A nanoparticle-organic memory field-effect transistor behaving as a programmable spiking synapse

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NABAB project

SEVENTH FRAMEWORK PROGRAMME

iemn *Recherche Formation Transfert* UMR CNRS 8520

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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Objectives

- feasibility of nano computing block (NAB) based on molecular electronics nanoscale devices, which can acquire a specific computing function by means of a post-fabrication adaptation process (learning, reconfiguration). Neuronal computer.
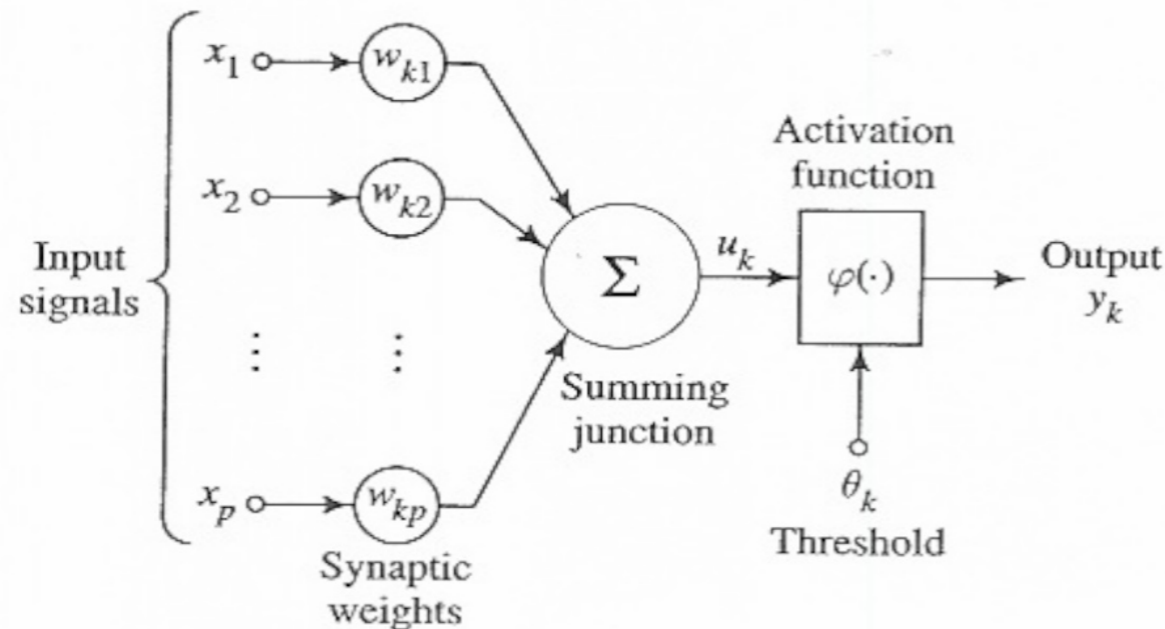
- scalable down to few tens of nanometer
- low cost
- suitable for flexible substrate
- bottom-up approaches and organic

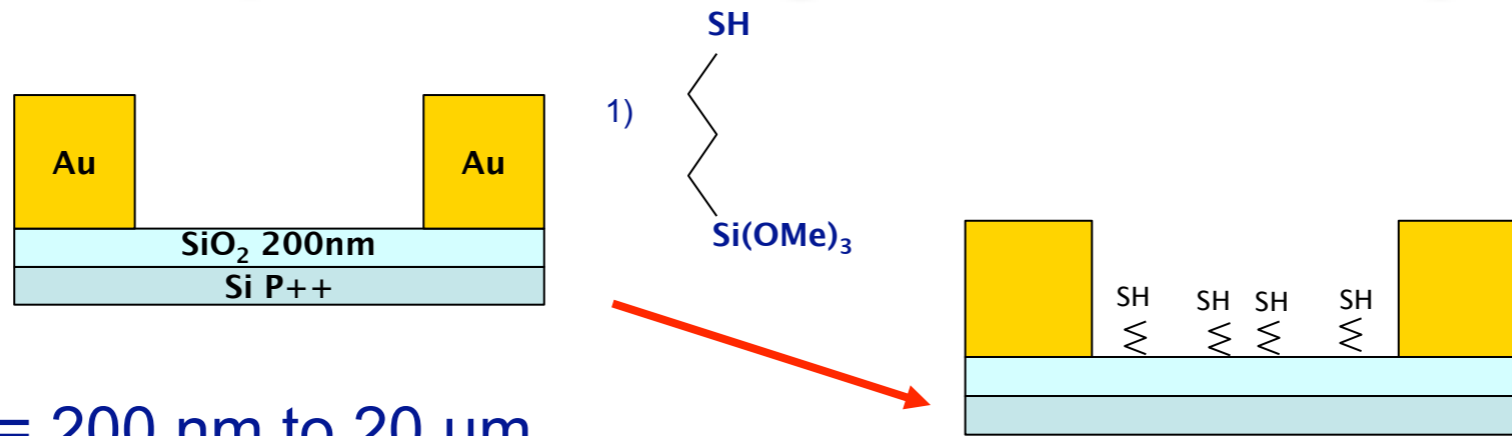|	
• <u>Function</u> : multiplier • <u>Device</u>: transistor with gain	• <u>Function</u> : synaptic weight • <u>Device</u>: data storage, memory

+

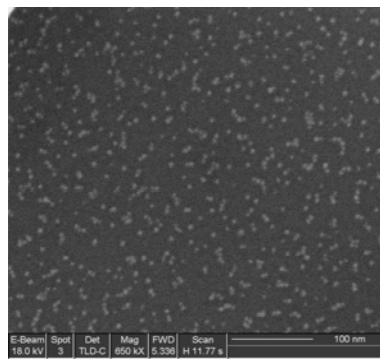**= NOMFET**

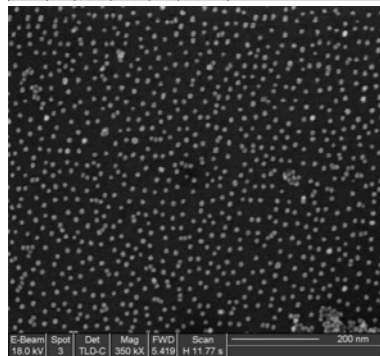**But not a non-volatile memory.**
Need a "leaky" memory ⟷ **synaptic plasticity**

Nanoparticle Organic Memory FET

1)

SH

Si(OMe)$_3$

Au   **Au**

SiO$_2$ 200nm

Si P++

L= 200 nm to 20 µm

SH   SH SH   SH
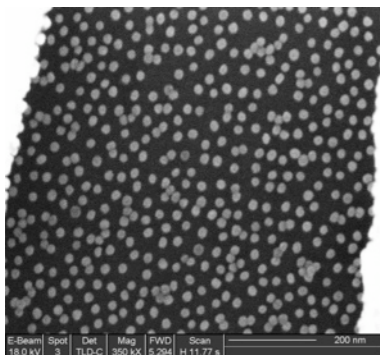
2) Immersion in Au dodecanthiol nanoparticles solution (in toluene)

5 nm
3.7x10^{11} NP/cm^2
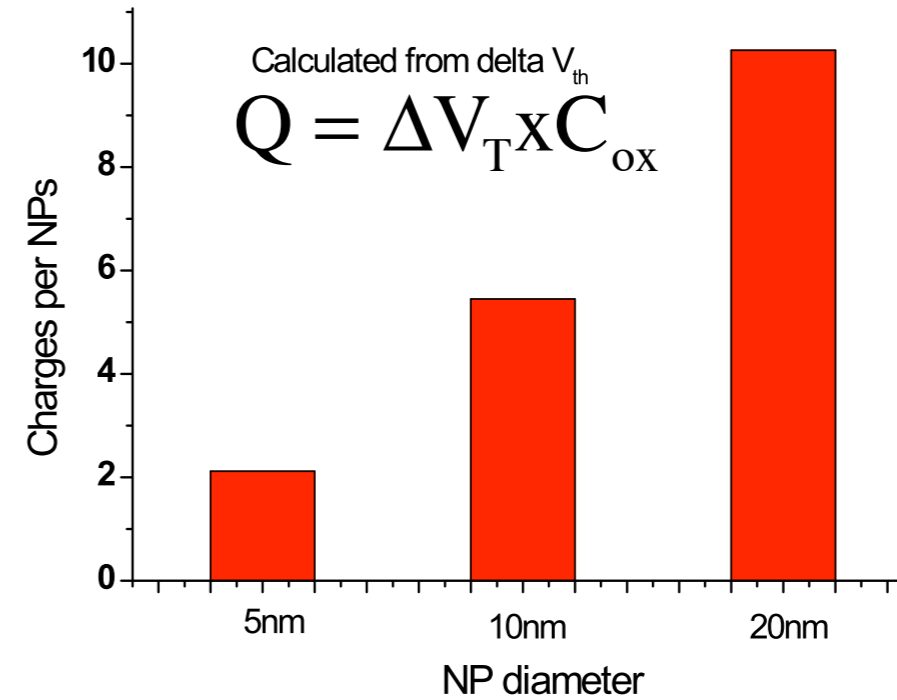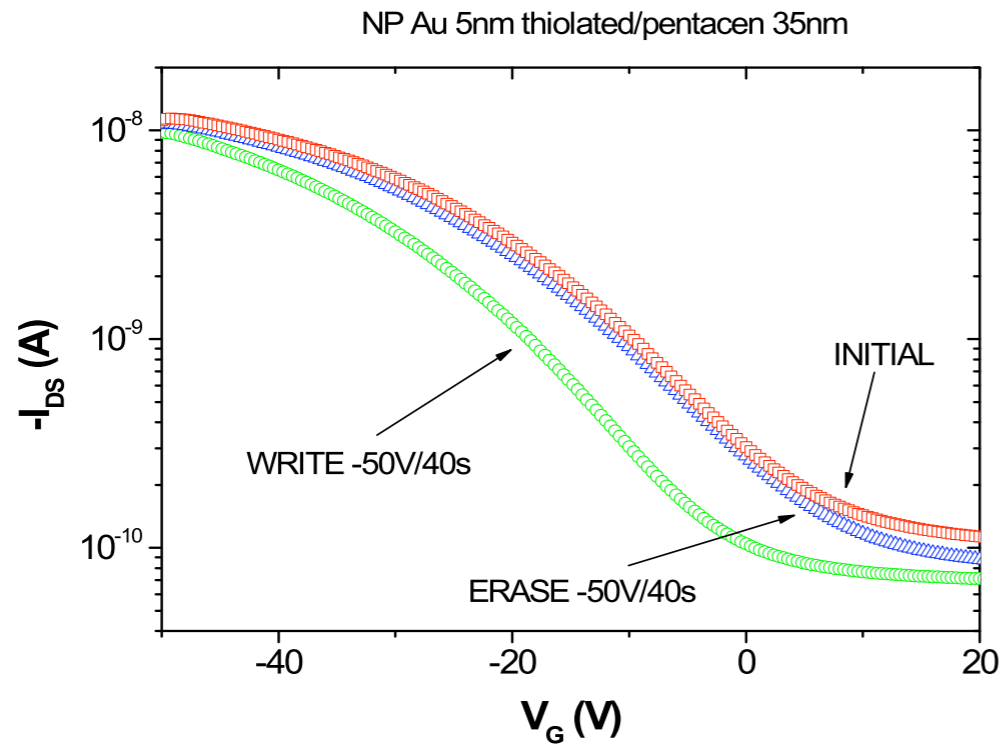
10 nm
1.8x10^{11} NP/cm^2

20 nm
9x10^{10} NP/cm^2
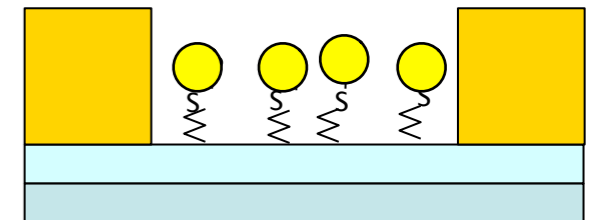
3) Pentacene evaporation 35 nm @ 0.1Å/s
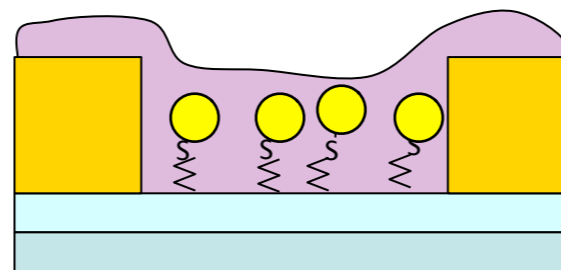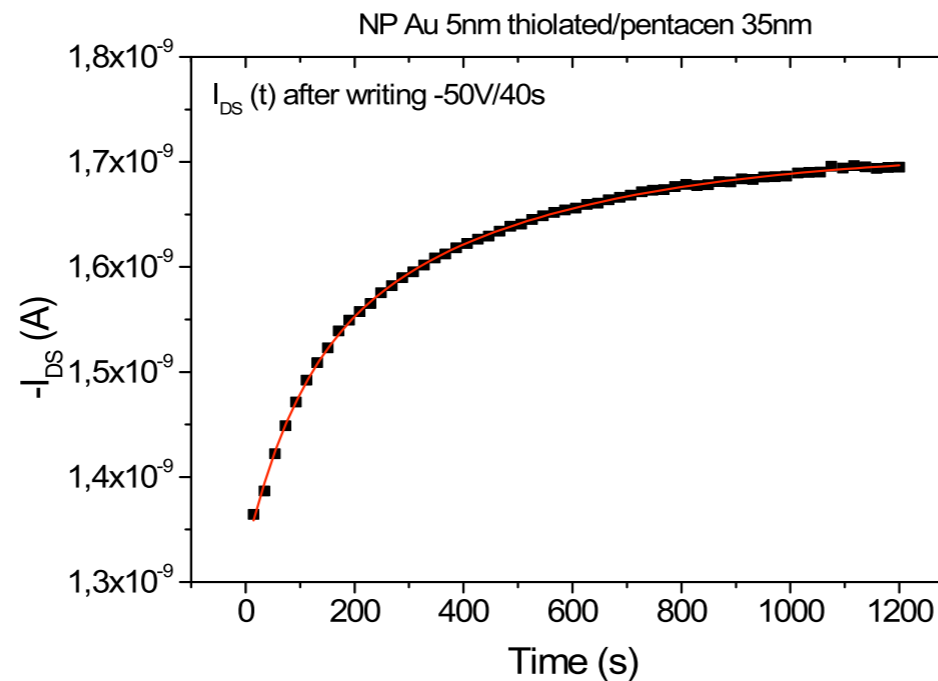
F. Alibart et al., *Adv. Func. Mater.*, in press

Memory behavior

C. Novembre et al., *Appl. Phys. Let.*, 92, 103314 (2008)

NP Au 5nm thiolated/pentacen 35nm

$$Q = \Delta V_T x C_{ox}$$

Calculated from delta V_{th}

Charges per NPs — NP diameter

Positive charge of the NPs = Negative voltage shift

NP Au 5nm thiolated/pentacen 35nm
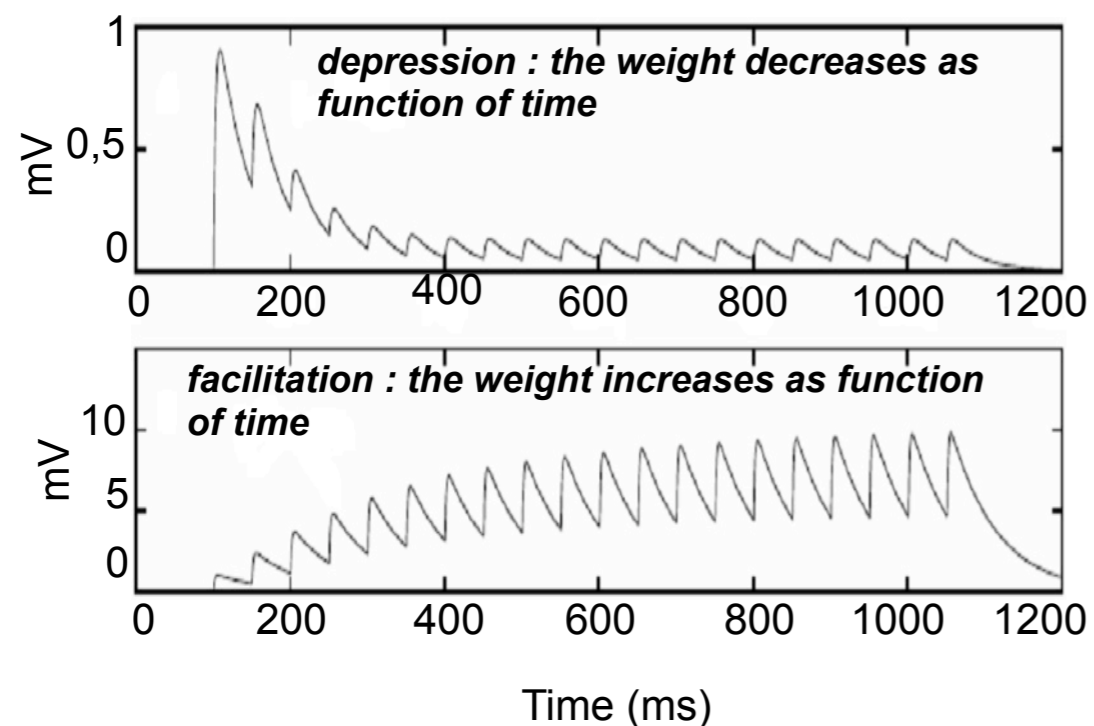
I_{DS} (t) after writing -50V/40s

τ = 95 and 430 s

Biological spiking synapse : dynamic behavior
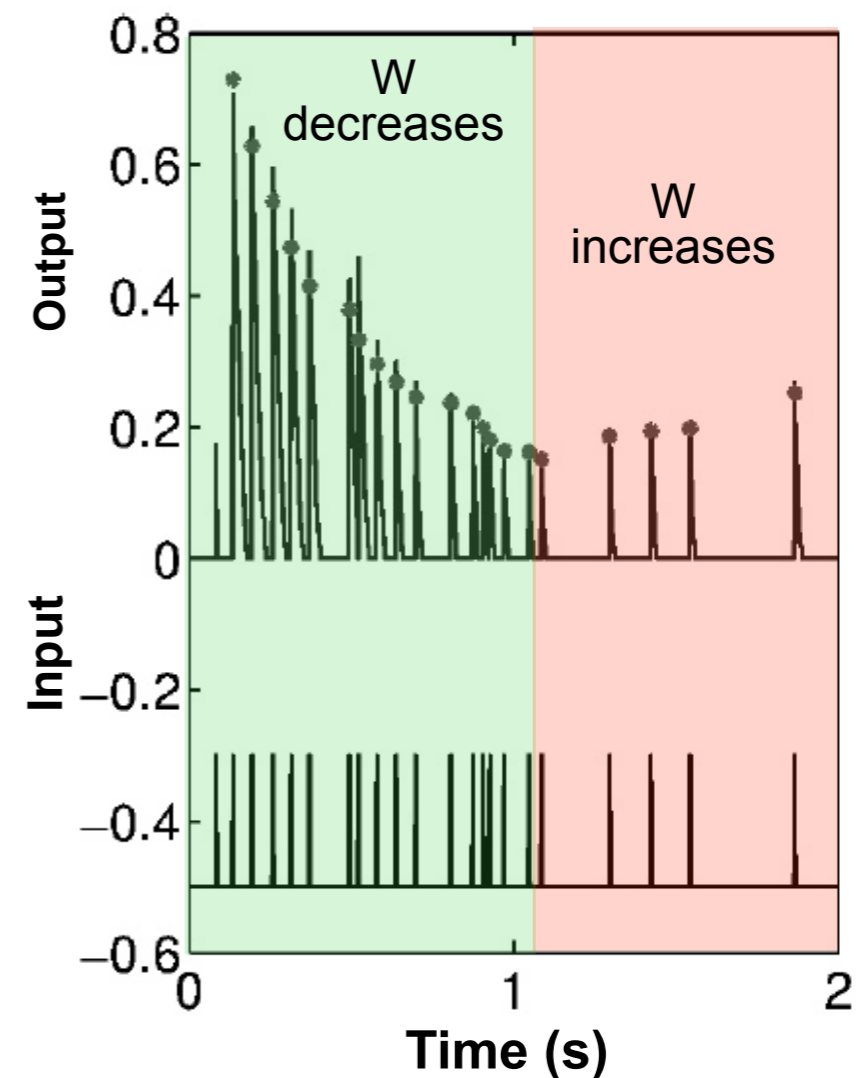
- **Facilitating or depressing synapse**

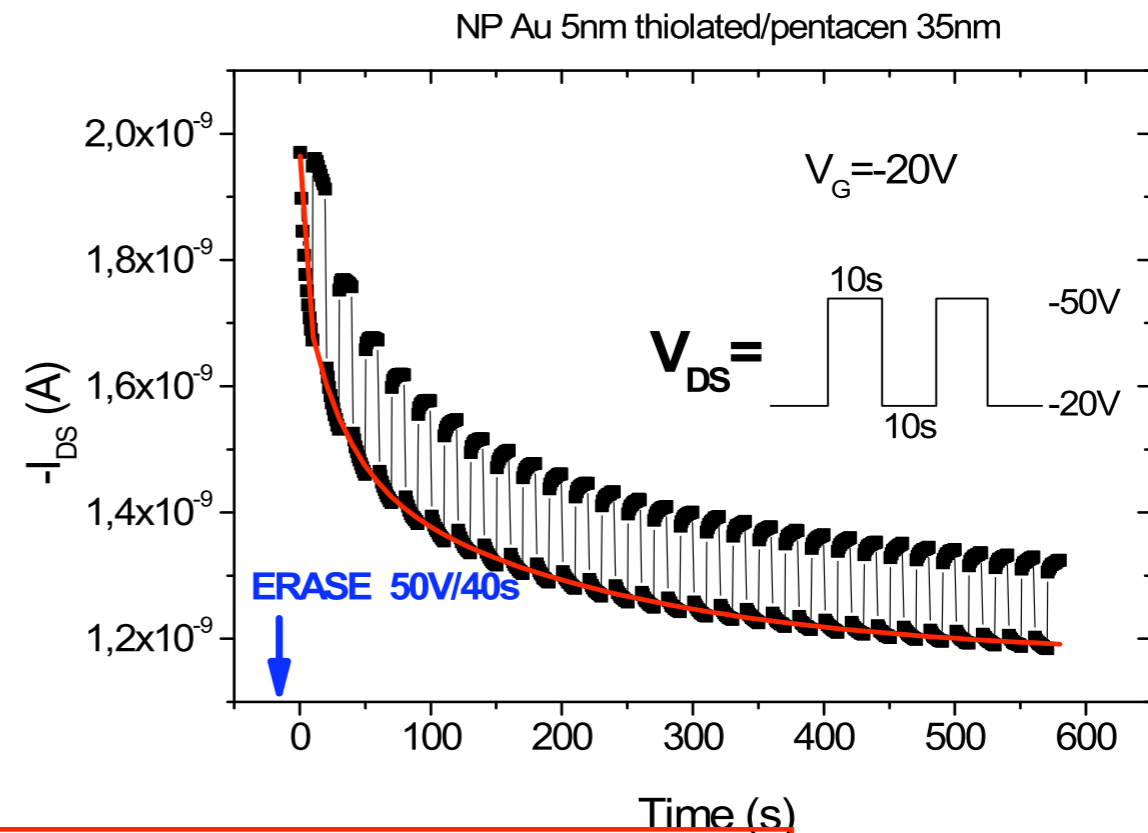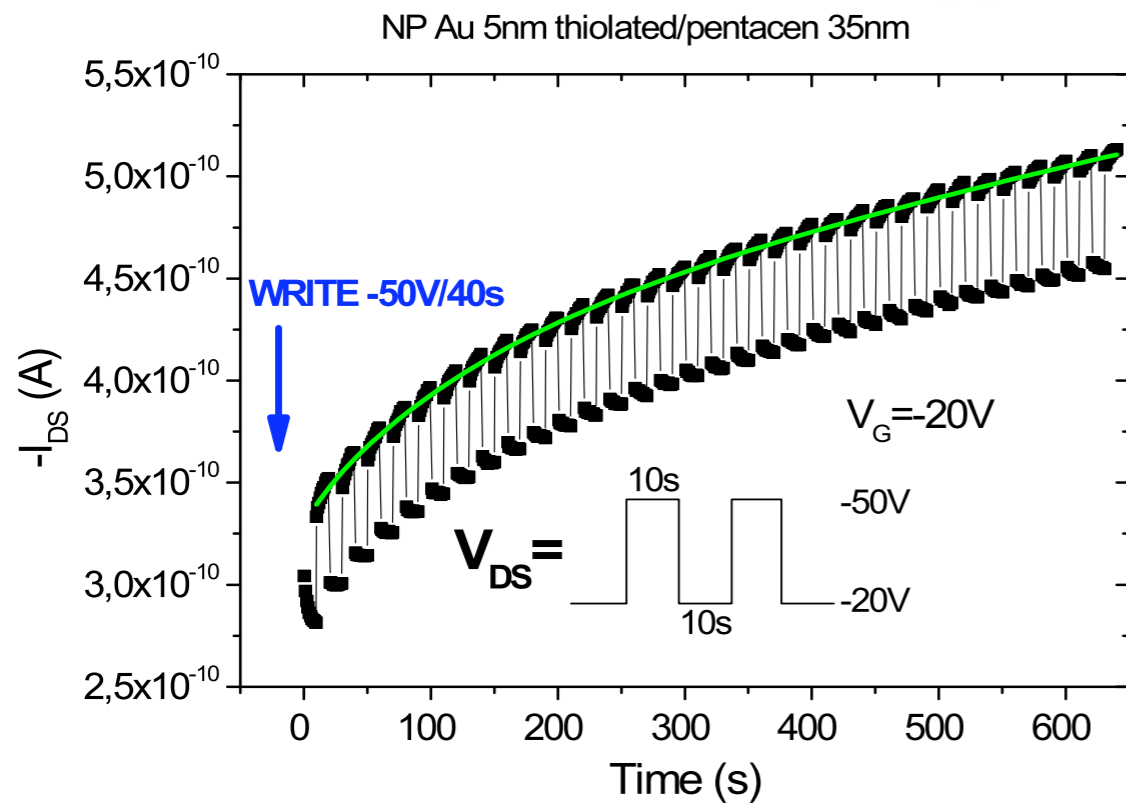 For a given frequency f, two post-synaptic responses are possible depending on the type of synapse.

depression : the weight decreases as function of time

facilitation : the weight increases as function of time

Time (ms)

- **Short-term plasticity**

  The post-synaptic signal depends on the frequency of the input signal

W decreases

W increases

Time (s)

Tsodyks (1998)

Boegerhausen (2003)

Programmable NOMFET synapse

NP Au 5nm thiolated/pentacen 35nm

NP Au 5nm thiolated/pentacen 35nm

WRITE -50V/40s

V_G=-20V

V_{DS}= 10s -50V 10s -20V
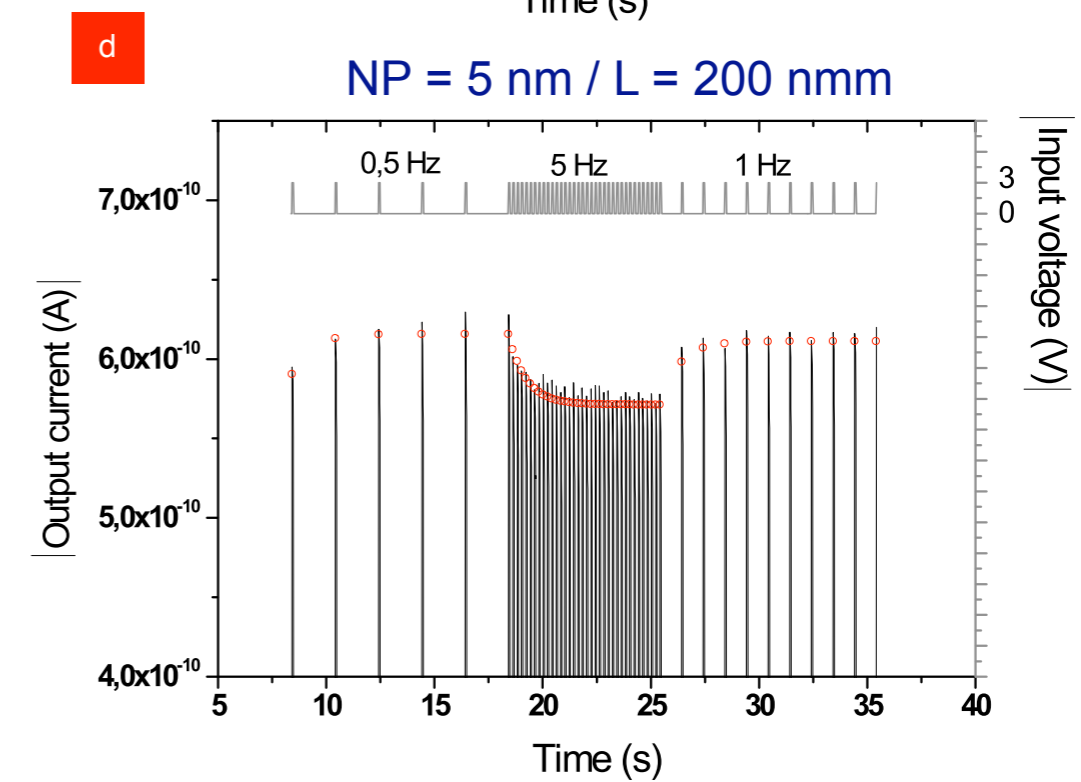
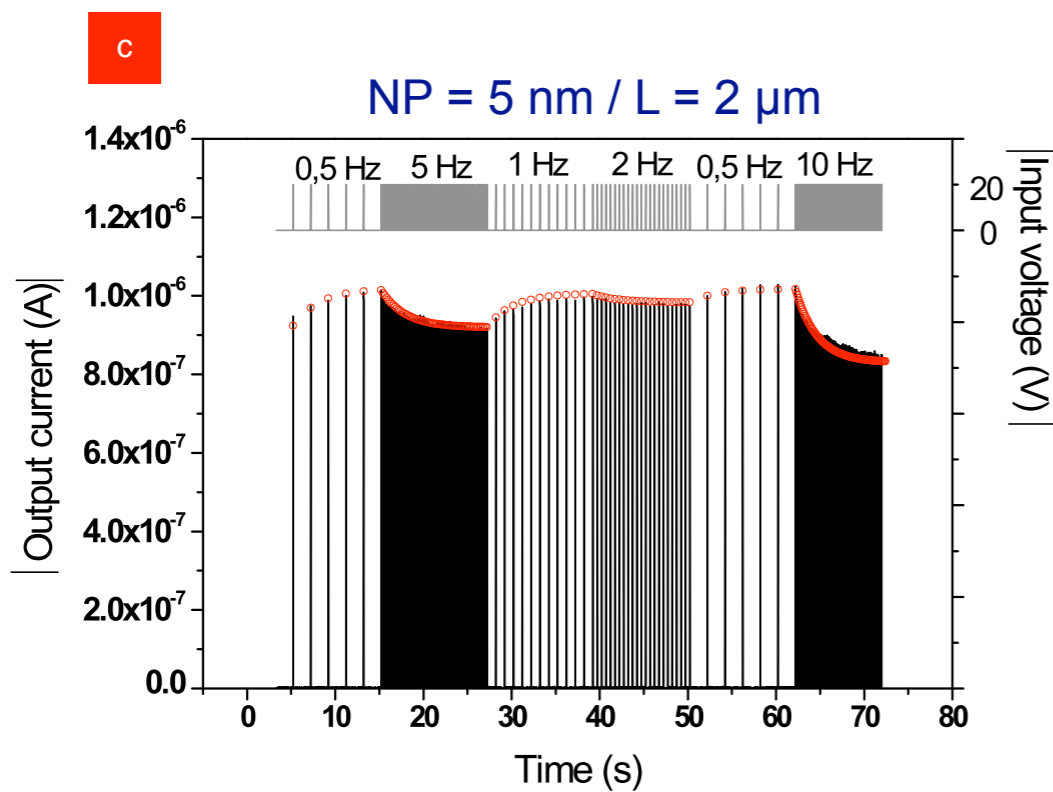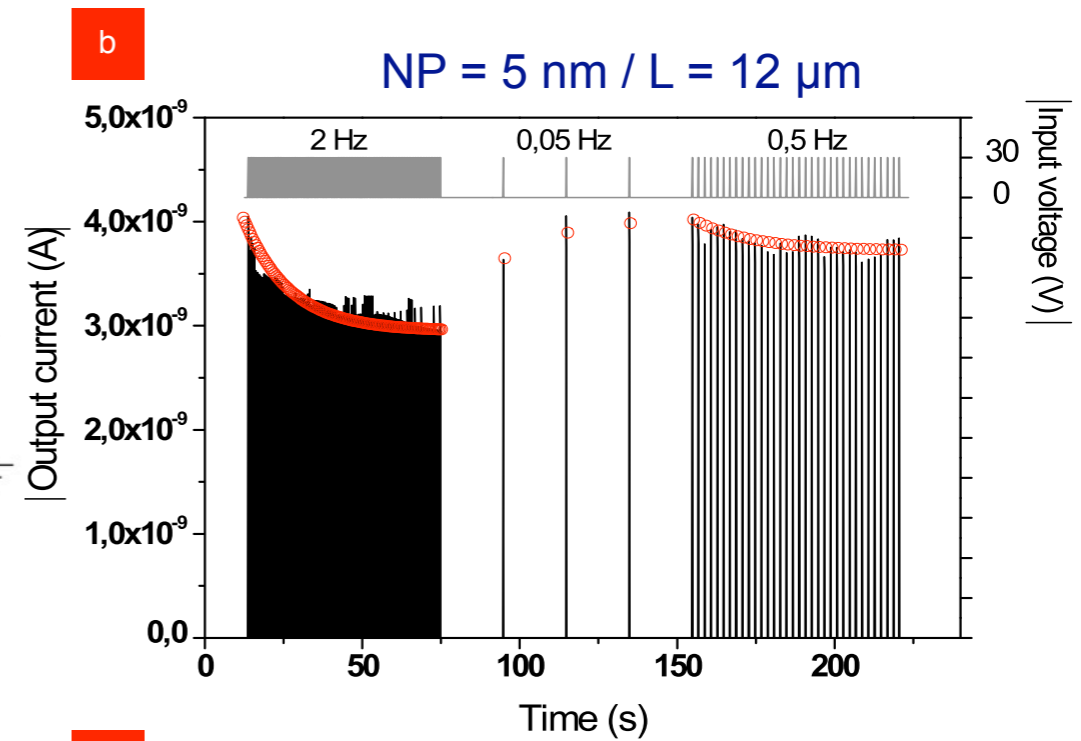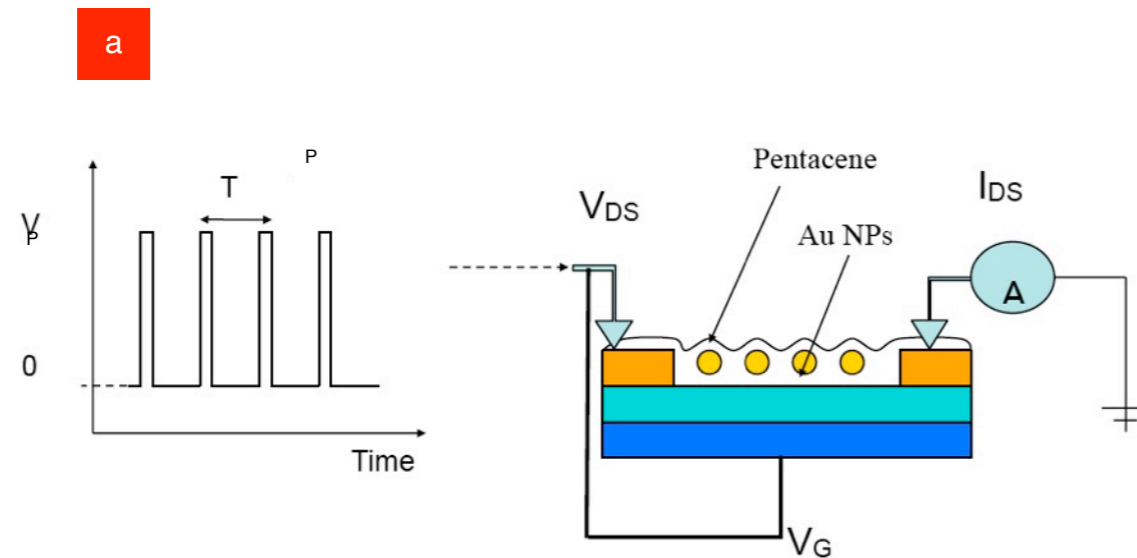V_G=-20V

V_{DS}= 10s -50V 10s -20V

ERASE 50V/40s
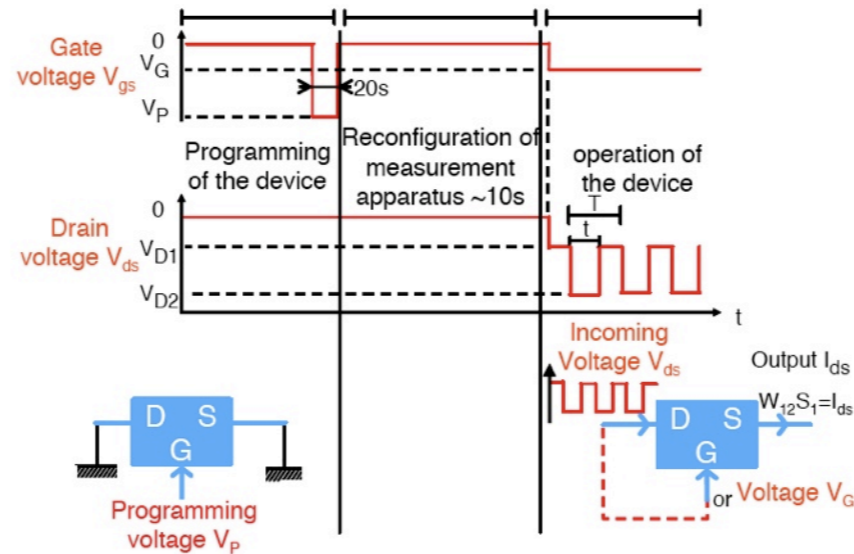
PROGRAMMATION
•Write pulse = facilitating behaviour (due to discharge of NPs)
•Erase pulse = depressing behaviour (due to charge of NPs)
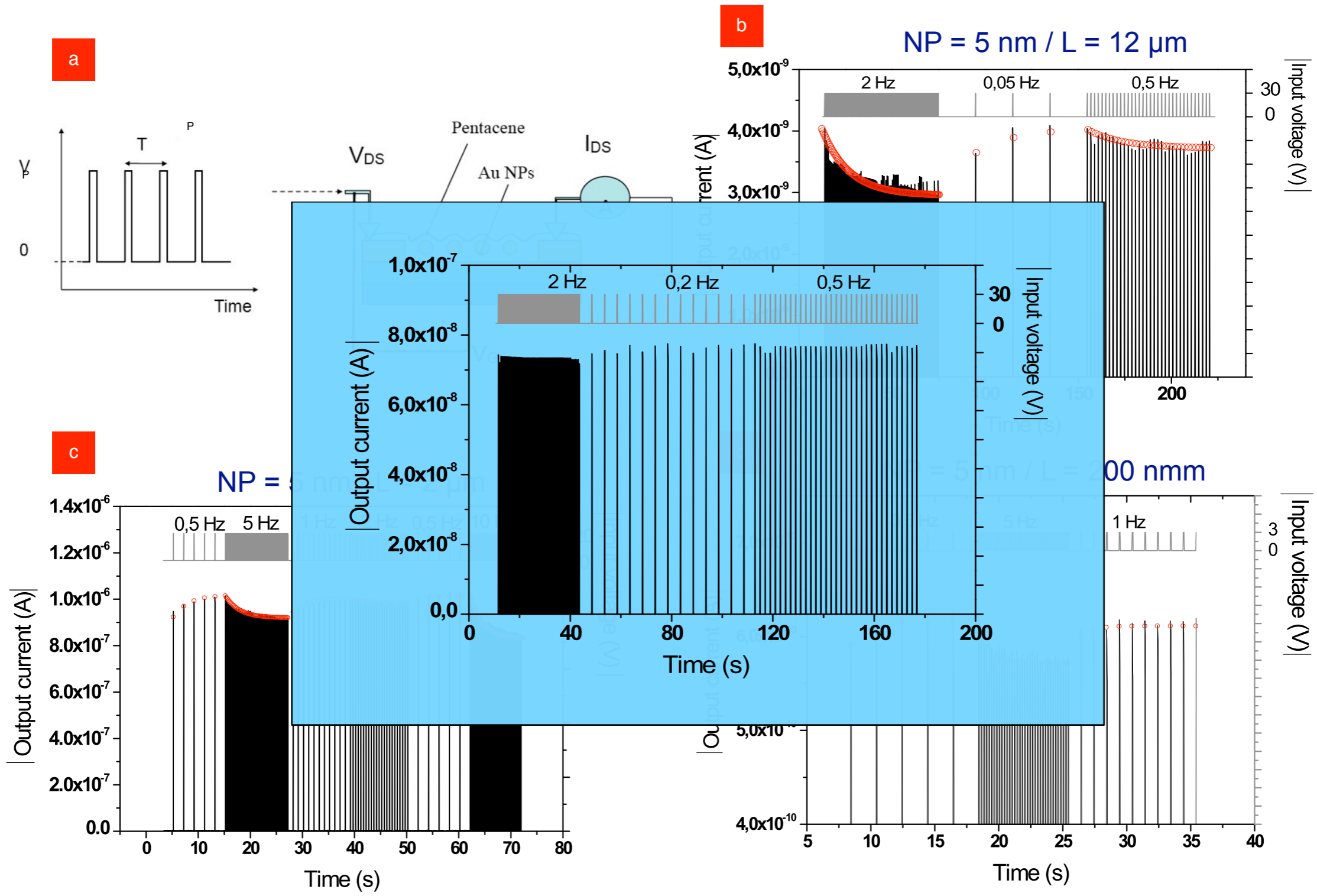
F. Alibart et al., *Adv. Func. Mater.*, in press

short term plasticity

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short term plasticity

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NPs size decreases

5 nm
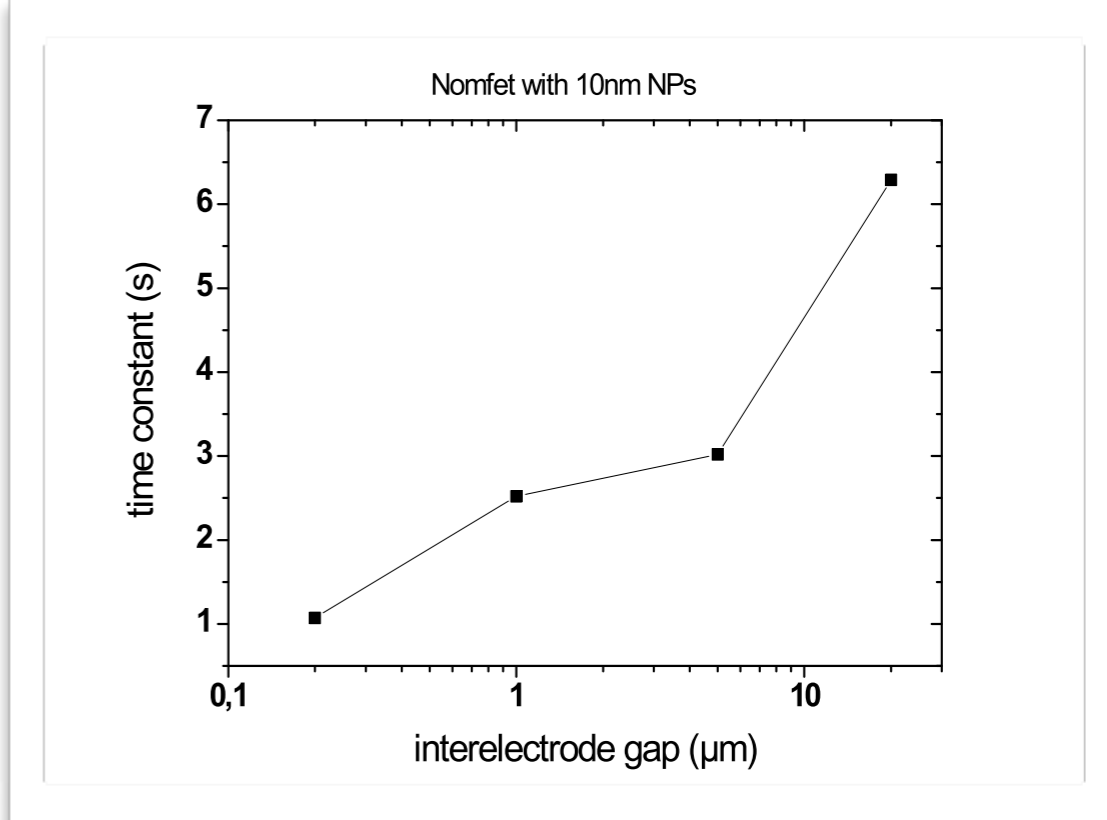

5µm gap NOMFET with NPs=5nm/ pulses V=-30V and W=50ms
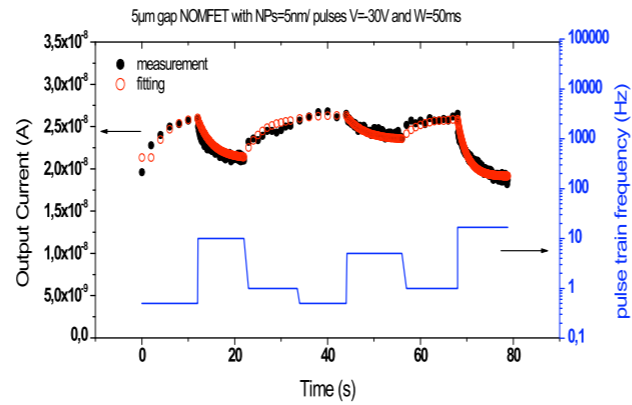
Interelectrode
gaps decreases

200 nm

20 µm

20 µm gap NOMFET with NPs=10nm/ pulses V=-30V and W=50ms

5µm gap NOMFET with NPs=10nm/ pulses V=-30V and W=50ms

200 nm gap NOMFET with NPs=10nm/ pulses V=-3V and W=50ms

5µm gap NOMFET with NPs=20nm/ pulses V=-30V and W=50ms

Nomfet with 10nm NPs

20 nm

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biological synapse - NOMFET analogy

N_n neurotransmiter (NT) activated at spike n

Recovery of NT with a time τ_d

$I_n = f(N_n)$

biological synapse - NOMFET analogy

N_n neurotransmiter (NT) activated at spike n

Recovery of NT with a time τ_d

$I_n = f(N_n)$

charge of N_n holes in the NP at spike n

Pentacene thin film

$I_n = f(N_n)$

Discharge of the holes with a time τ_d

Gold nanoparticles

Conclusions

- the NOMFET behaves as a biological spiking synapse
  - it is programmable
  - STP is working

- it can be srinked down to 200 nm channel length and 5 nm NPs. (work in progress for L< 200 nm)
  - possibility of high-integration

- we also developed a theoretical model suitable for device and circuit simulation.
  - see poster : O. Bichler et al, session B

- Integration of several NOMFET in simple neuronal circuits (perceptron, Hopfield network,...) is in progress.