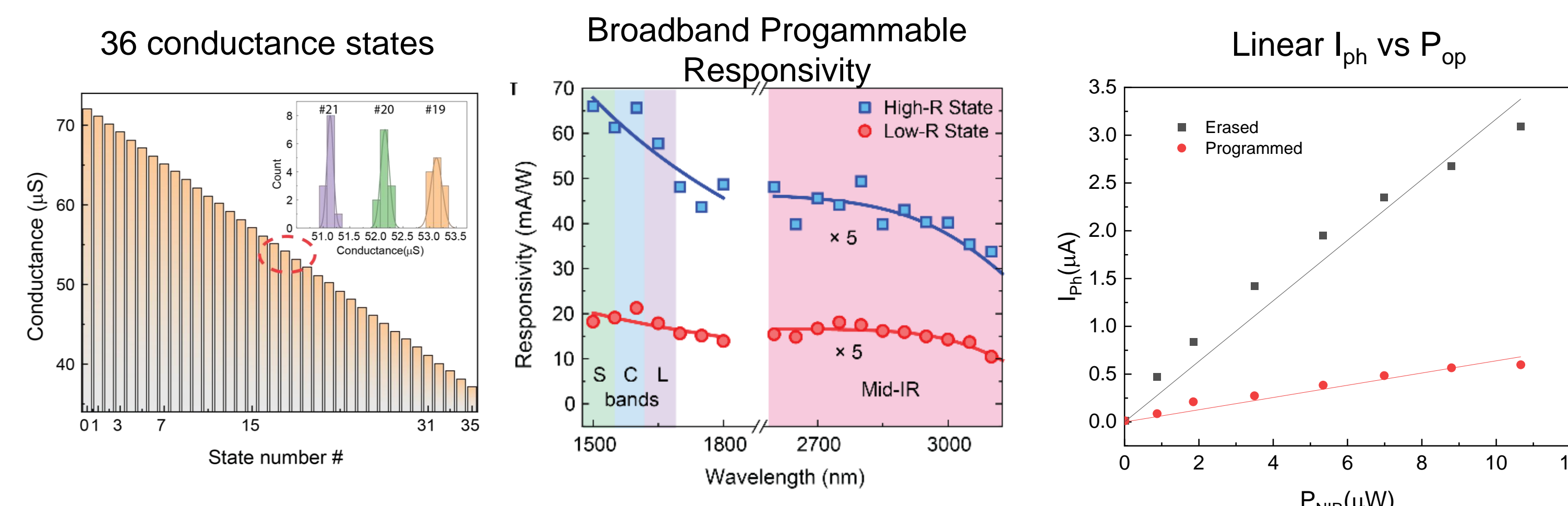
- $\text{Al}_2\text{O}_3/\text{HfO}_2/\text{Al}_2\text{O}_3$ (AHA) stack of dielectric layers traps charges in the HfO_2 [1]
- ITO for transparent top gate
- BP (11 nm) as a channel material with 200 on-off ratio
- ~8% inter-device variation



Electrical/Optical Programming and Readout

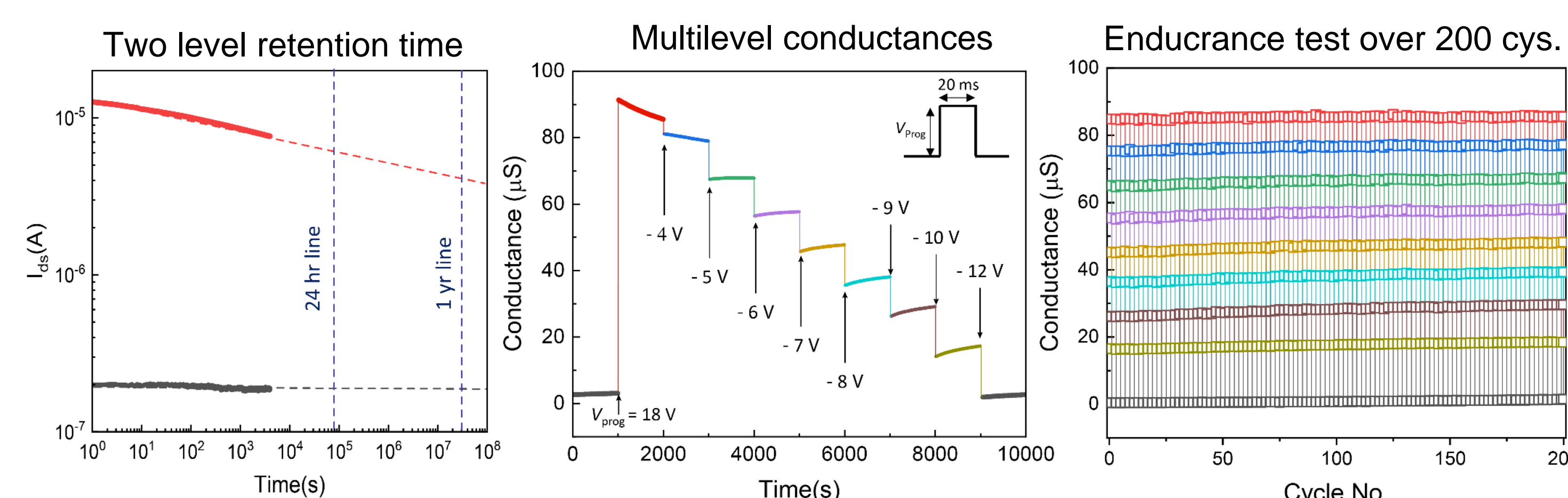


- 18 V top gate pulse makes the BP channel least conductive. (erased)
- Different top gate pulses (10 - 18 V) set the channel conductivity (programmed)
- Each state shows linear I-V characteristics.
- Optically programmed states: Fine control of the states with 36 states.
- Each state separated well in conductivity, and stayed stable > 1000 s.
- Programmable responsivity over broad IR spectra
- Linear dependence of optical power and photocurrents.

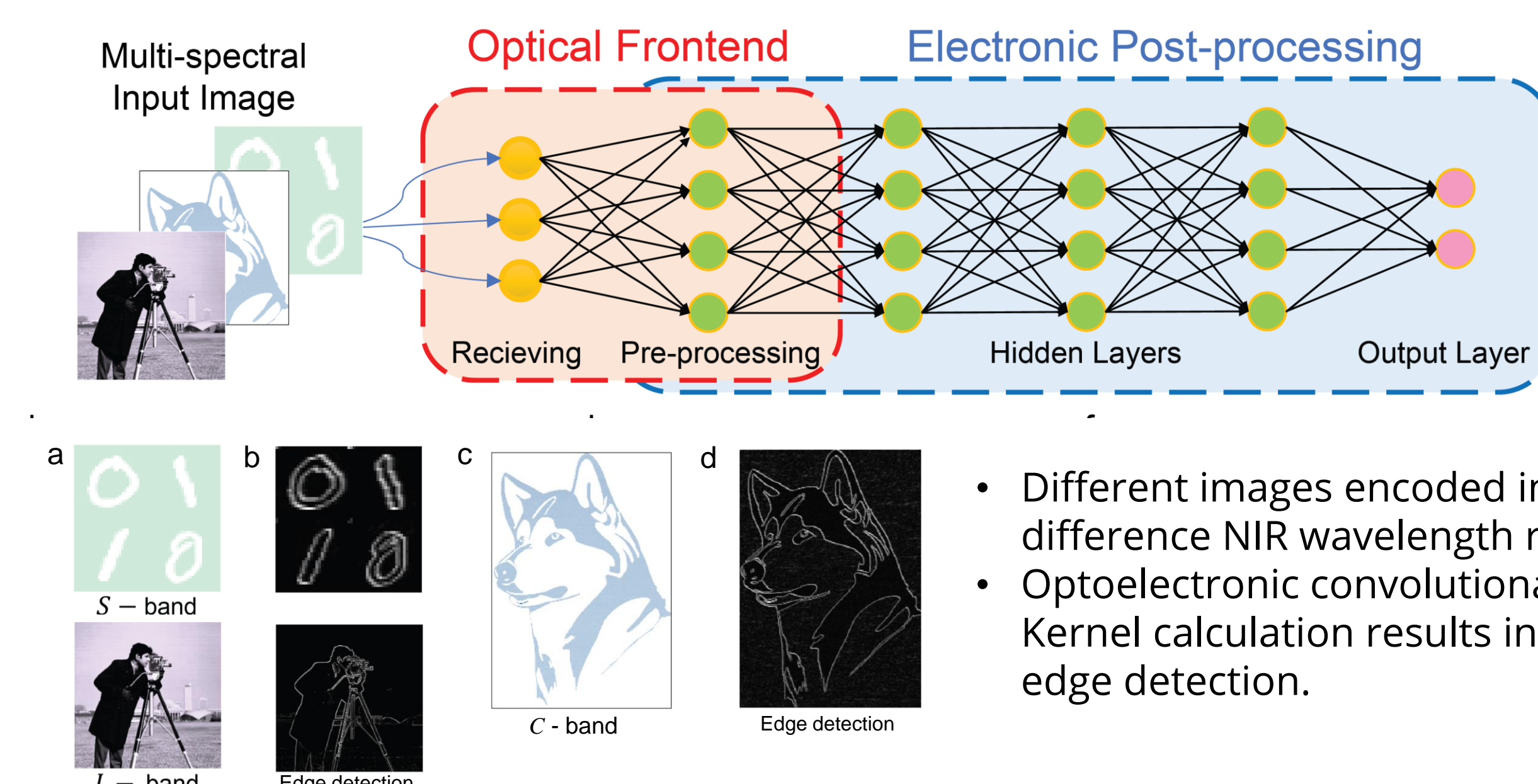


Device retention time, repeatability and durability

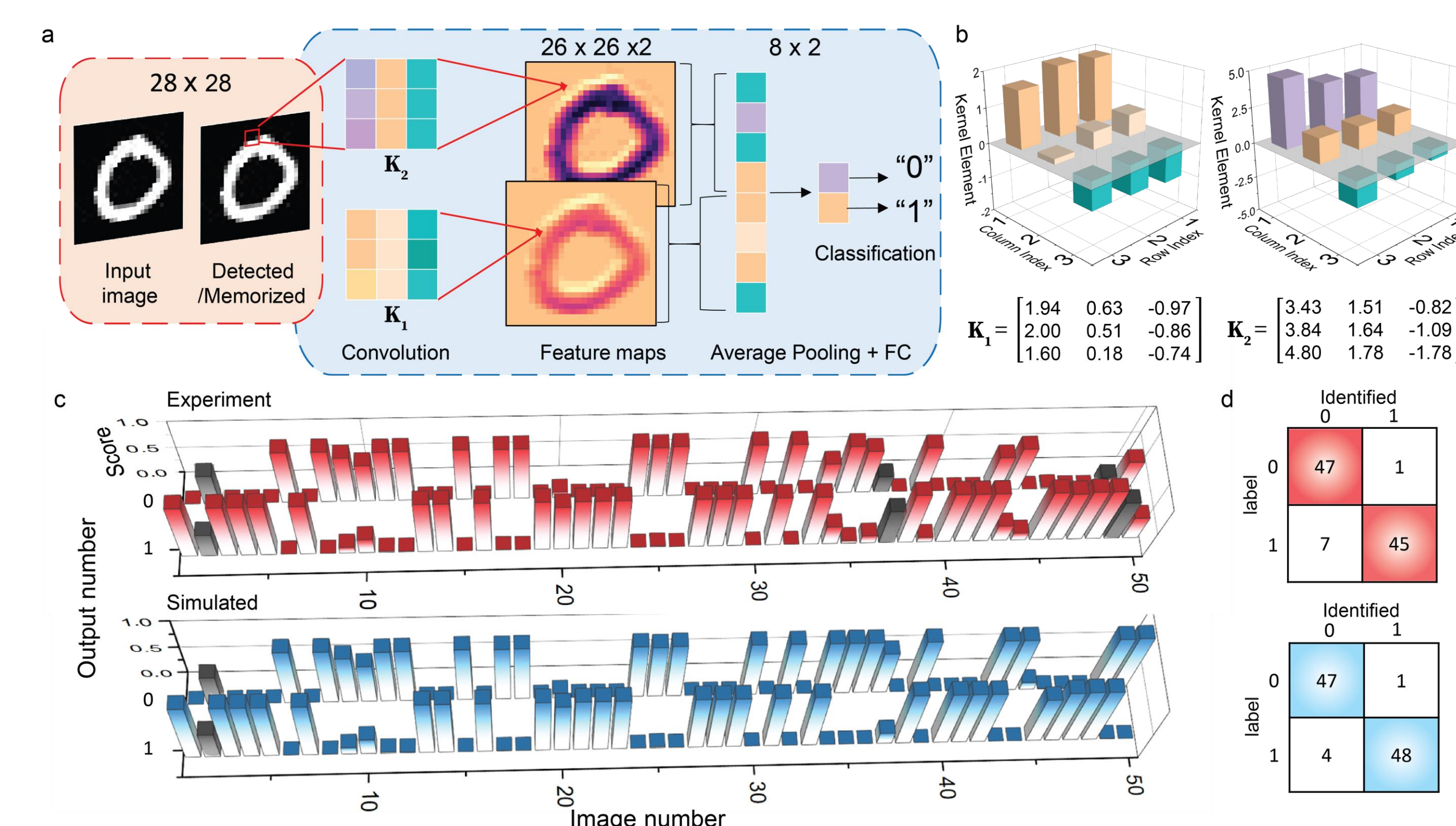
- Electrically programmed states: retention time (30%) ~ 1 year.
- Repeatable conductance states over 200 programming cycles with long retention time >1000s



Optoelectronic Edge Detection



Hand-written digit classification



- Input can also be encoded electrically.
- 36 steps, or more than 5 bits of conductivity states enable the computation with more complex kernel matrix.
- MNIST hand-written digits are classified for randomly picked '0' and '1' with 92 % accuracy. [4]

References

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- Feng, Q., Yan, F., Luo, W., & Wang, K. Charge trap memory based on few-layer black phosphorus. Nanoscale 8, 2686-2692 (2016)
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