Advancing Machine Vision Technology:

Band structure of oxide semiconductors for optical neuromorphic devices to realize highly efficient and accurate machine vision

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LANT
UVision Lab

Outline

- **Basic IDEA**
  - Synaptic behavior from light signal?

- **Expanding to vision inspired optical synaptic transistors**
  - Appropriate electronic band structure for optical synaptic devices
  - Pentachromatic-vision inspired optical synaptic transistors

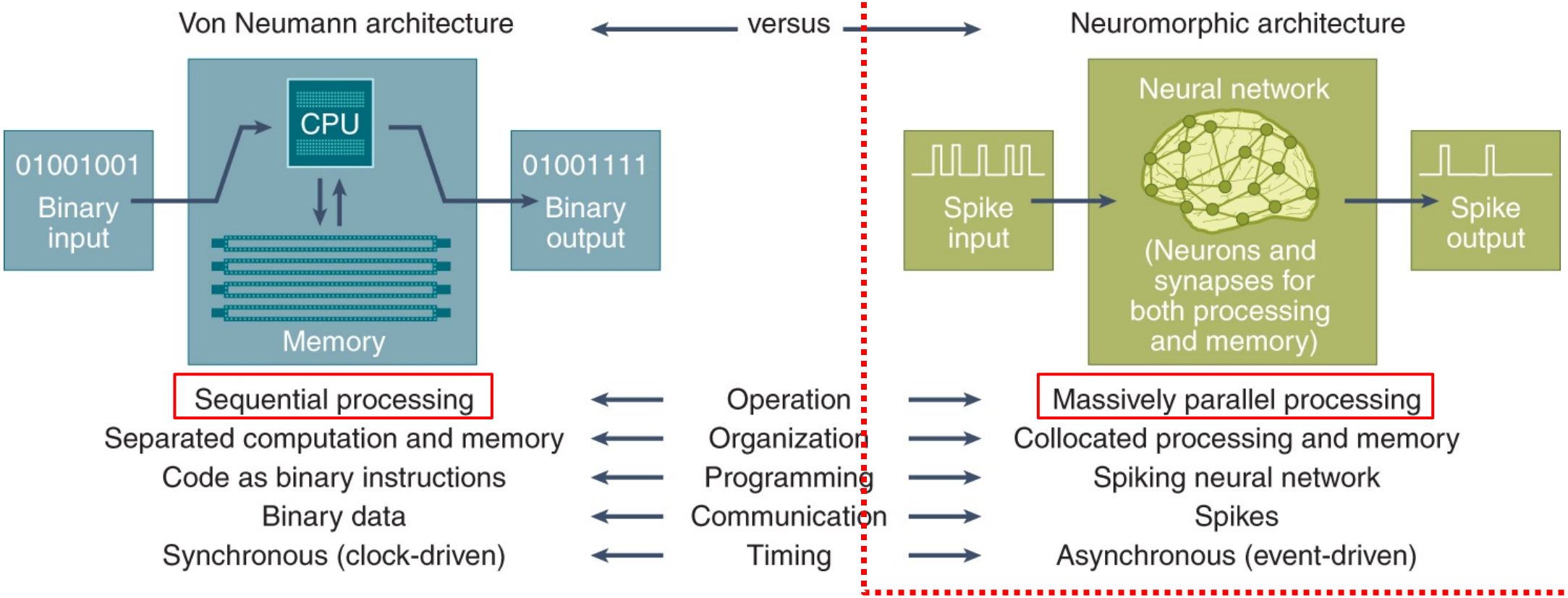
- **Advancing machine vision technology**
  - A brief insight into AI vision technology
  - In-sensor & in-memory optical synaptic devices for enhancing vision systems and machine learning validation

PERSPECTIVE
https://doi.org/10.1038/s43588-021-00184-y
nature computational science
Check for updates

Opportunities for neuromorphic computing algorithms and applications

Catherine D. Schuman[1,2], Shruti R. Kulkarni[1], Maryam Parsa[1,3], J. Parker Mitchell[1], Prasanna Date[1] and Bill Kay[1]

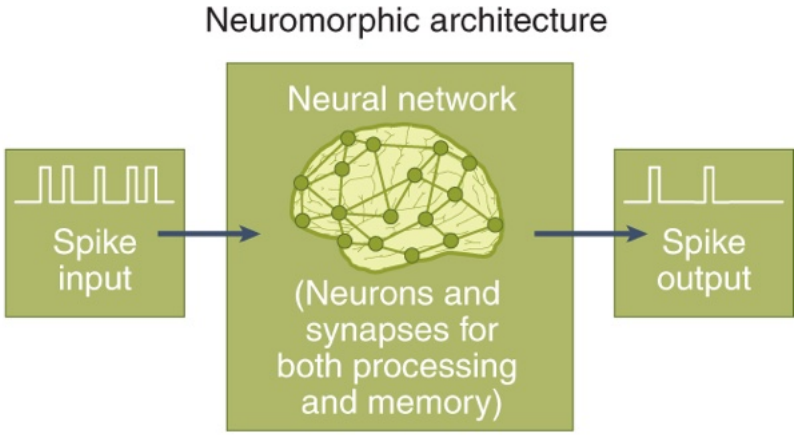
Better architecture for massively parallel processing of "electrical signal"



Nature Computational Science 2, 10 (2022)

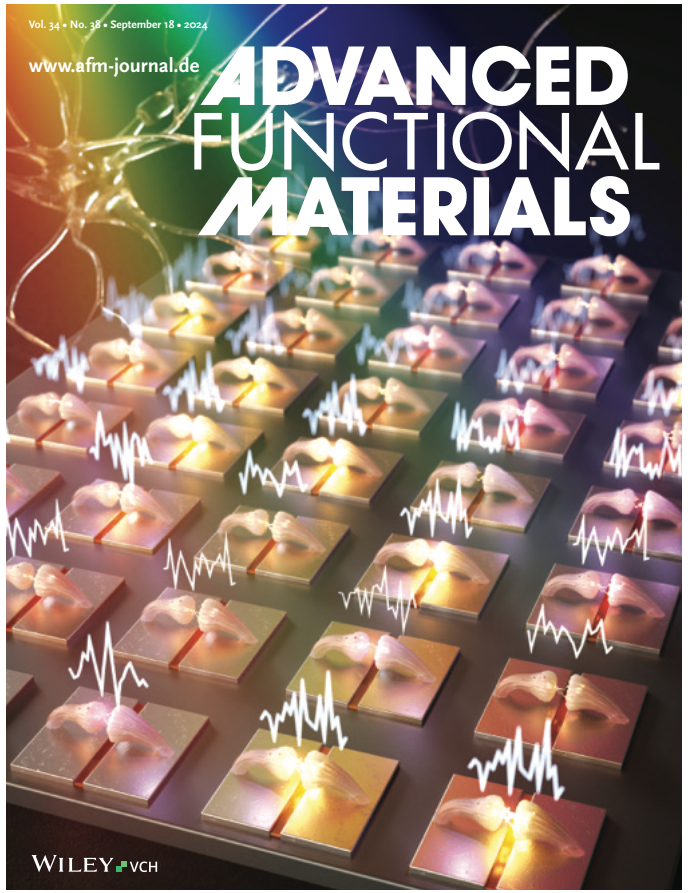
Scientific issues: What about "light signals"?

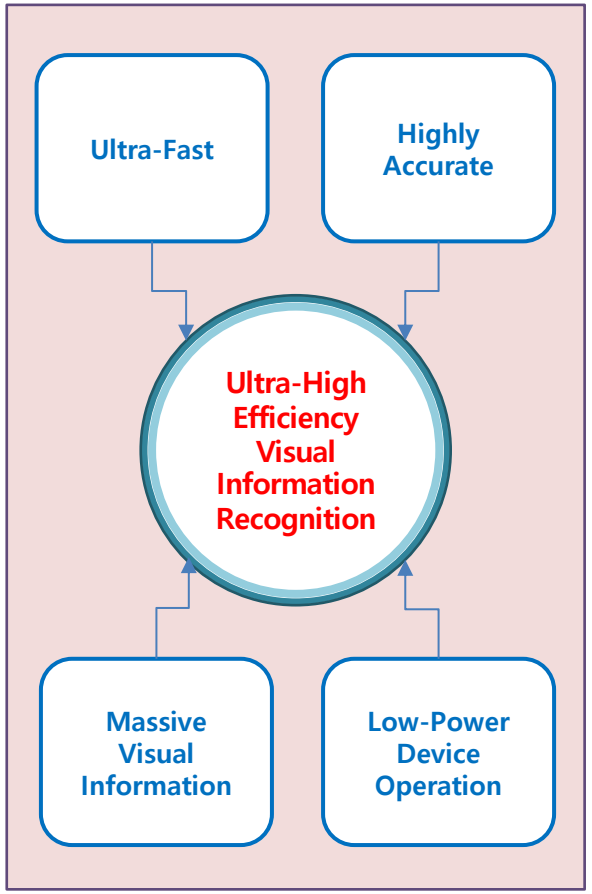
Traditional neuromorphic devices for electrical signal



Massively parallel processing
Collocated processing and memory
Spiking neural network
Spikes
Asynchronous (event-driven)

Processing "light signal"





Advanced Functional Materials (2024)

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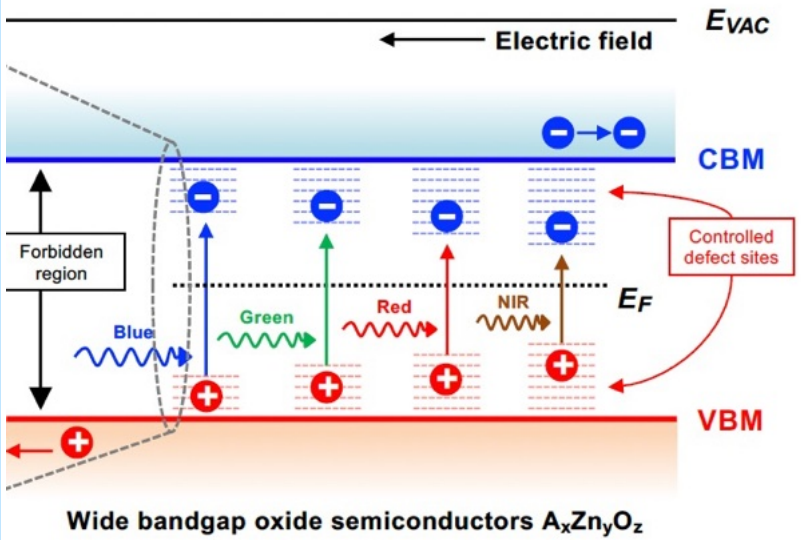
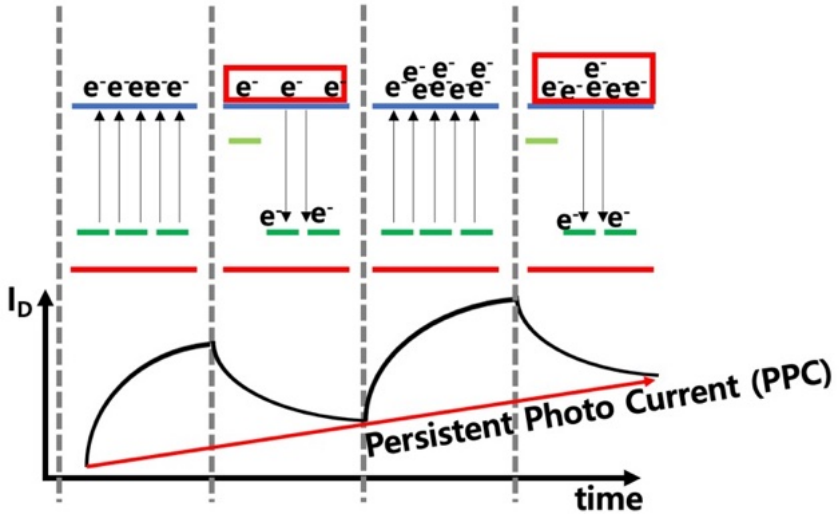
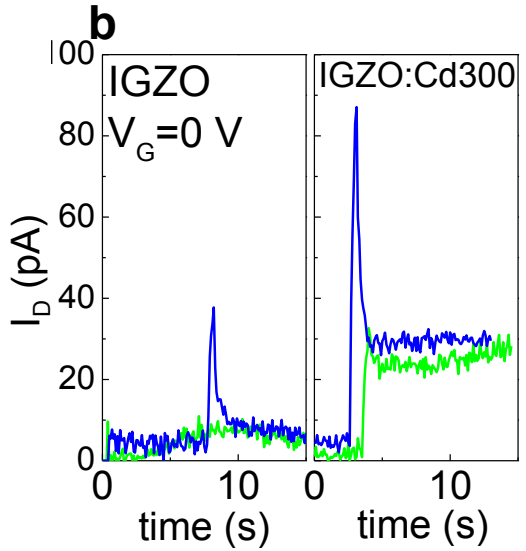
Appropriate electronic band structure for optical synaptic devices

Multi-band structure exhibits **a persistent photocurrent effect**, which demonstrates synaptic behavior in response to the optical signals.





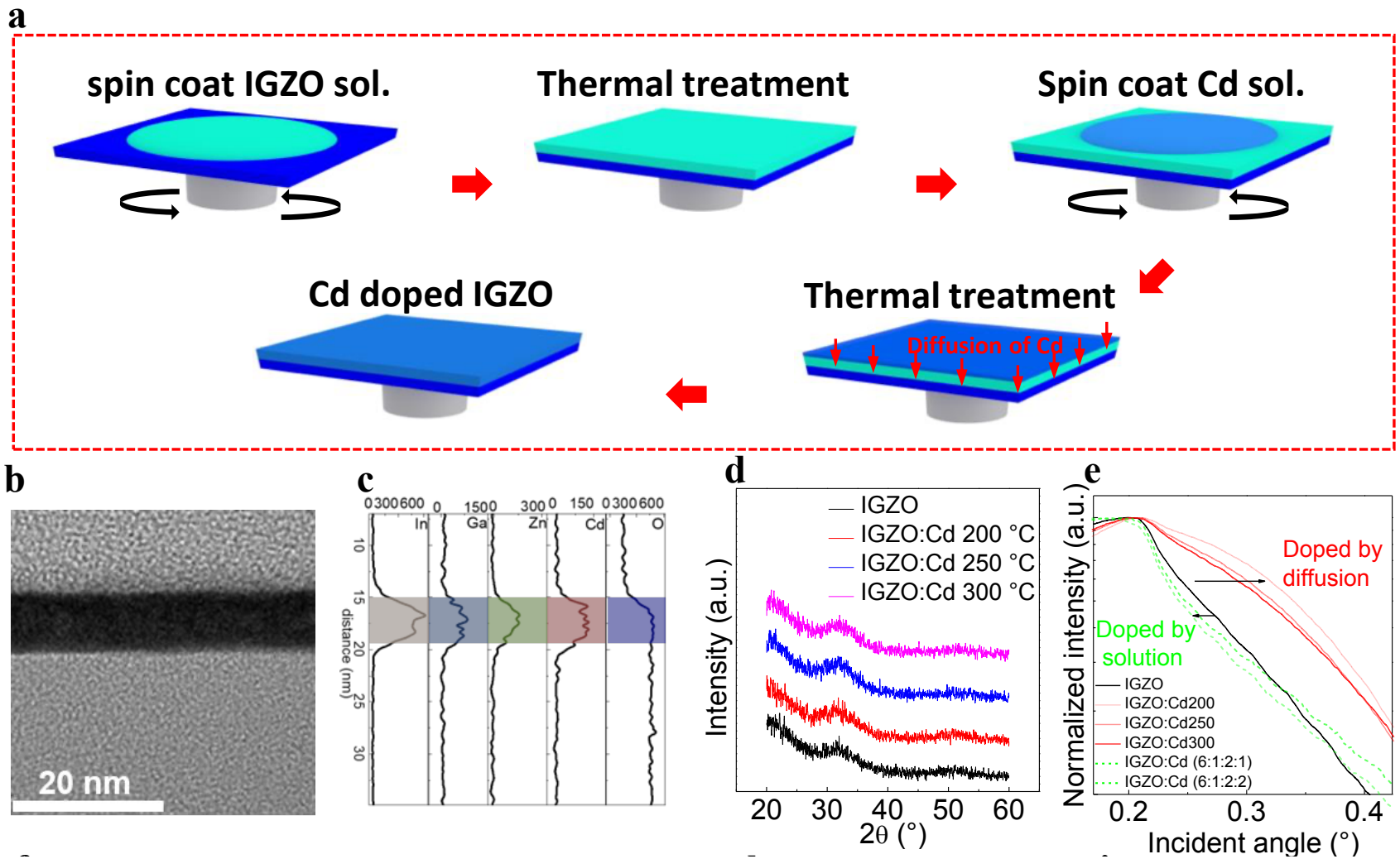


Multi-band structure | **Persistent photocurrent effect** | **Optical synaptic behaviors**

Optical synaptic transistors: Solution process of Cd doped IGZO

Vertically diffused Cd doping process of IGZO

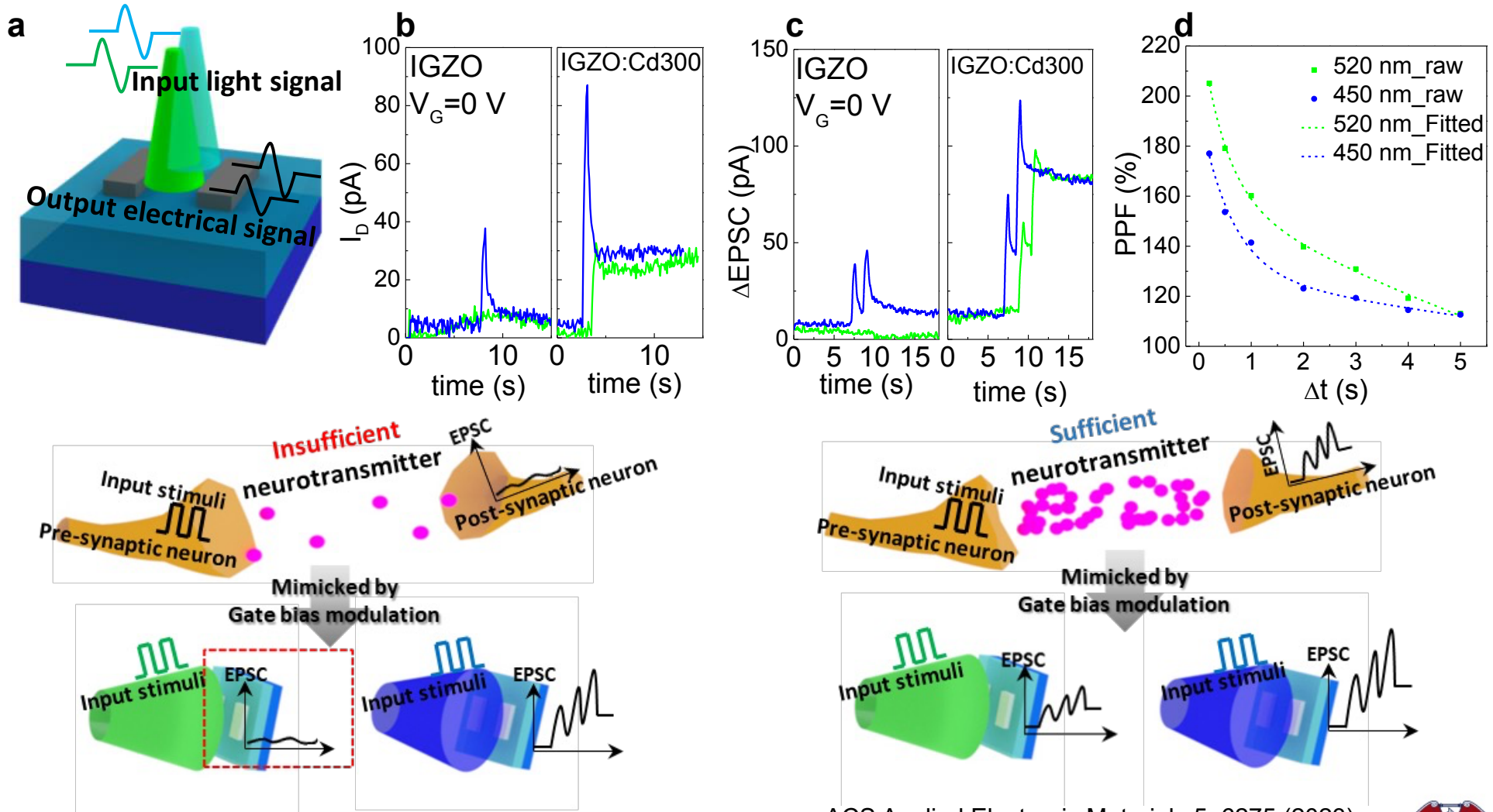
- Cd dopants were uniformly diffused into the IGZO film, and the film density was increased.



Optical synaptic transistors: Solution process of Cd doped IGZO

Optoelectronic synaptic behavior of the device under the green and blue light stimulation

Excitatory postsynaptic current (EPSC) and paired-pulse facilitation (PPF)

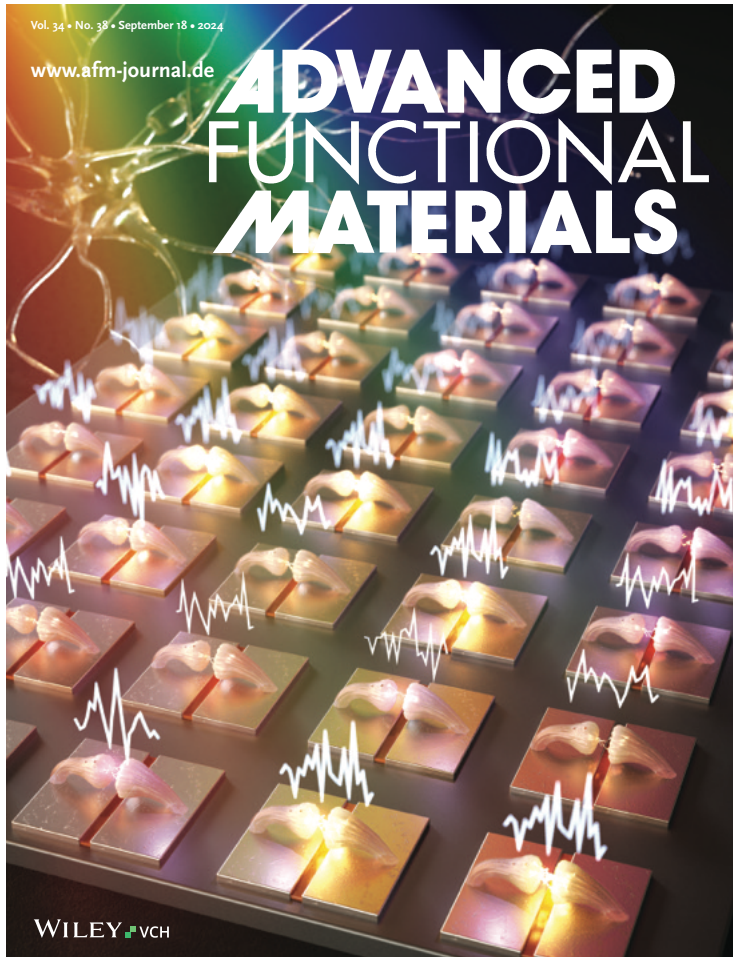


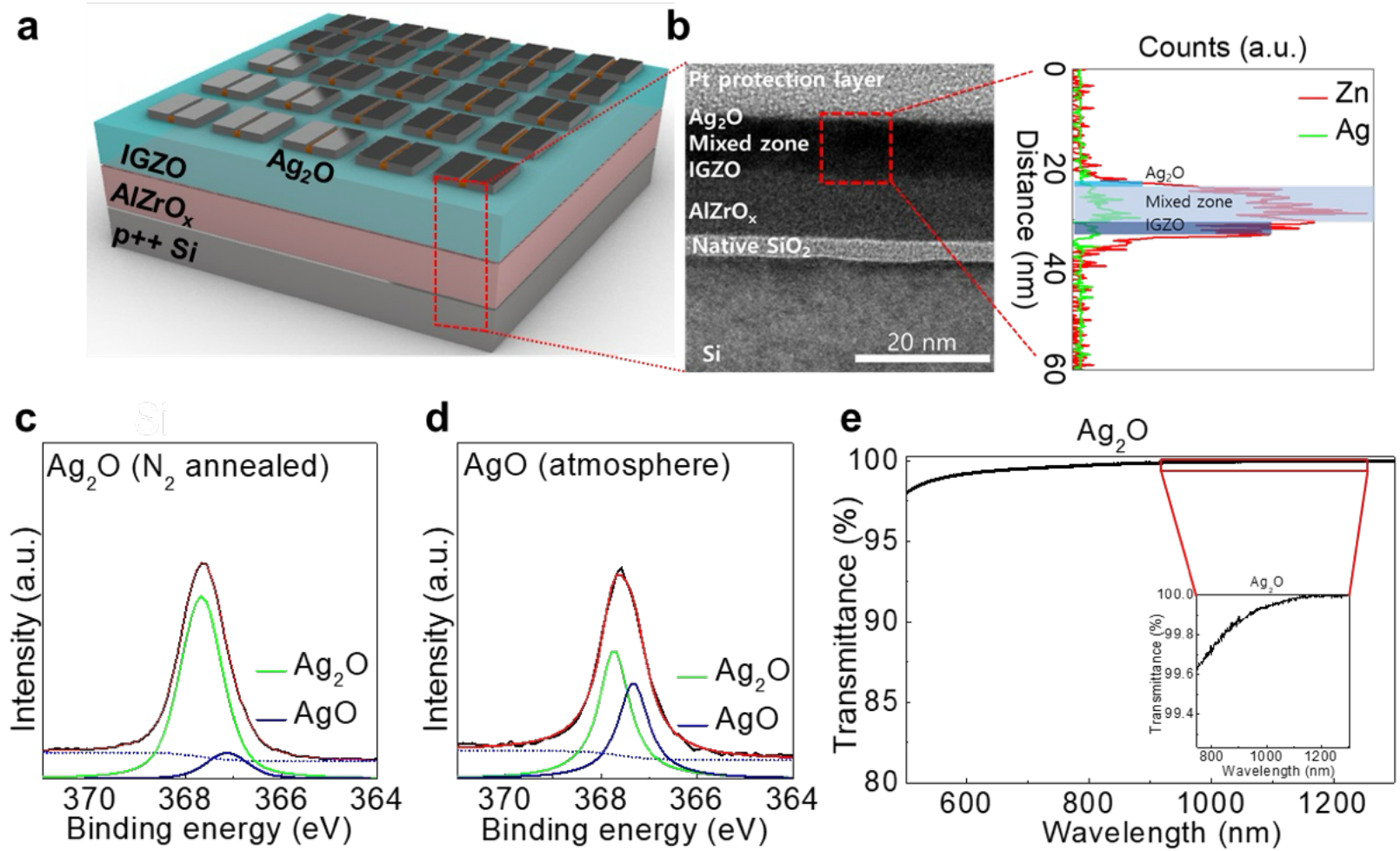
ACS Applied Electronic Materials 5, 6275 (2023)

Pentachromatic vision inspired optical synaptic transistor

UV-Vis-NIR pentachromatic vision for vision inspired optical synaptic transistor

Control gap states at the mixed zone of Ag_2O and IGZO



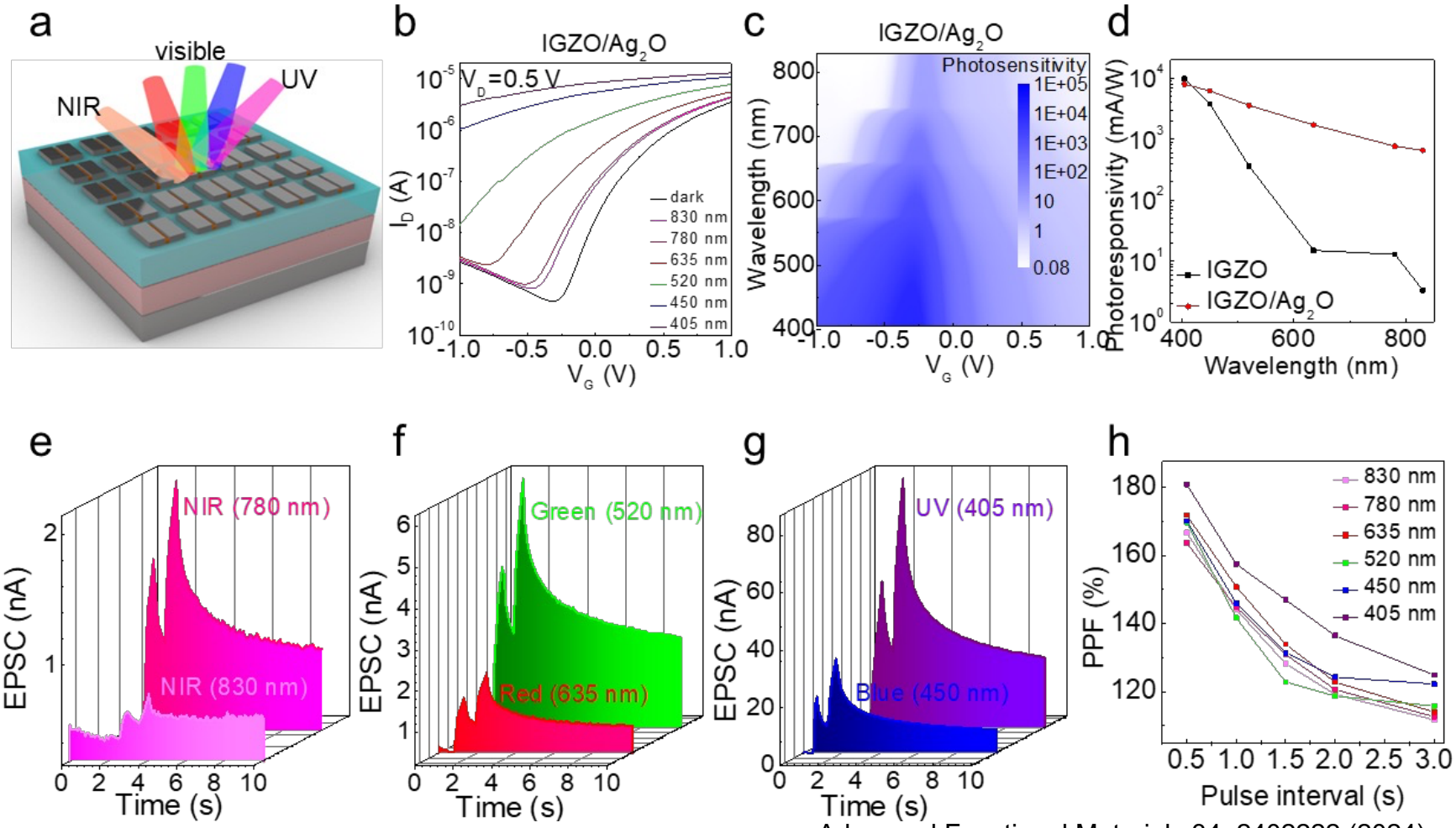


Pentachromatic vision inspired optical synaptic transistor

Excitatory postsynaptic current (EPSC) shows pentachromatic response

Paired-pulse facilitation (PPF) shows synaptic response

- Low working voltage & wide wavelength response (405 nm ~ 830 nm)



Advanced Functional Materials 34, 2402222 (2024)

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In reality, incidents still occur due to insufficient visual information processing.

A new technological paradigm is needed for next-generation visual information recognition system.

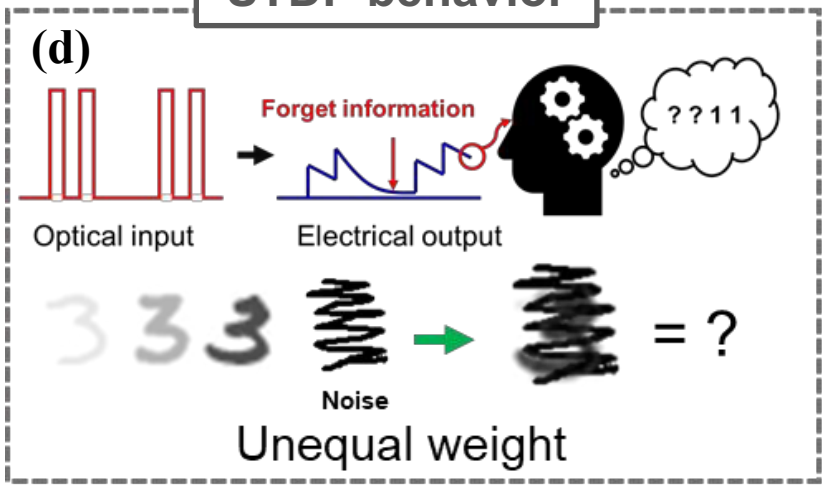
Optical synaptic device is a key technique for future visual information recognition systems

In-sensor & in-memory optical synaptic device

Image overlapping pre-process via in-sensor & in-memory device

- Need **suppressed spike-timing-dependent plasticity (STDP) characteristics and increase spike-number-dependent plasticity (SNDP)** to reduce processing image data

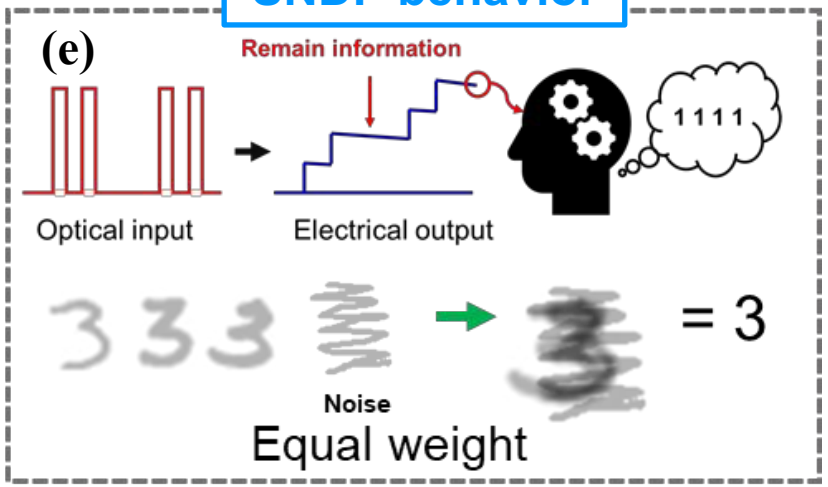
STDP behavior

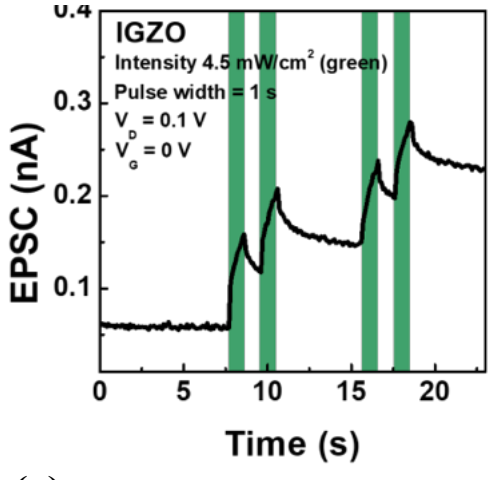


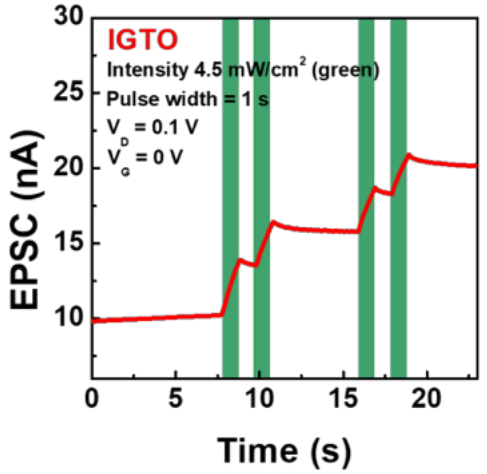
Comparing the signal process of the device with/without STDP characteristics

To enhance accuracy, it is important to maintain **equal weight for the sequence image**

SNDP behavior





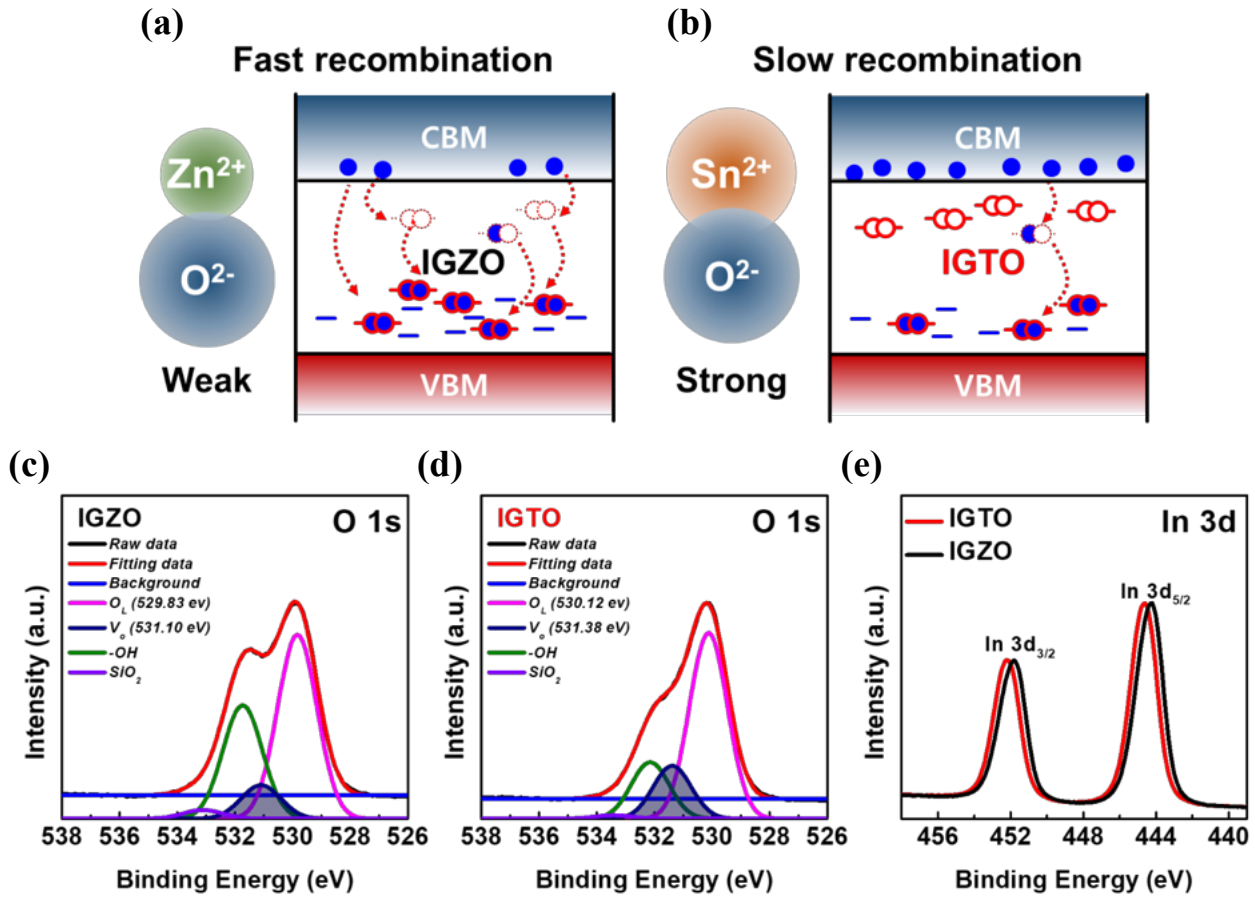


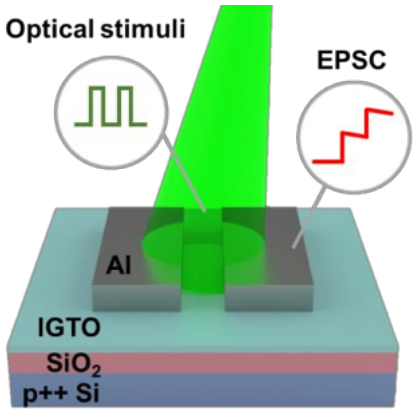
ACS Nano 19, 13107 (2025)

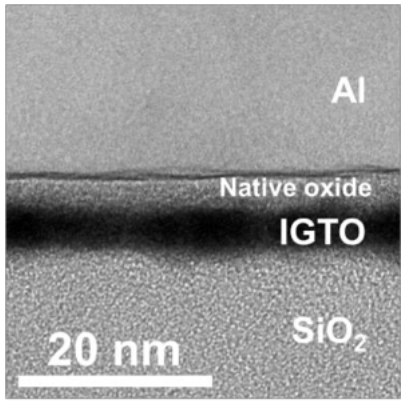
In-sensor & in-memory optical synaptic device

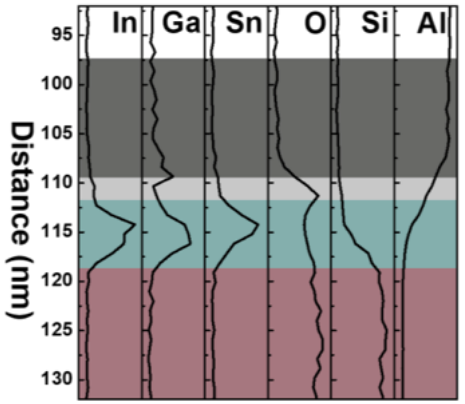
InGaSnO synaptic device to suppress STDP and increase SNDP

- **Strong bonding energy between Sn and O & Slow recombination**
- InGaZnO vs. InGaSnO









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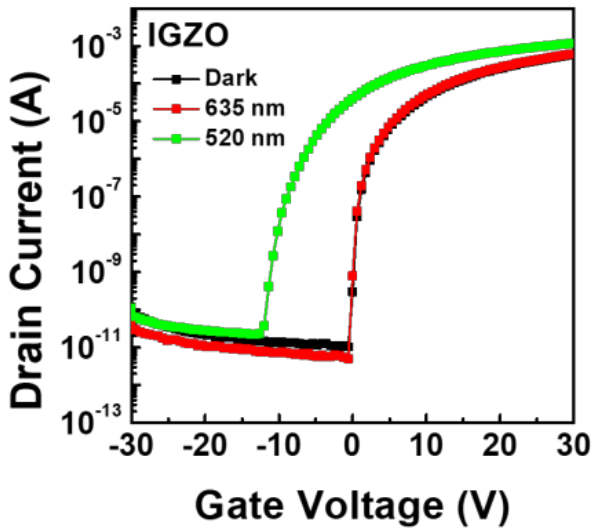
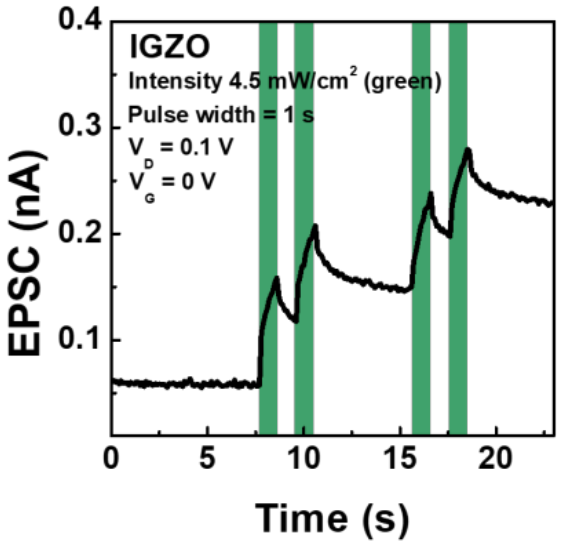
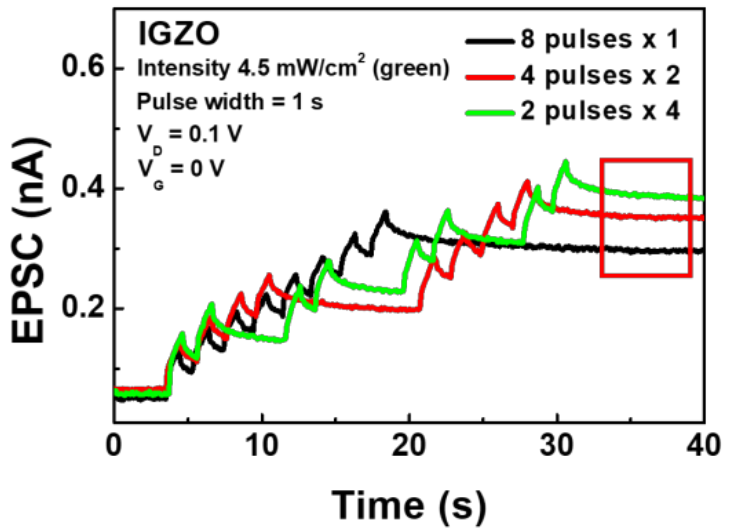
In-sensor & in-memory optical synaptic device

STDP behavior

SNDP behavior







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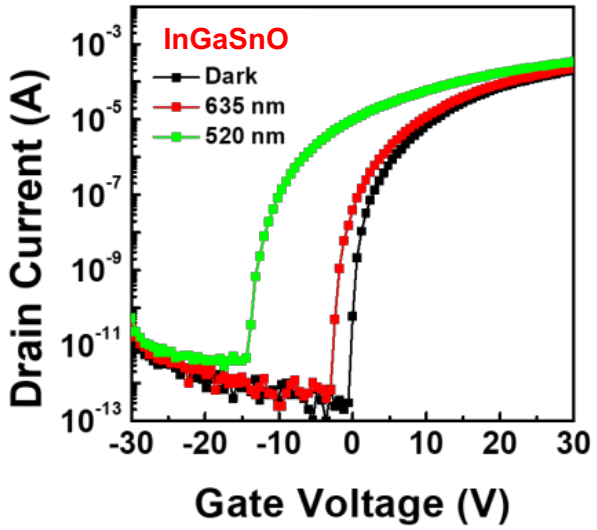

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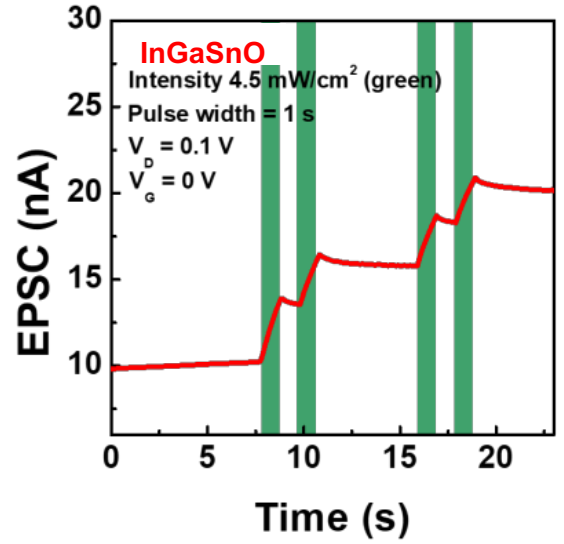

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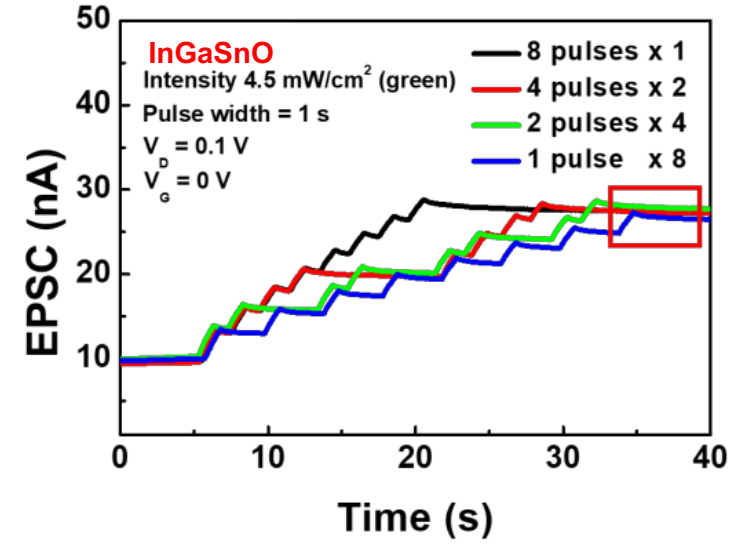
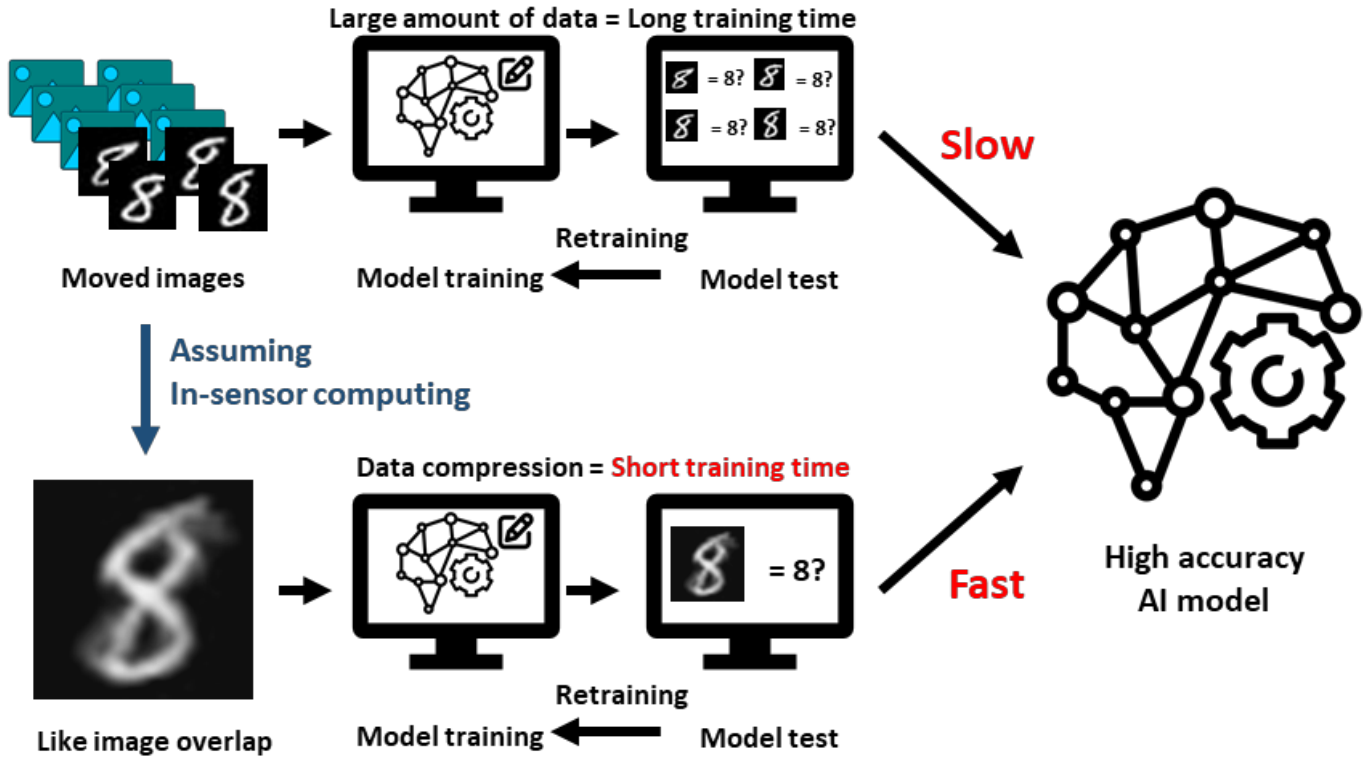
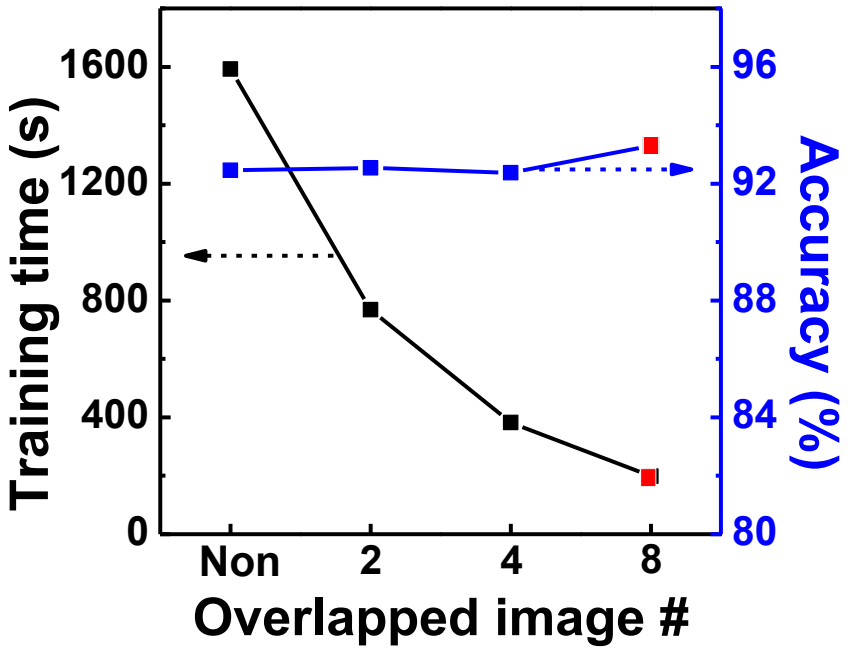


Prove the concept via Machine Learning

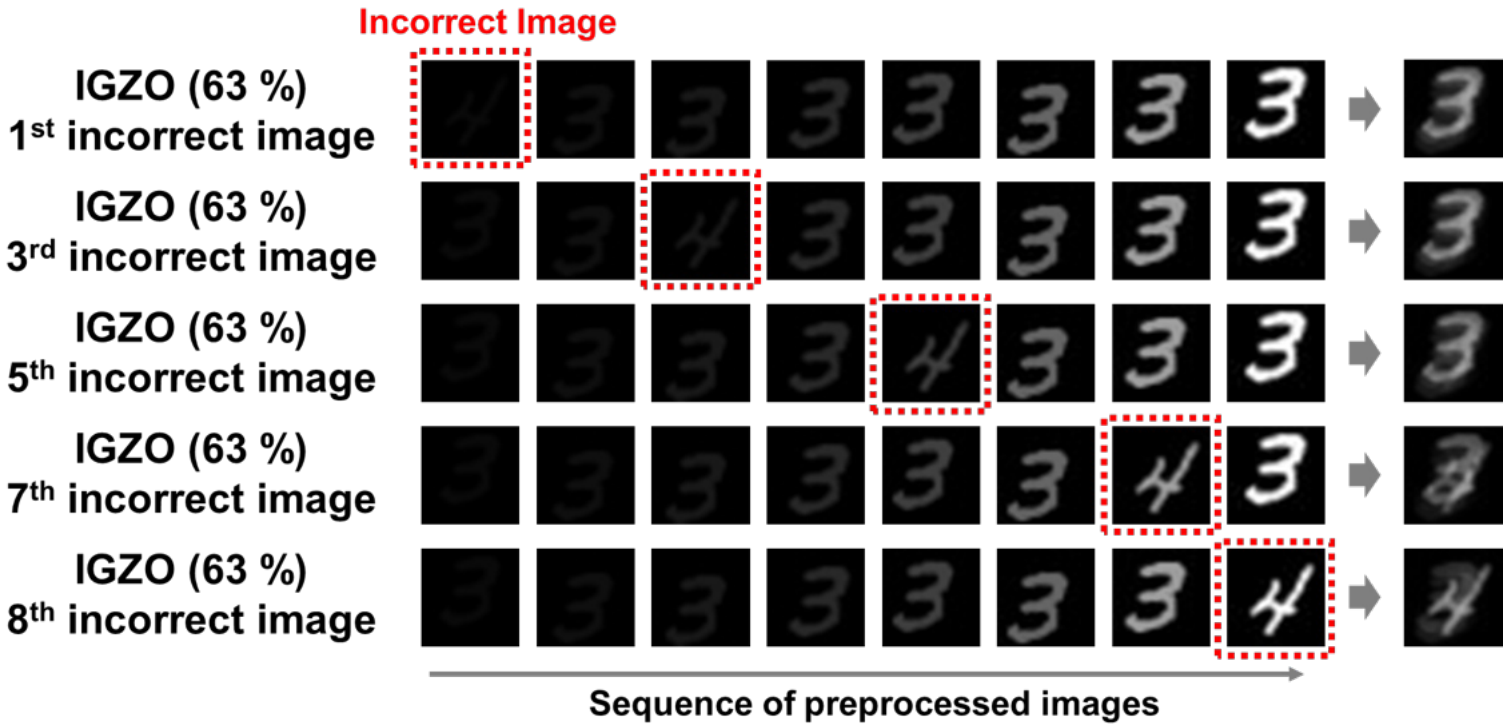
- 28 x 28 pixels image data input to the machine learning (480,000 images)
- Reduce the training time according to increase the number of overlapped images without change the accuracy

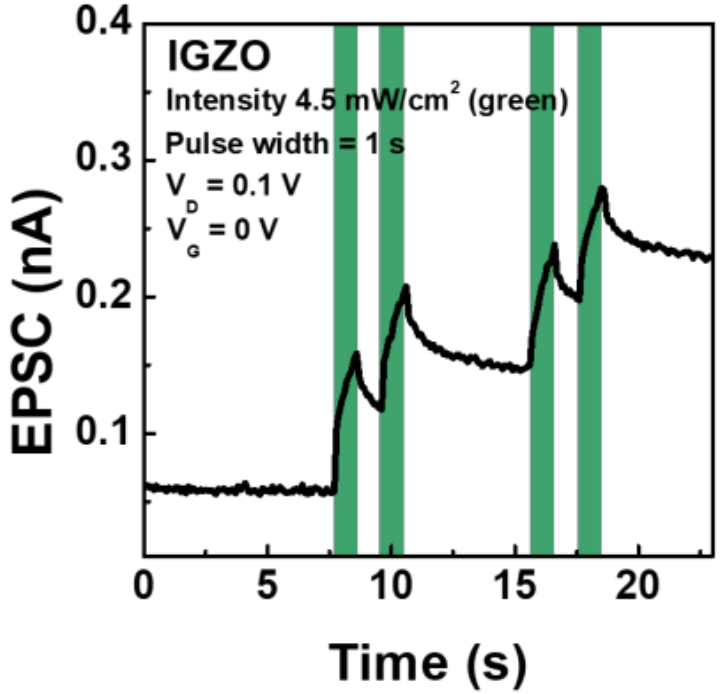




Prove the concept via Machine Learning

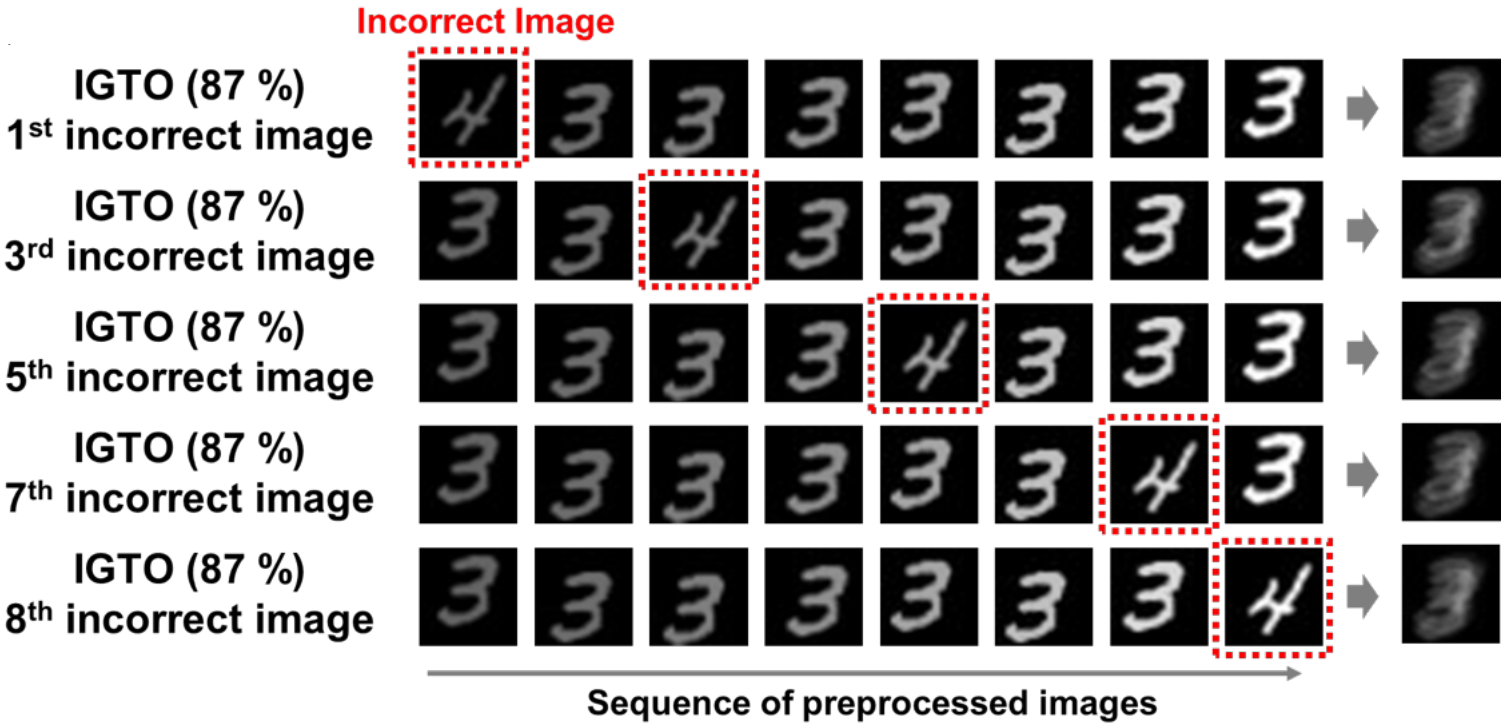
- Image recognition via a device with the STDP (IGZO TFTs).

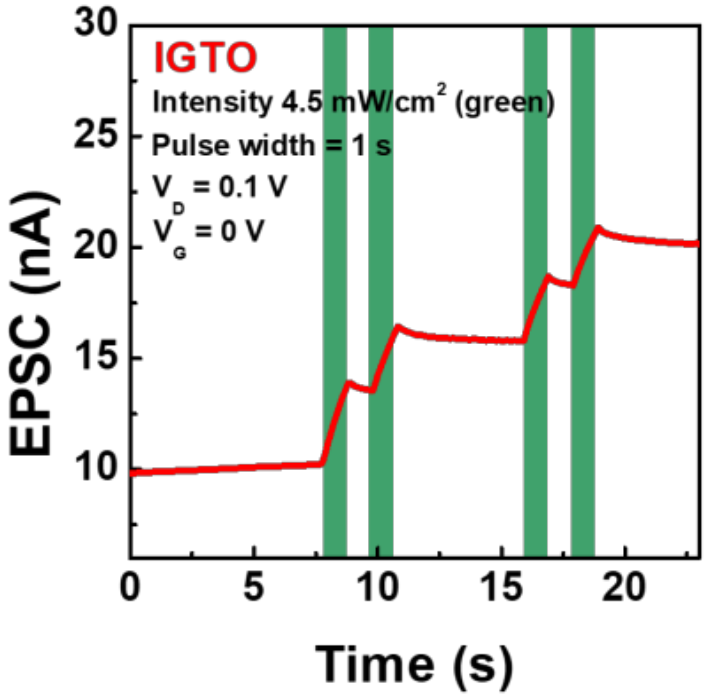




Prove the concept via Machine Learning

- Image recognition via a device by the SNDP (InGaSnO TFTs).

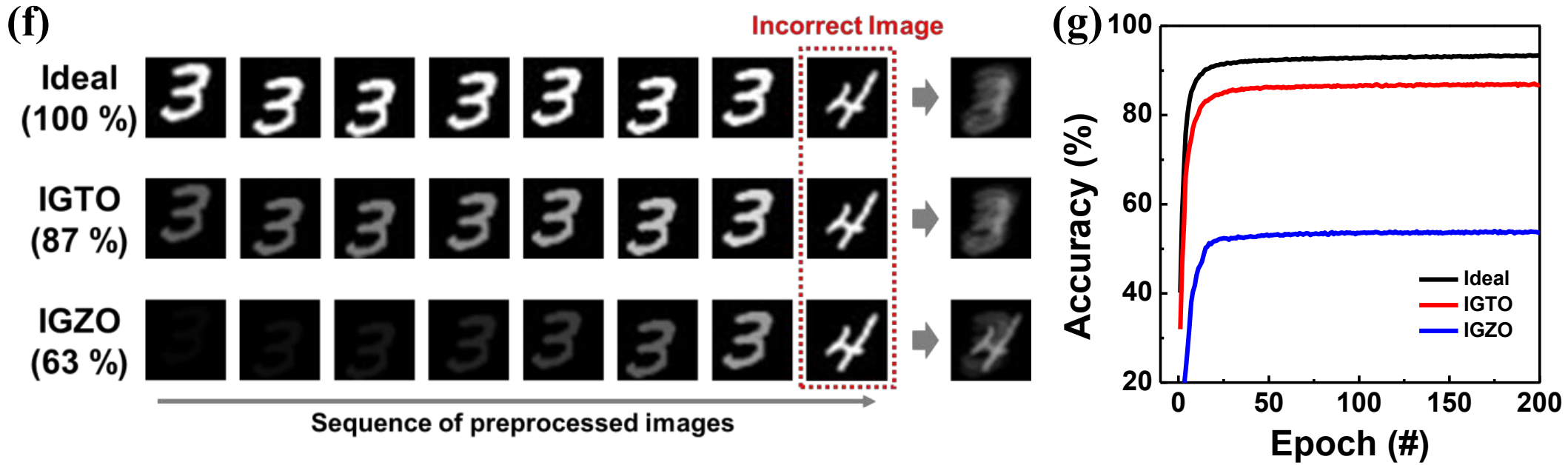




Prove the concept via Machine Learning

- Compare the result of image recognition of ideal/InGaSnO/IGZO device, with the wrong information at the end

Device with the SNDP (InGaSnO) gives more accurate image recognition result



More accurate and fast image recognition system is possible with InGaSnO in-sensor devices!

Summary

- We have suggested an appropriate electronic band structure of oxide semiconductor for optical synaptic devices.
- We have demonstrated a pentachromatic vision inspired optical synaptic transistor with 512 conduction states to the light signal.
- More accurate and fast image recognition system is possible with SNDP in-sensor devices!
- We believe that optical synaptic devices could be a key technique for developing fast and accurate machine vision.

Additional information

Lab members

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