National Taiwan University

Chemical Engineering

NTU ARC-GMST

前瞻綠色材料高值化研究中心

Advanced Research Center for Green Materials Science and Technology

MOE 113L9006

Utilization of Conjugated Self-Assembled Molecules in Photosynaptic Transistors for Achieving Ultralow Energy Consumption

Date: 2024/02/20

Speaker: Ya-Shuan Wu

Advisor: Prof. Wen-Chang Chen

Outline

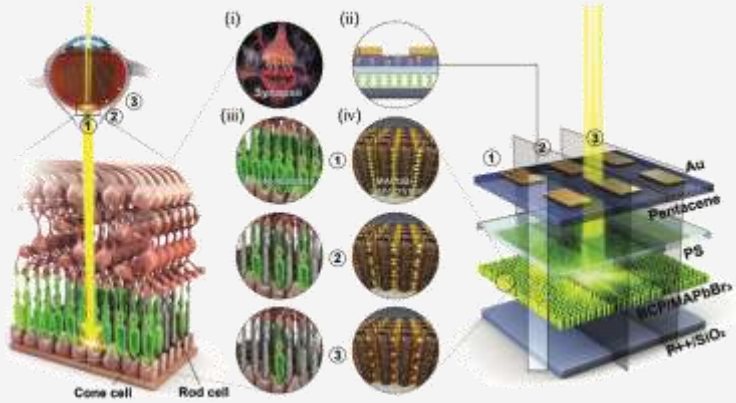
Introduction

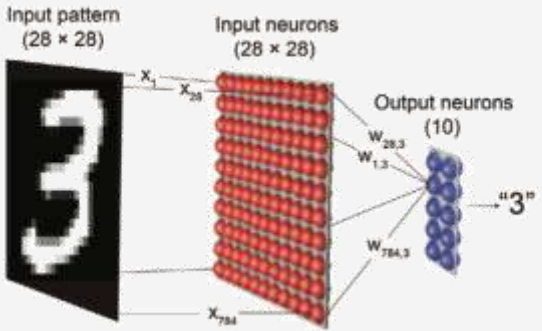
von Neumann bottleneck:

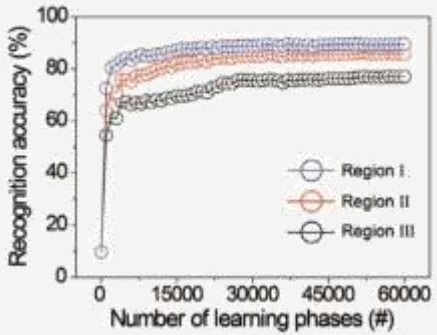
- ✓ Separation between memory and computing system
- ✓ Low data capacity and long processing time

Photosynaptic transistor:

- ✓ Integrate sensing and information storage
- ✓ Mimic human learning behavior
- ✓ Light ⟹ noncontact programming







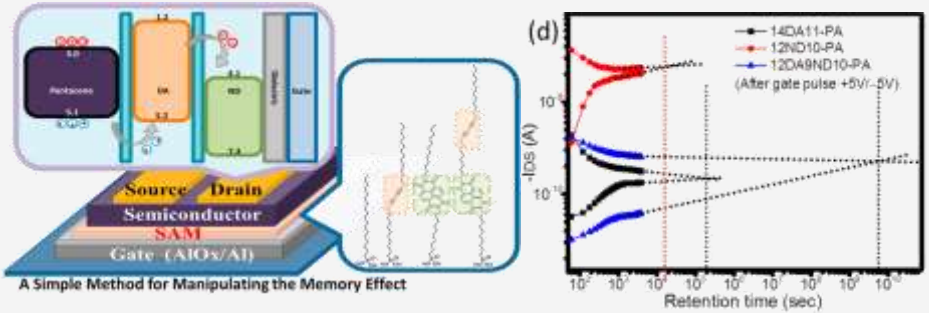
Lee, K., Han, H., Kim, Y., Park, J., Jang, S., Lee, H., ... & Park, C. (2021). Retina-Inspired Structurally Tunable Synaptic Perovskite Nanocones. *Advanced Functional Materials*, *31*(52), 2105596.

Introduction

Self-assembled molecules (SAMs):

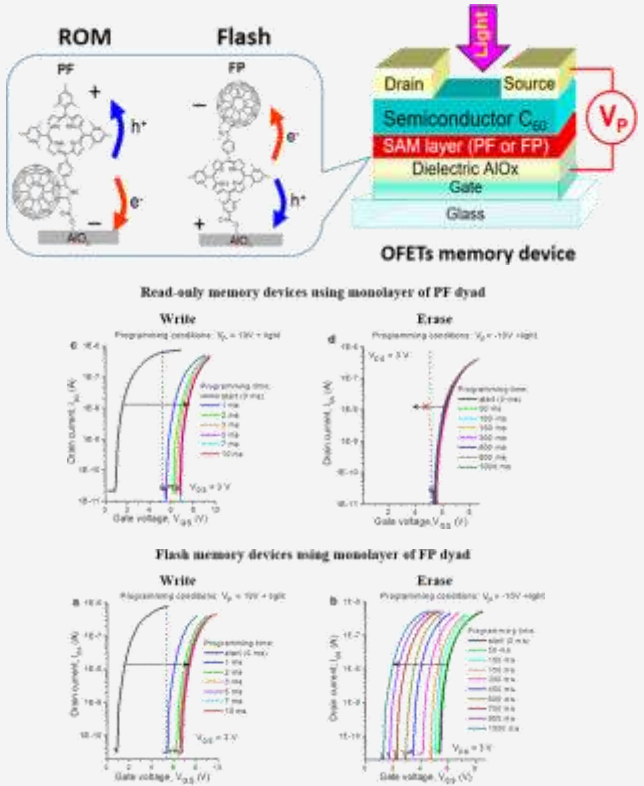
- ✓ Surface modification and defect passivation
- ✓ Formation of an ultrathin layer
- ✓ High capacitance and low current leakage

- **Design of Charge-trapping Moiety**



Tseng, C. W., Huang, D. C., & Tao, Y. T. (2015). Organic transistor memory with a charge storage molecular double-floating-gate monolayer. *ACS applied materials & interfaces*, *7*(18), 9767-9775.

- **Sequence of Molecular Structures**



Frolova, L. A., Furmansky, Y., Shestakov, A. F., Emelianov, N. A., Liddell, P. A., Gust, D., ... & Troshin, P. A. (2022). Advanced Nonvolatile Organic Optical Memory Using Self-Assembled Monolayers of Porphyrin–Fullerene Dyads. *ACS applied materials & interfaces*, *14*(13), 15461-15467.

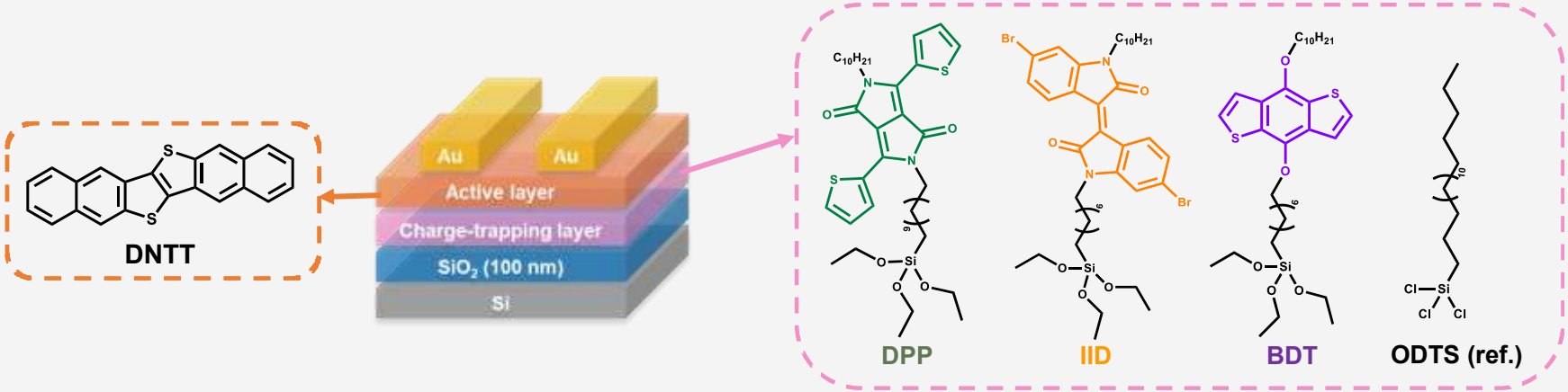
Introduction

Objective:

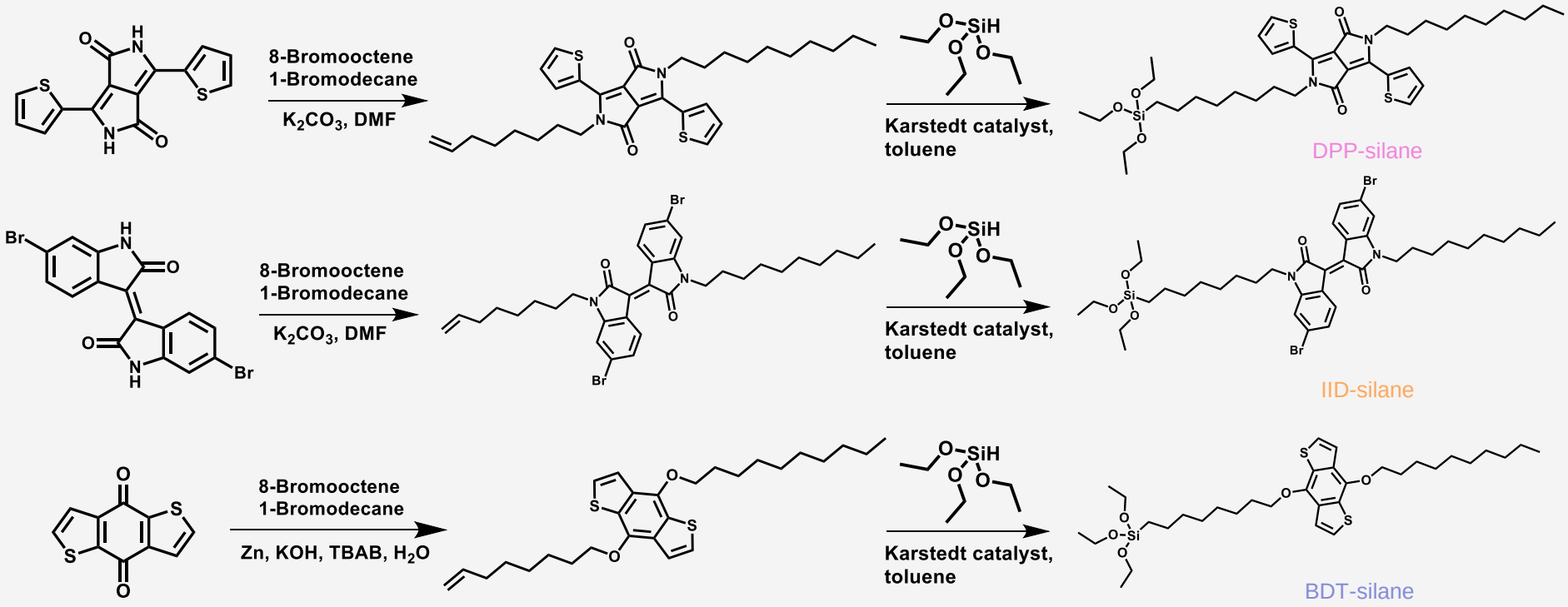
- ✓ Simple device architecture with photoactive SAMs
- ✓ Low energy consumption
- ✓ Photosynaptic transistor

Comparison with ODTS:

- ✓ Chains with equal number of carbon atoms
- ✓ Existence of chromophore
- ✓ Ability for charge storage



Synthesis

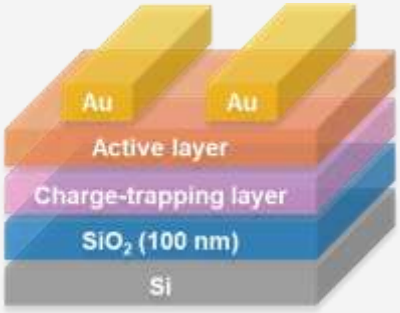

8-Bromooctene
1-Bromodecane
K_2CO_3, DMF
Karstedt catalyst, toluene
DPP-silane
8-Bromooctene
1-Bromodecane
K_2CO_3, DMF
Karstedt catalyst, toluene
IID-silane
8-Bromooctene
1-Bromodecane
Zn, KOH, TBAB, H_2O
Karstedt catalyst, toluene
BDT-silane

Device Fabrication

- Electrodes : 70 nm thick by deposition
- Active layer : 50 nm thick by deposition
- Electret :

SiO_2 (100nm)/Si substrate

→ plasma-treated for 8 min



Rinsed by toluene

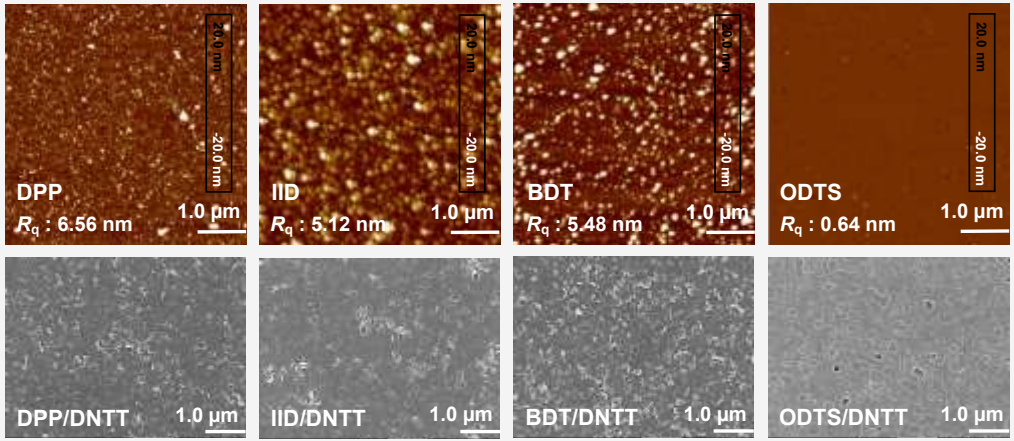
→ 30 min at 80 ℃ in vacuum

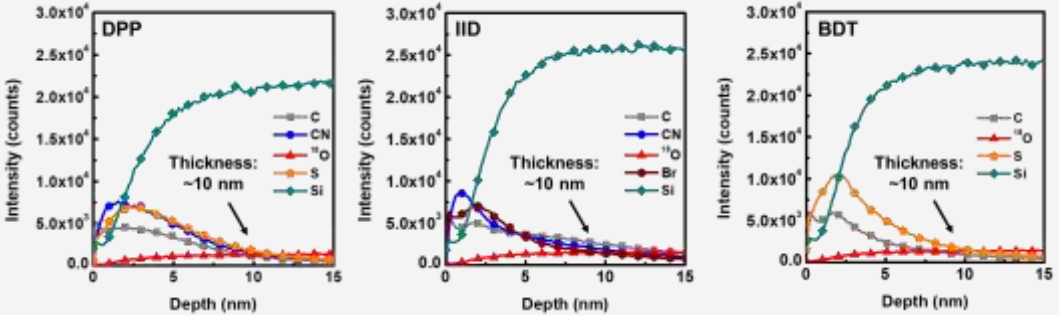
Dipped in the solution for 72 hr at 80 ℃

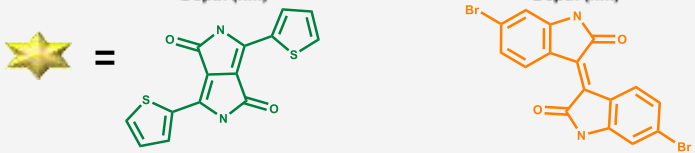
Solvent: anhydrous toluene

Concentration: 3×10^{-3} M

Morphology Analysis

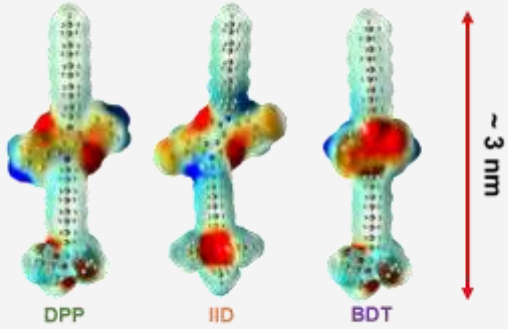


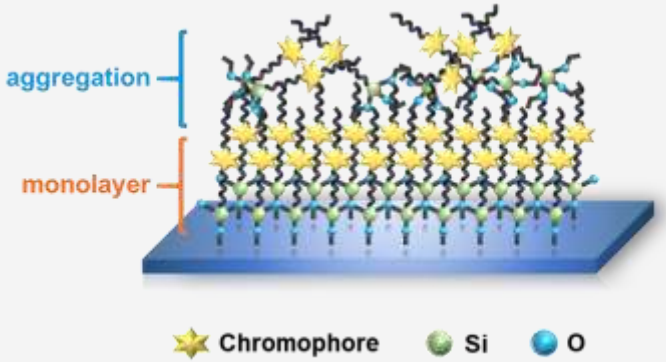




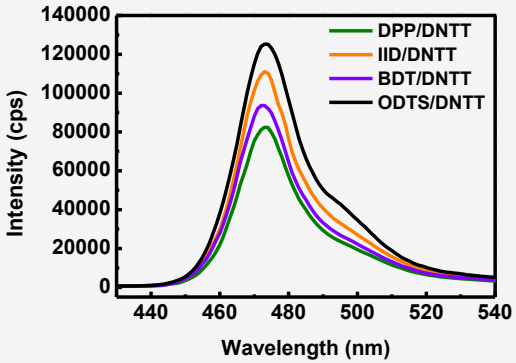
- Intermolecular interaction ⟹ aggregation
- Roughness: DPP > BDT > IID > ODTS

⟹ morphology of active layer was affected

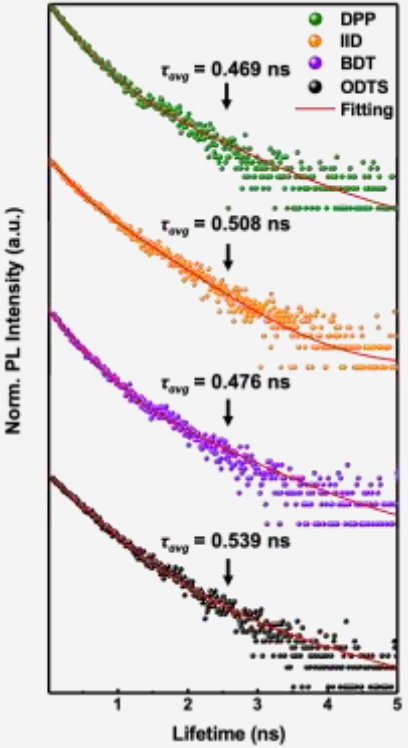


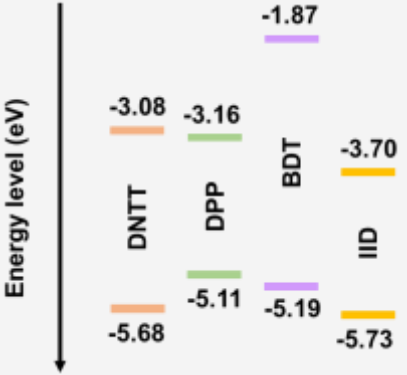


Energy level and Optical Analysis

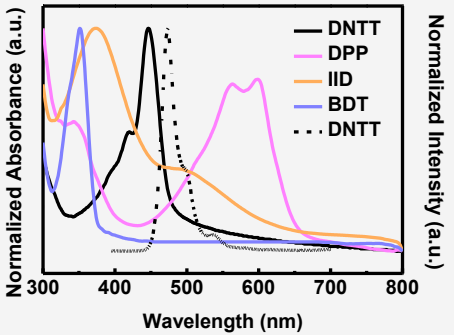


Exciton quenching and charge trapping



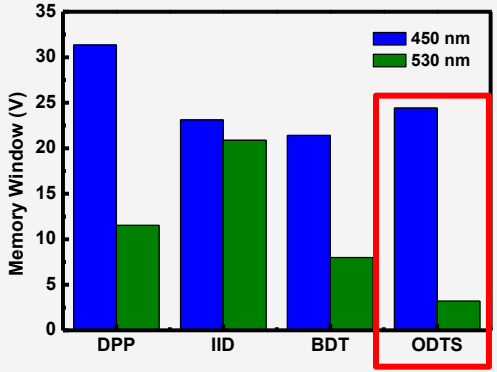


Strong donor—acceptor interaction
⇒ unstable excitons

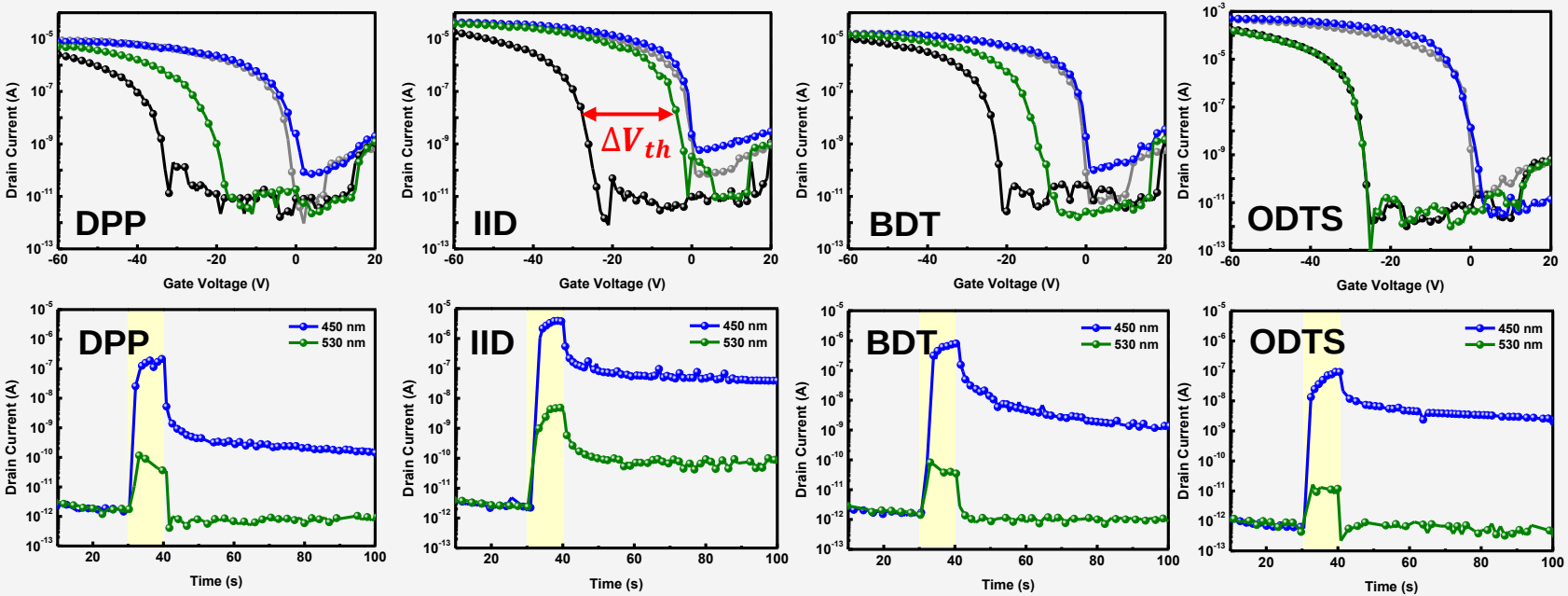


Electrical Characteristic

- IID shows the best photoresponsivity
- Short-term memory characteristic ⟹ Artificial synapse

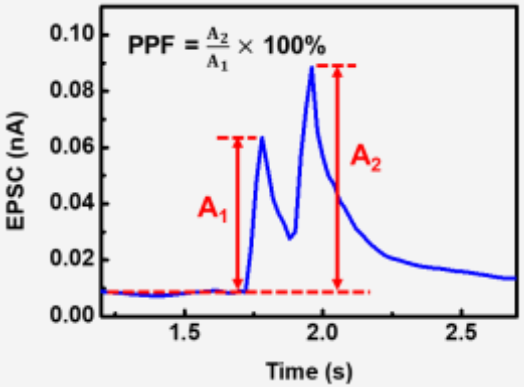


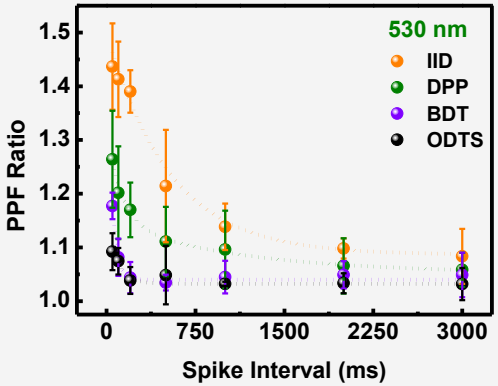
Effect of active layer for 450 nm

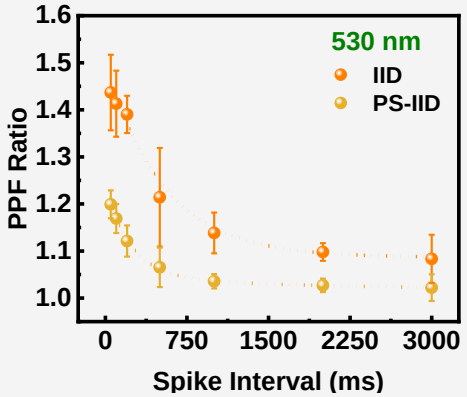


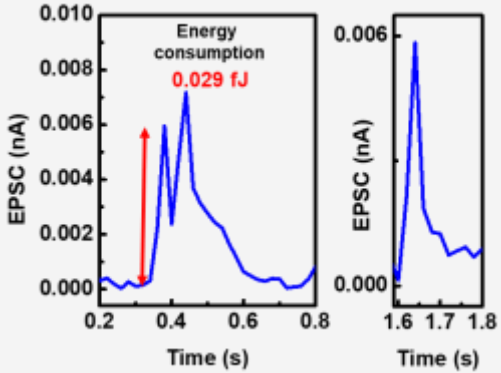
Electrical Characteristic

High PPF ratio ⇒ 144%





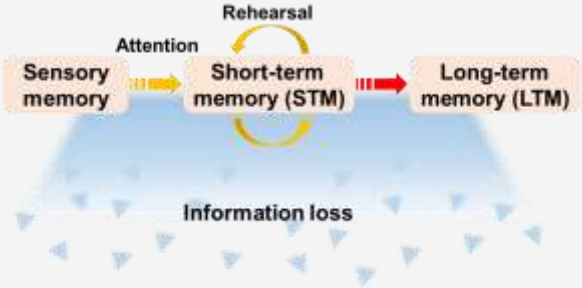




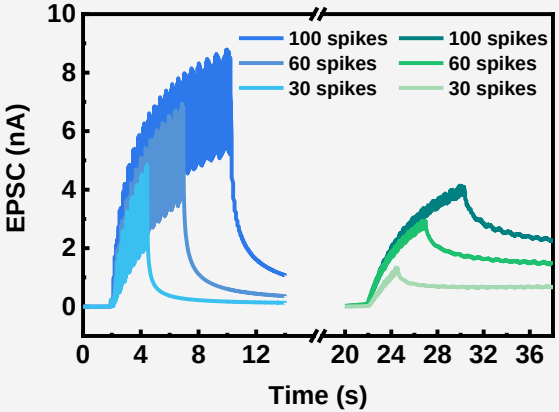
Energy consumption = $V_d \times I \times t$

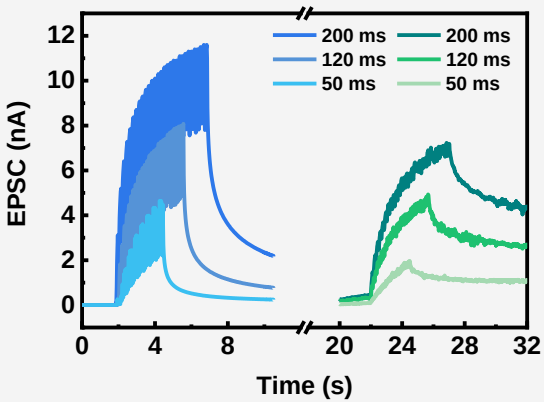
V_d: drain current
I: EPSC of each spike
t: spike width

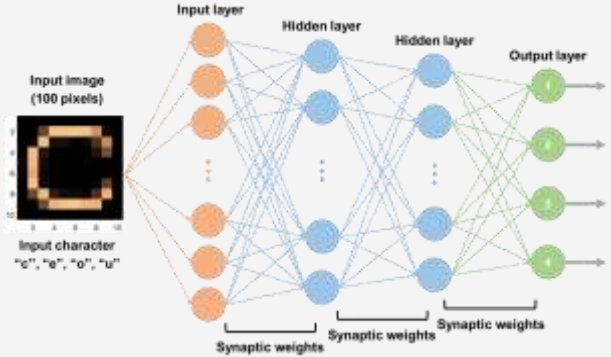
Ultralow ⇒ 0.029 fJ

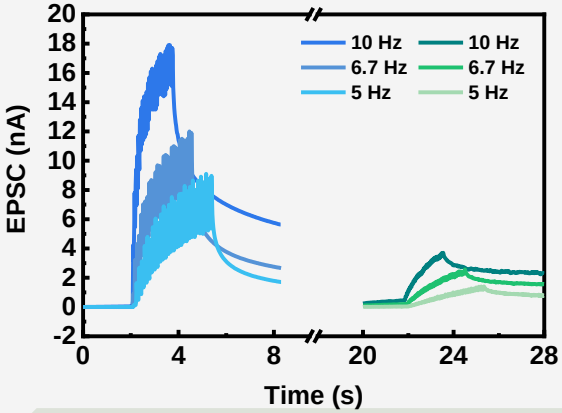


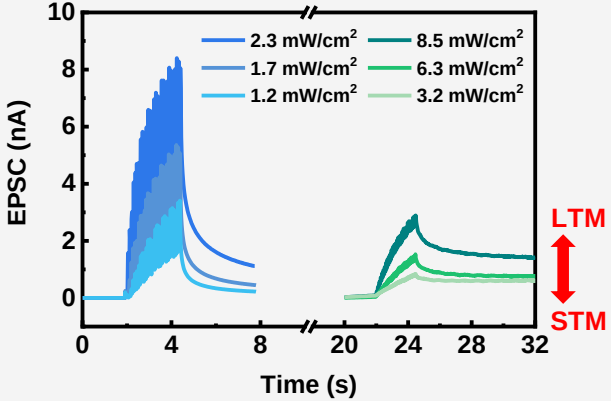
Electrical Characteristic

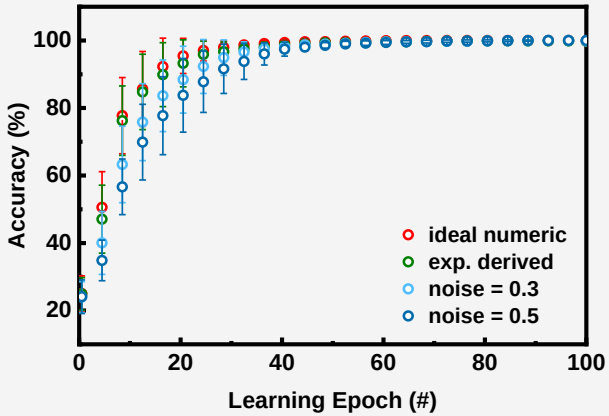






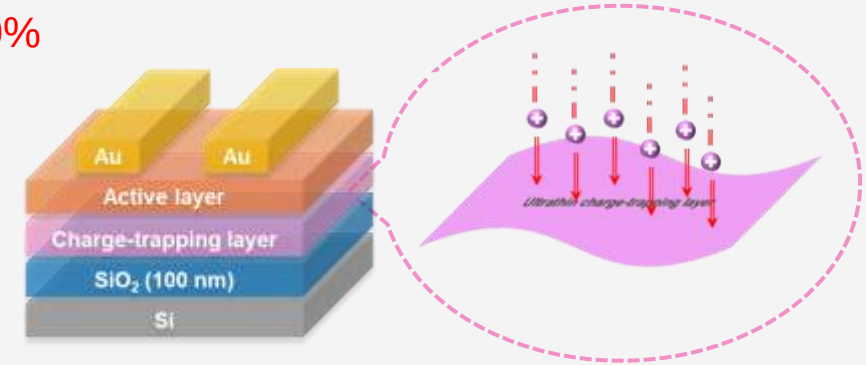






Conclusion

1. IID performs STM to LTM behavior in photosynaptic device
2. High PPF ratio is achieved using 530 nm ⟹ 144%
3. Ultralow energy consumption is attained at low V_d ⟹ 0.029 fJ
4. Recognition accuracy ⟹ ~100%



Thanks for your attention

Optoelectronic Polymer Laboratory