6/19/2018

Hot carrier engineering with titanium nitride nanostructures

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Marco Polo

"Zipangu (Japan) as a golden country"

(The Travels of Marco Polo, 13th century)

Kyoto, Japan

Gold nanostructures

gold (Au)

nanoscale

Au nanoparticle

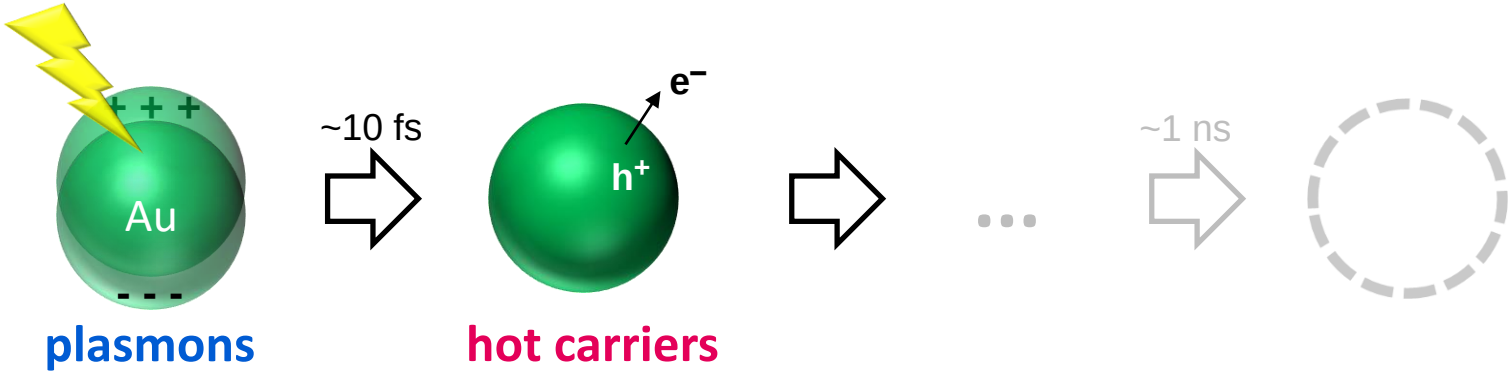
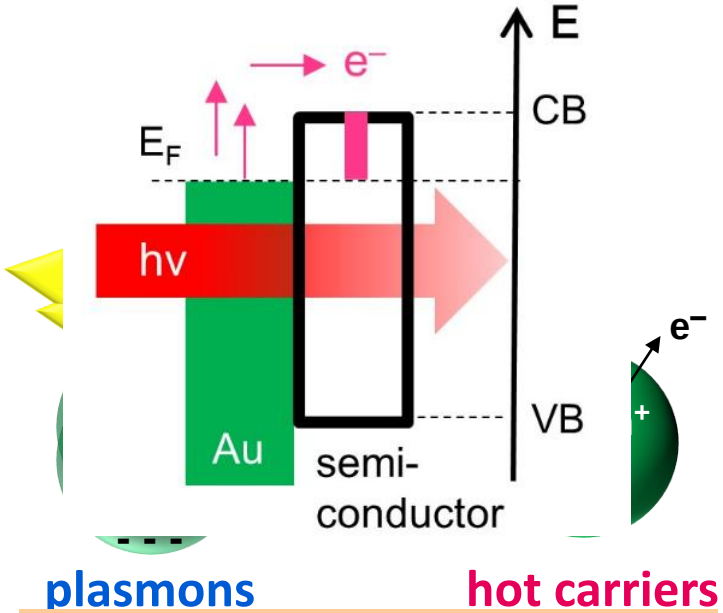


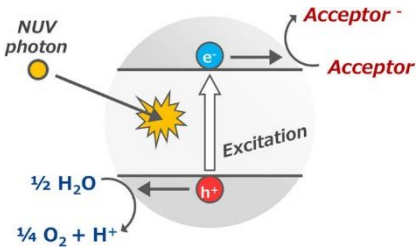
Photo-carrier excition

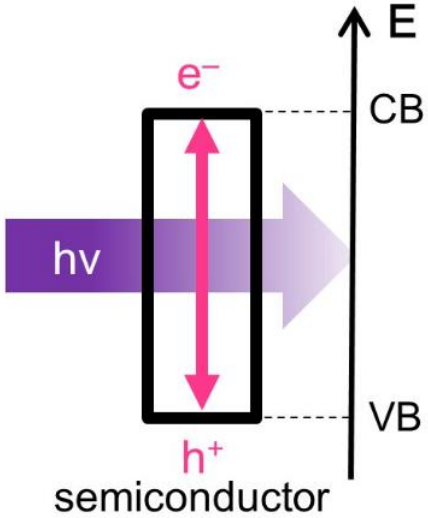


Sub-bandgap photo-excitation

Narita, et al, Sci. Rep. (2015);
© SHARP

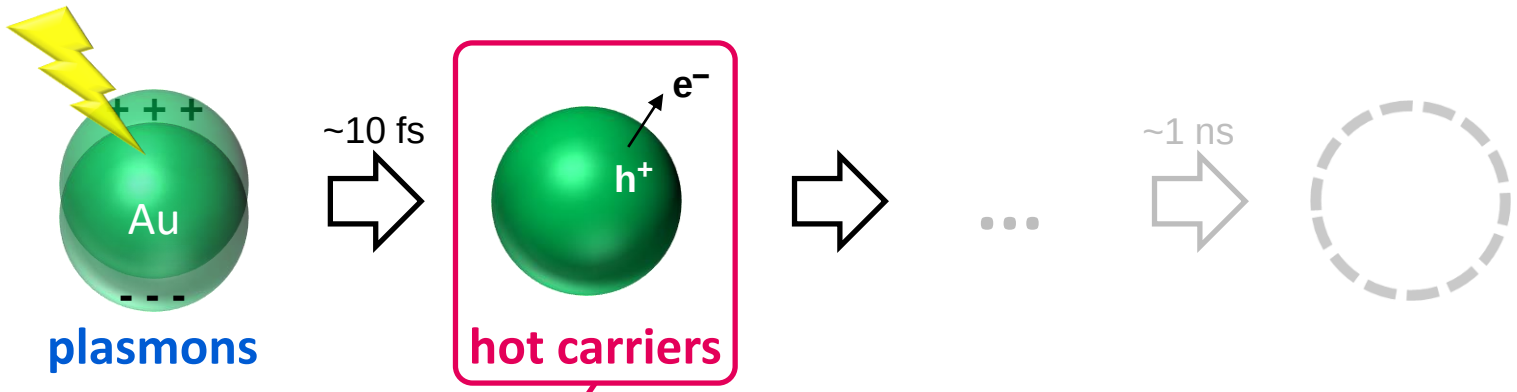
Semiconductors

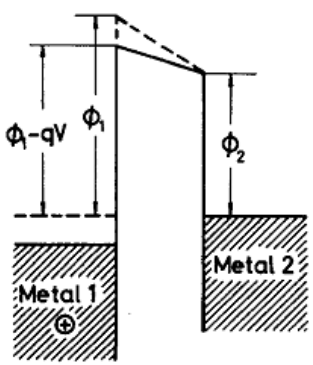




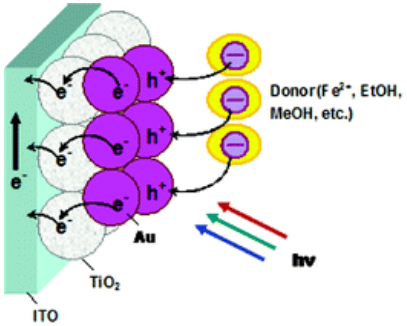
Bandgap limited photo-excitation

Hot carrier engineering

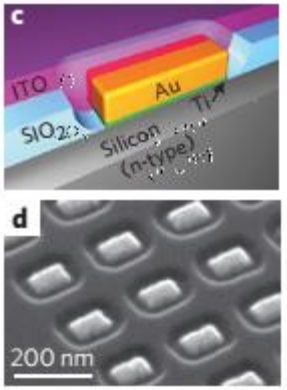




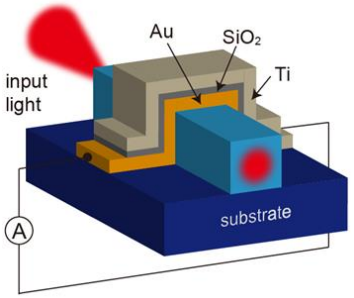
Visible photocurrent
K.H. Gundlach, et al, JAP (1975)



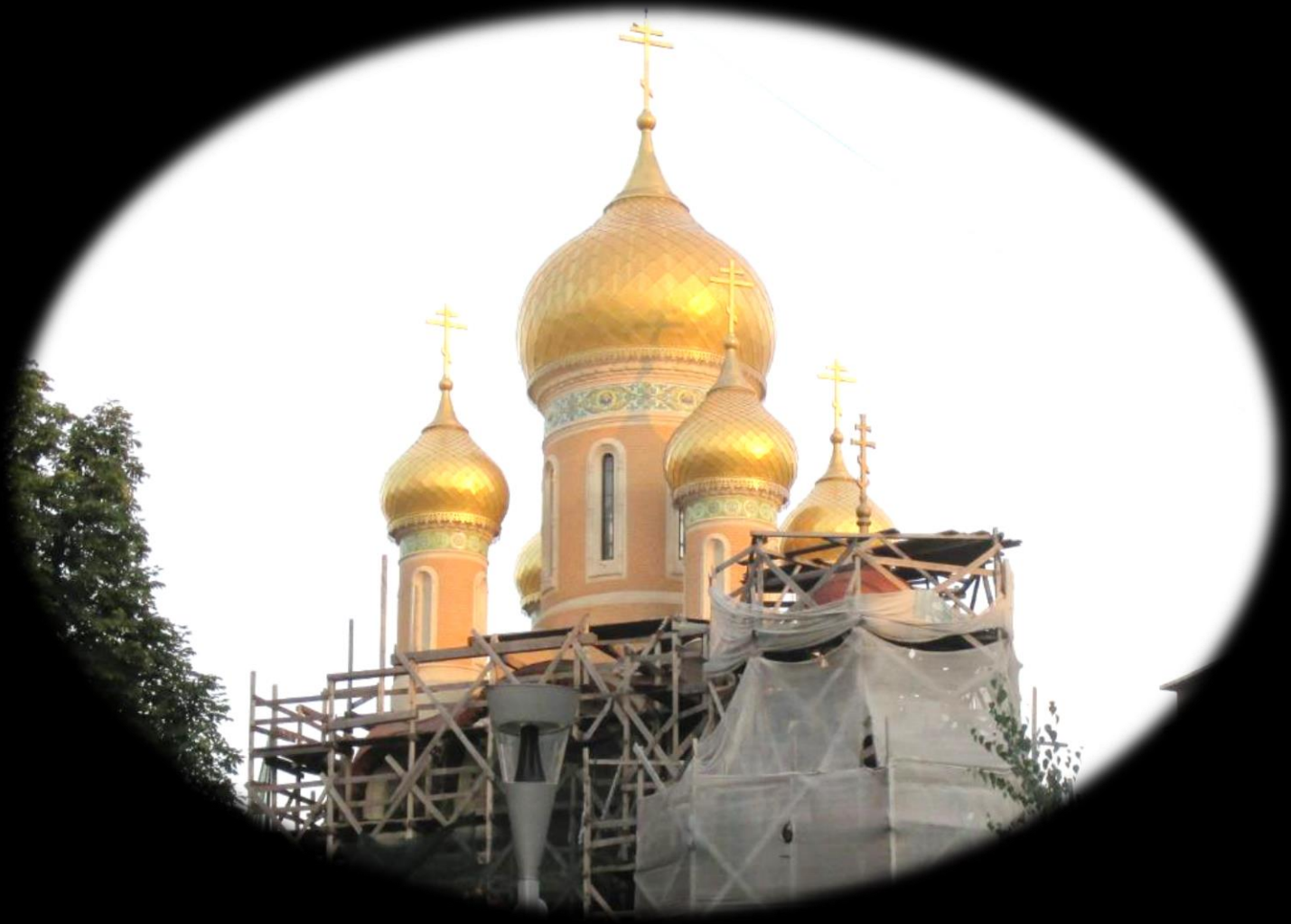
Visible photocatalysis
Tian & Tatsuma, Chem. Comun. (2004); Tian & Tatsuma, JACS (2005)



NIR Si detector
M.W. Knight et al, Science (2011)



Waveguide photodetector
S. Ishii, et al, ACS Photonics (2014)



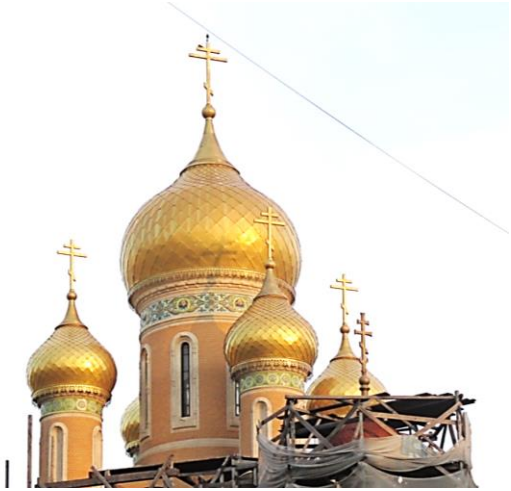
Bucharest, Romania

Titanium nitride (TiN)

gold (Au)

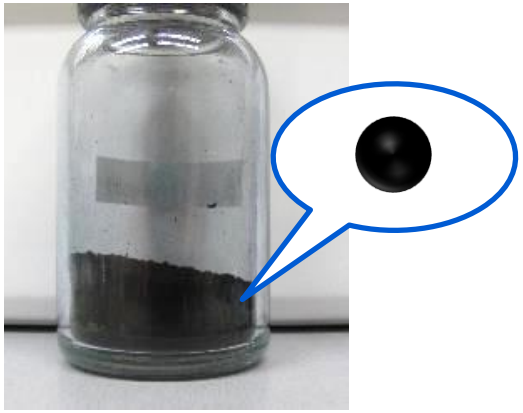
nanoscale →

Au nanoparticles



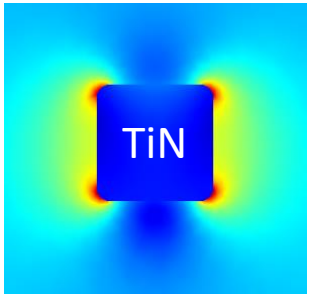
titanium nitride (TiN)

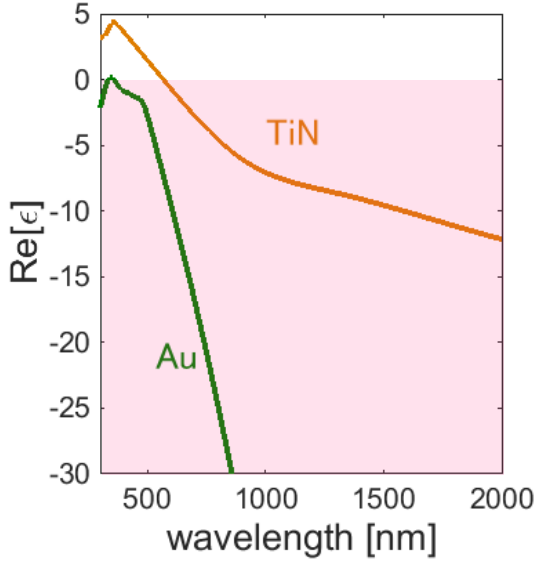
nanoscale →

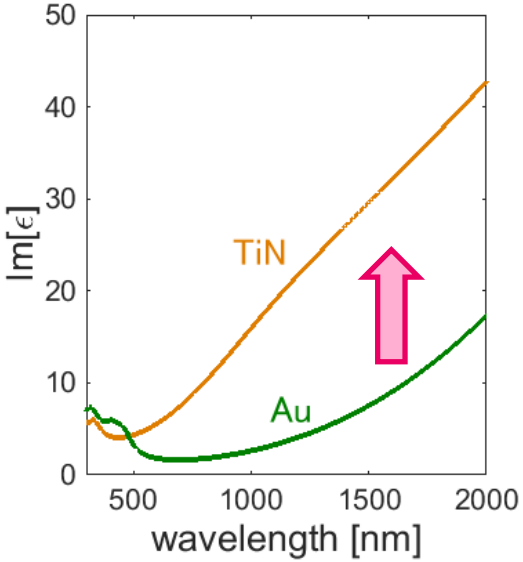


TiN nanoparticles

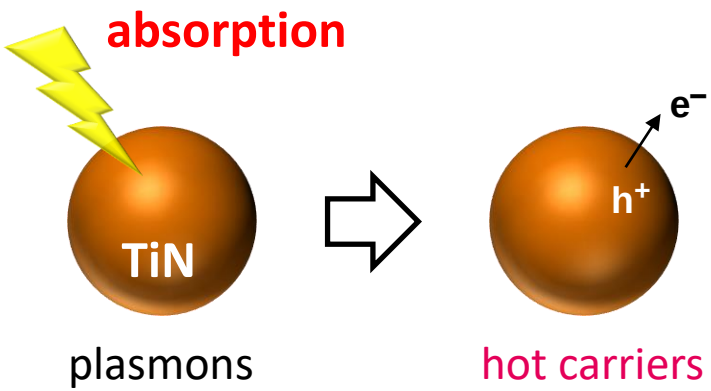
Dielectric function of TiN



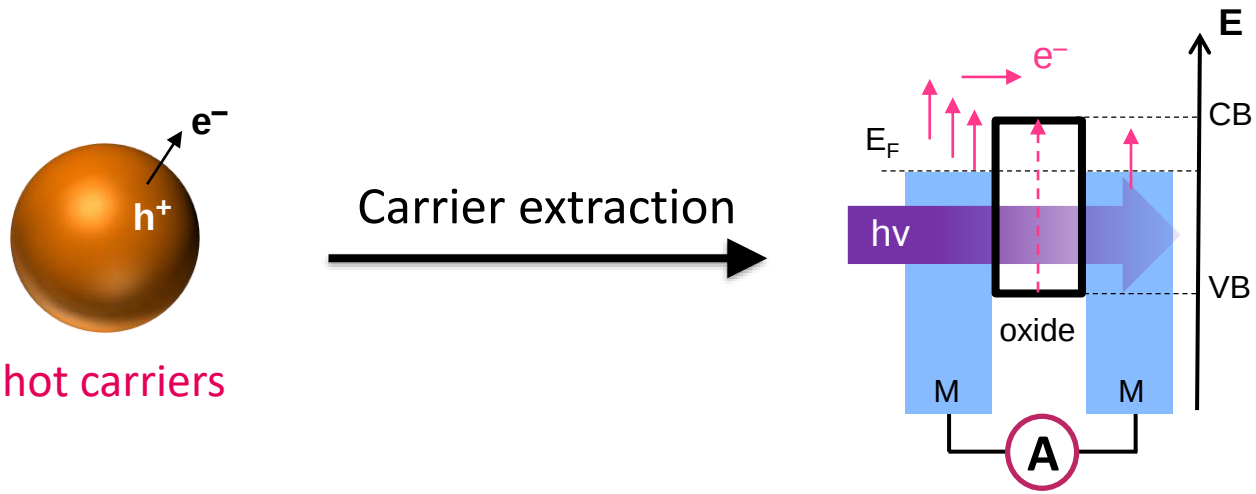


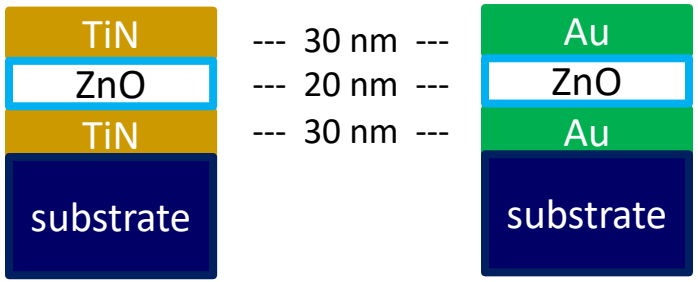


- Re[ε] < 0
  ⇒ Plasmonic
- Large Im[ε]
  ⇒ Strong absorption

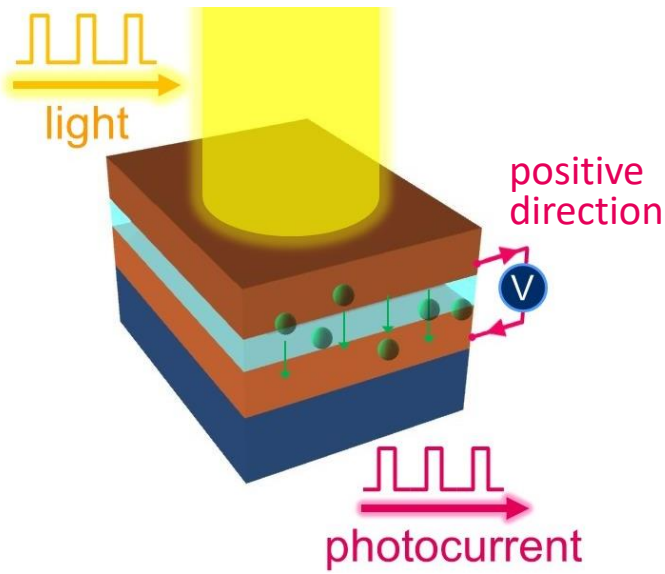


Hot carrier excitation from nitride/metal





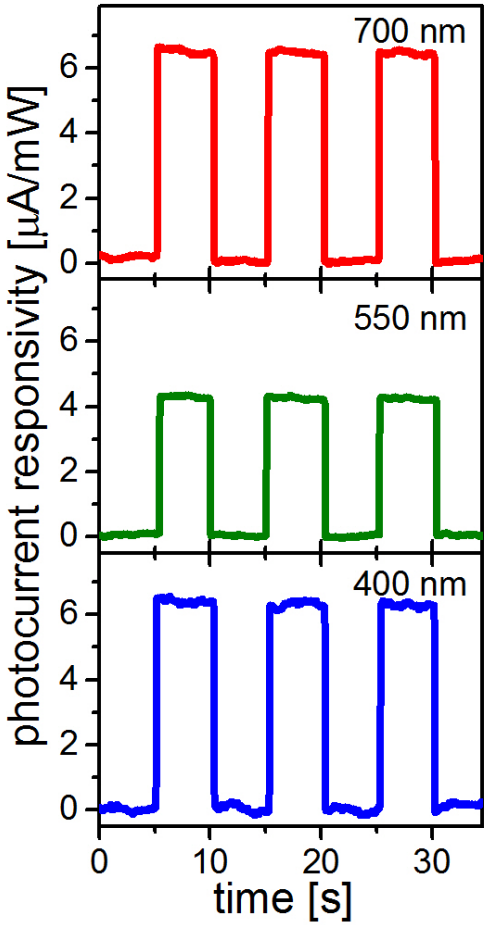
TiN/ZnO/TiN Au/ZnO/Au

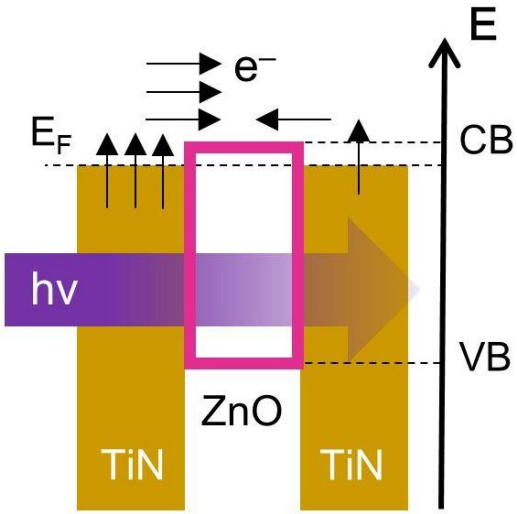


1. Thin film deposition by sputtering
2. Photocurrent measurement with a wavelength tunable light source (no bias voltage)

Photocurrent from TiN

TiN: 30 nm
ZnO: 20 nm





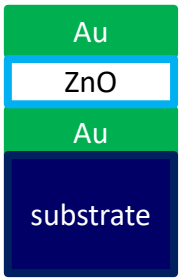
- Bandgap of ZnO : 3.2 eV (388 nm)
- Hot electron excitation from TiN

Visible photocurrent w/ TiN

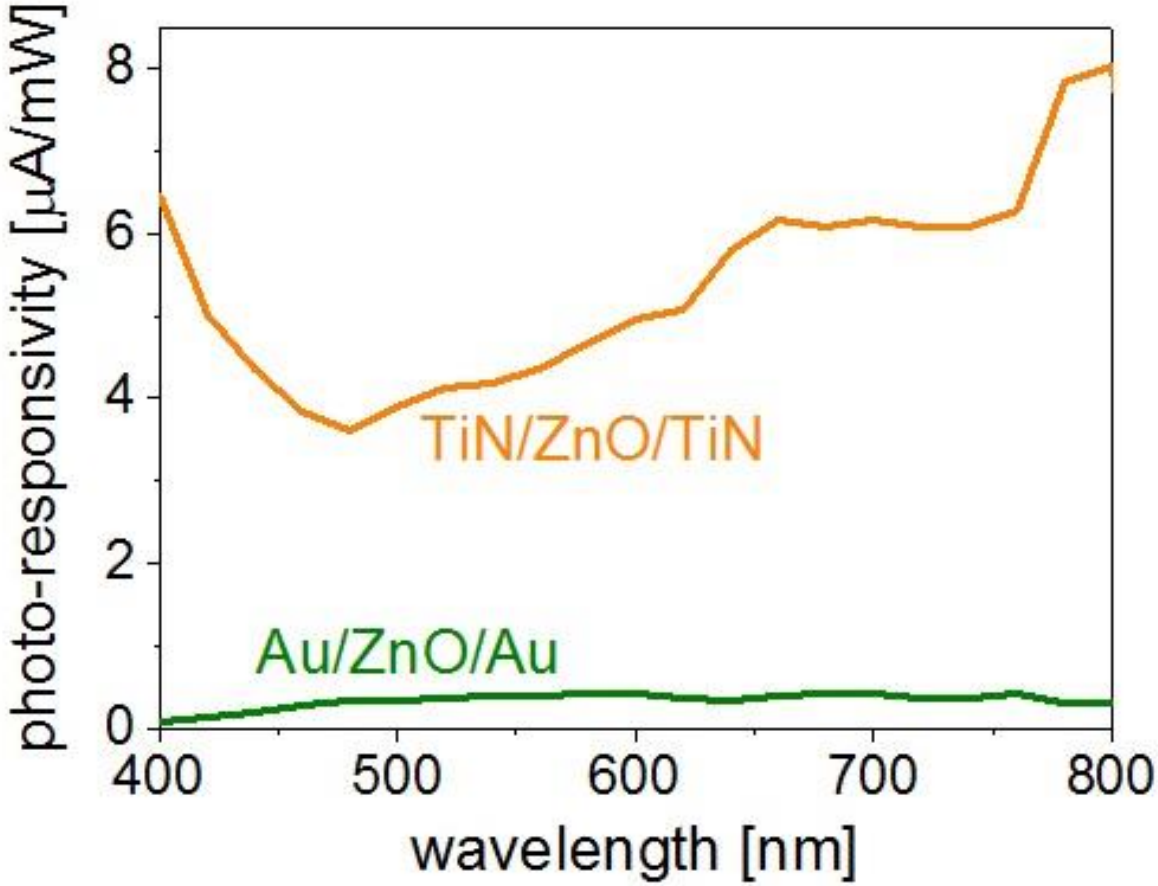
S. Ishii, et al, ACS Photonics, 3, 1552 (2016)

Comparison of TiN & gold

TiN/ZnO/TiN



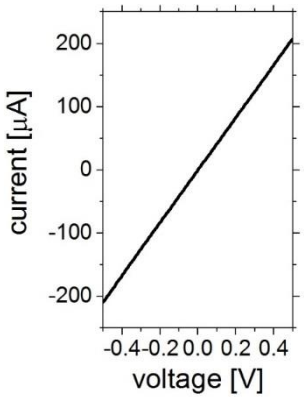
Au/ZnO/Au

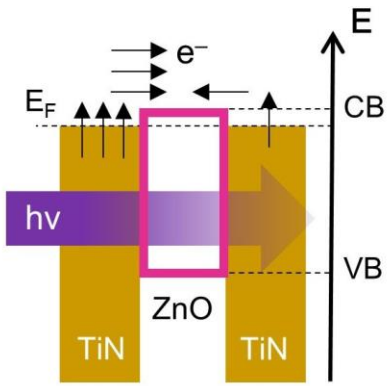


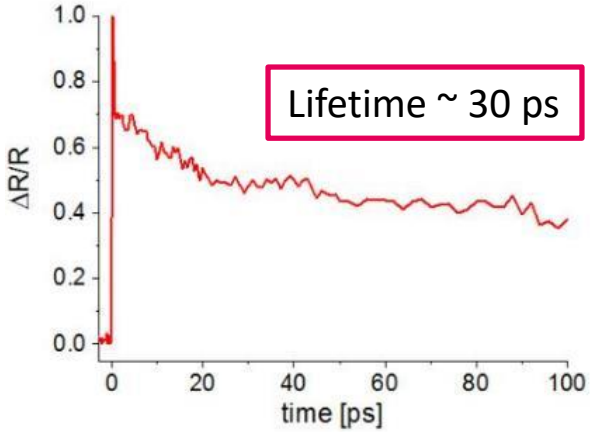
TiN can generate larger photocurrent than gold (Au)

Electric properties

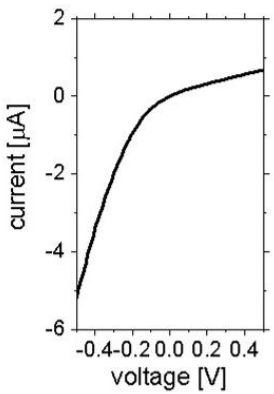
TiN

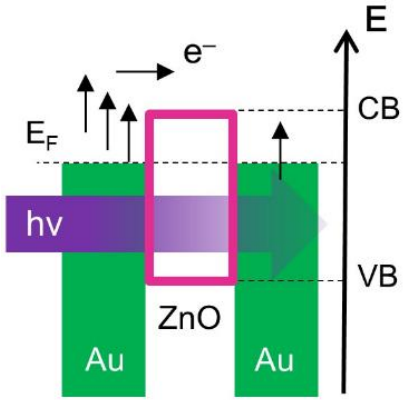


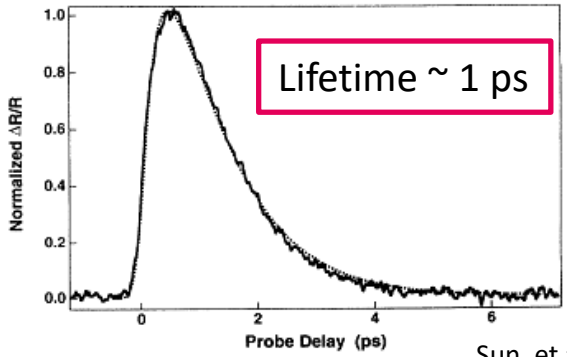




Au







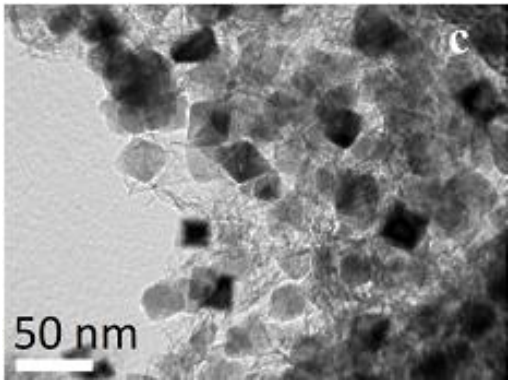
Sun, et al, PRB (1994)

Y. Wada

- Smaller energy barrier for TiN
- Longer life time for TiN

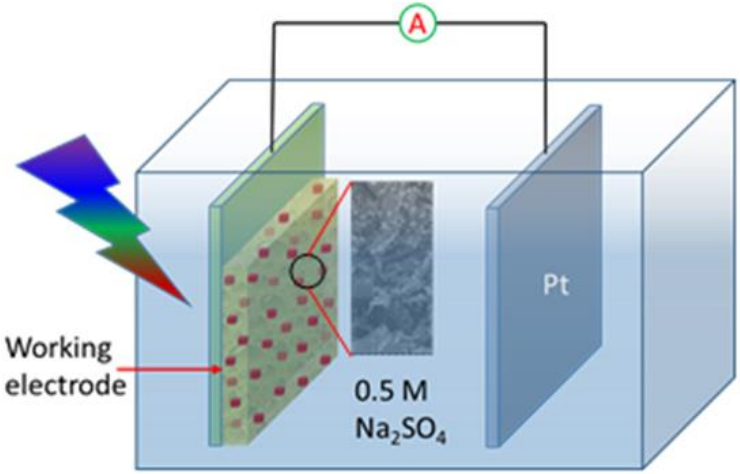
TiN for visible photocatalytic activity

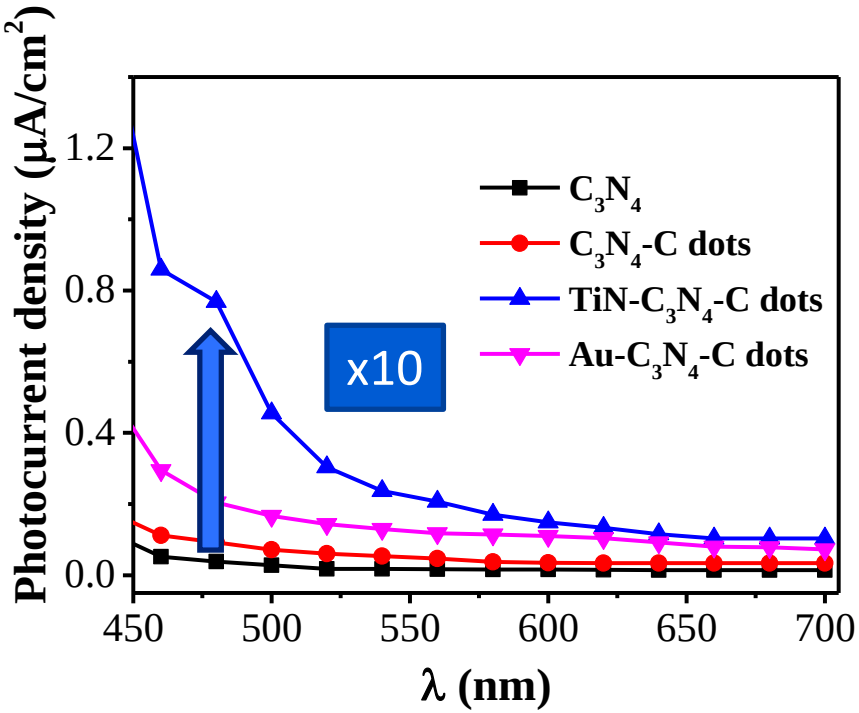
- Photocatalyst : C_3N_4
  - Metal-free, abundant
  - Bandgap: ~2.7 eV
- Mixing TiN NPs to C_3N_4 for visible activity



TiN NPs embedded C_3N_4-C dots

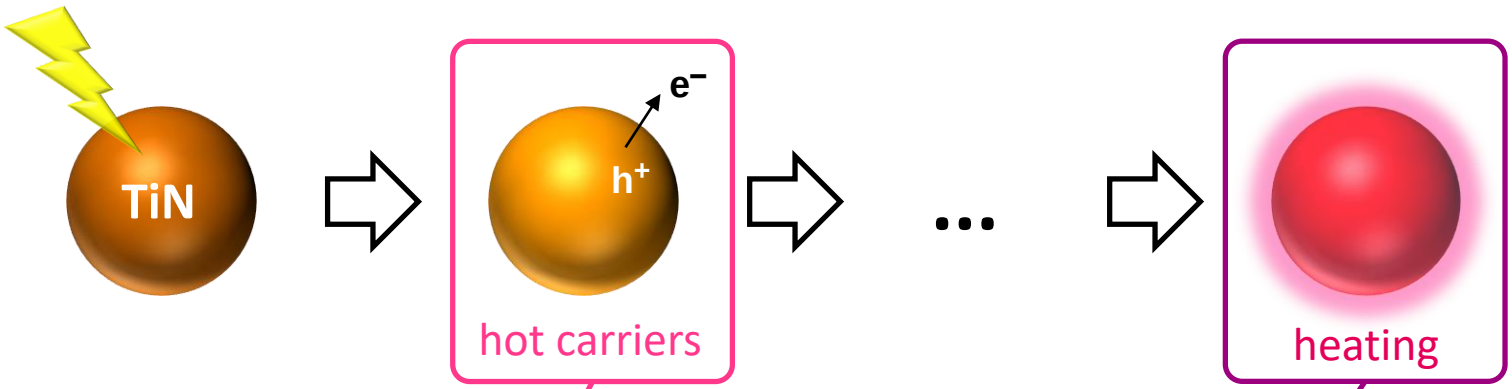
S. Shinde

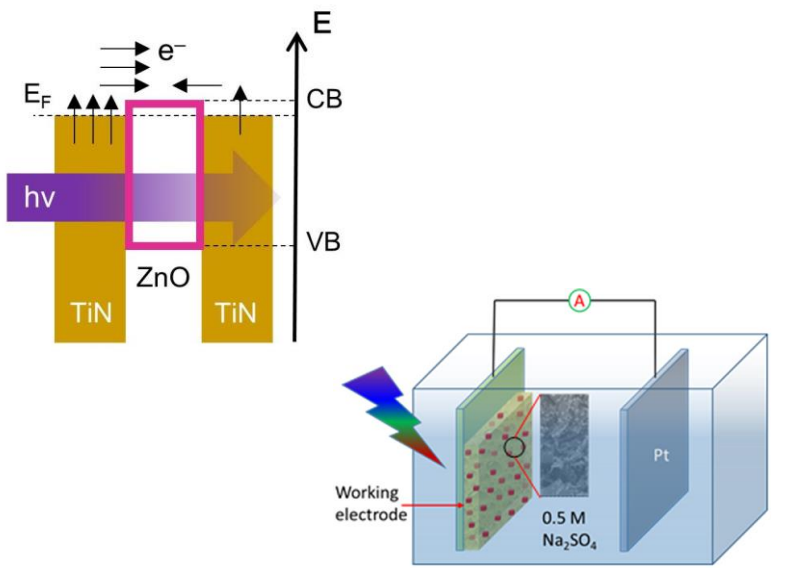




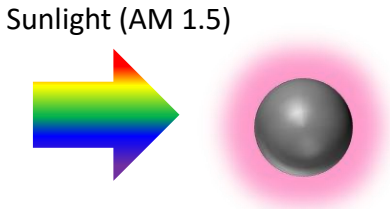
Shinde, SI, et al, ACS Appl. Mater. Interfaces (2018)

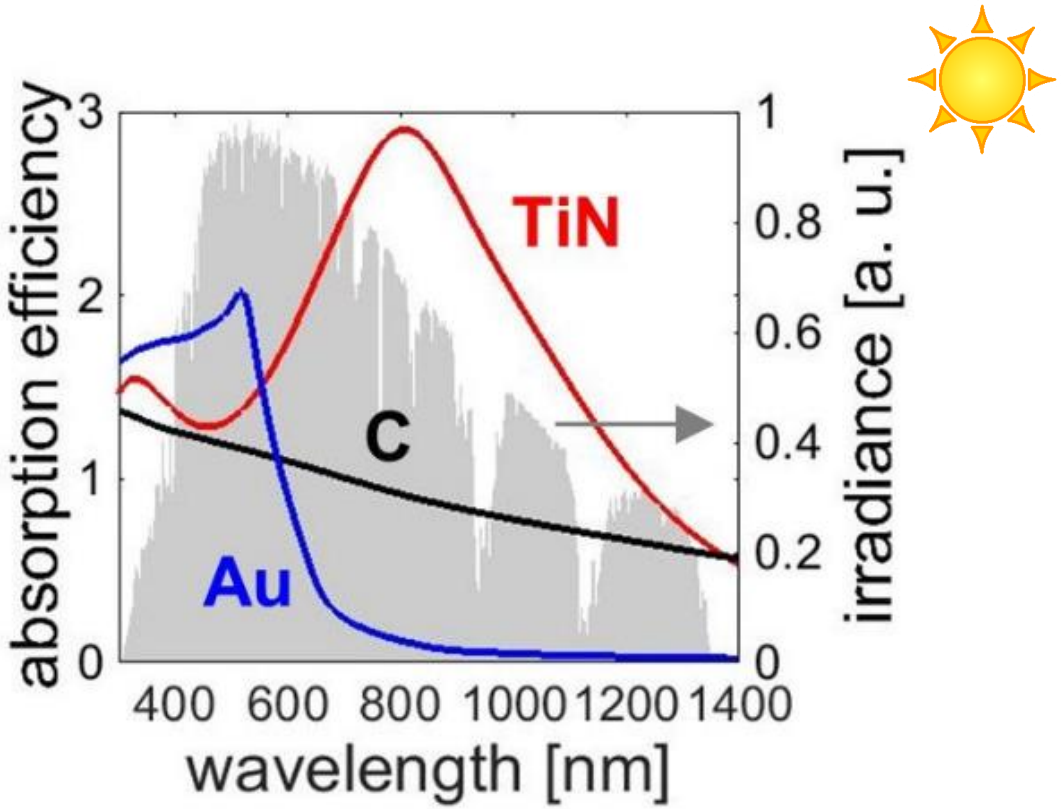
Photothermal heating with TiN





Sunlight absorption efficiency





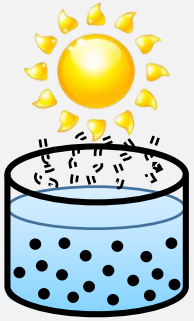
TiN NP absorbs more sunlight than Au NP and carbon NP

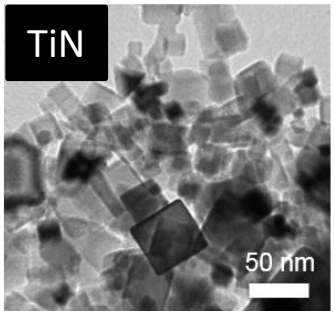
S. Ishii, et al, J. Phys. Chem. C 120, 2343 (2016)

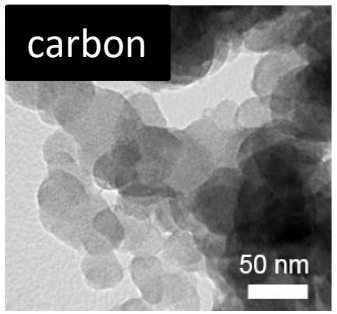
Solar water heating

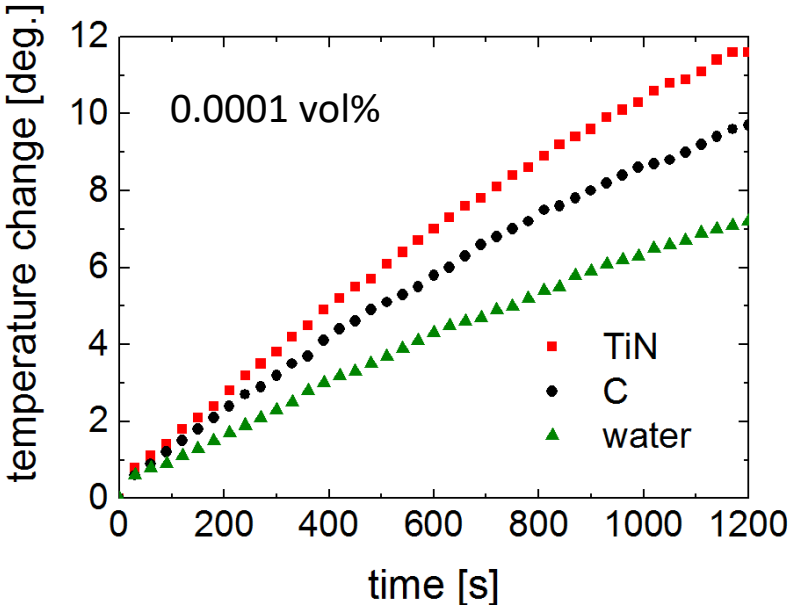
Solar simulator,
80 mW/cm^2

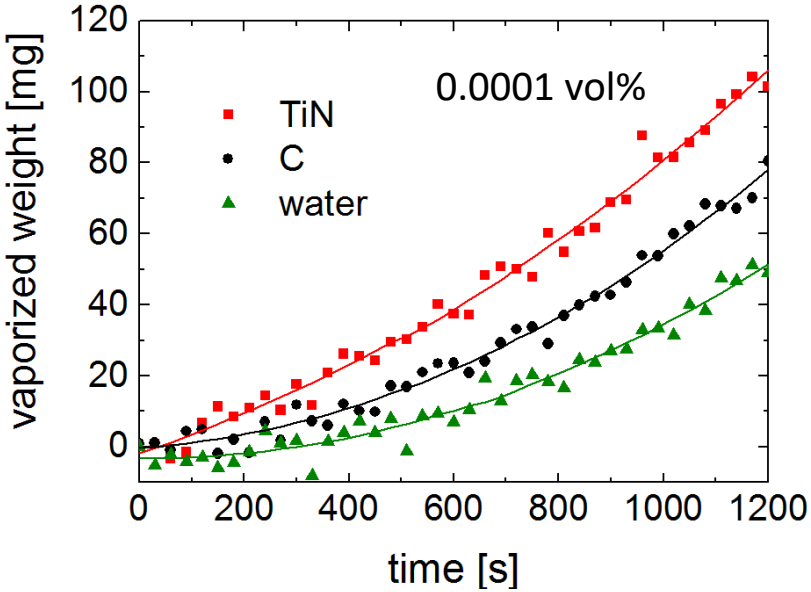
Room temp.: ~20 deg. C







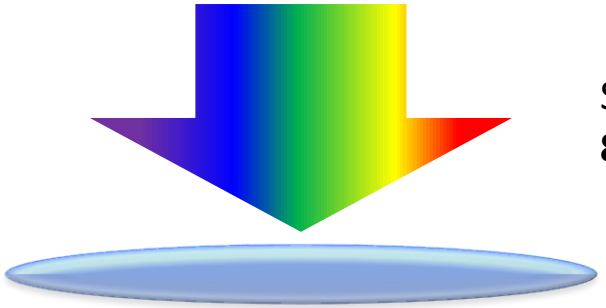




- TiN NPs have higher heating rates than carbon NPs
- Efficiency **~90 %** (0.1 vol%) <= <u>solar cell: < 20 %</u>

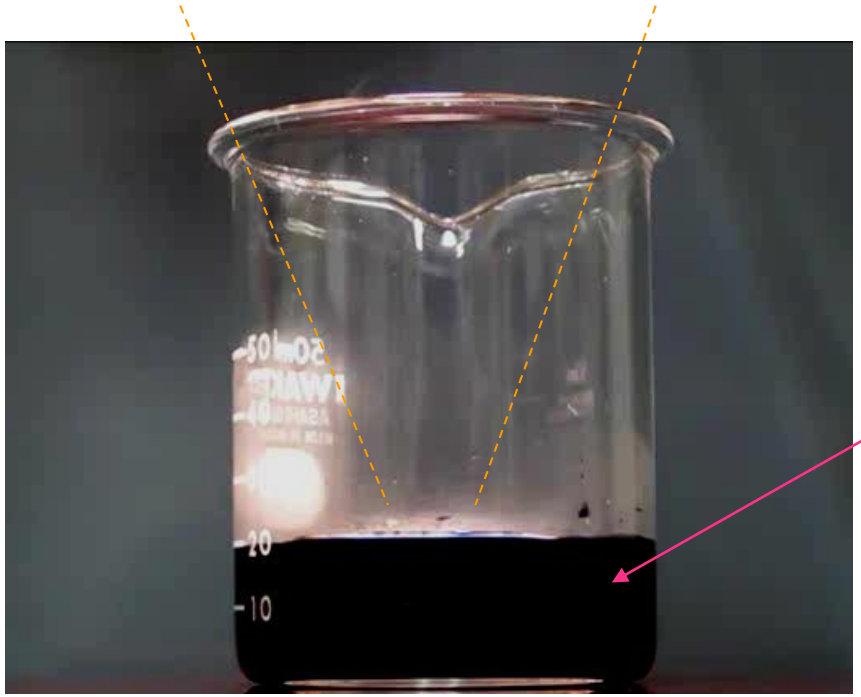
Solar vapor generation

Room temp.: 24 °C



Solar simulator,
800 mW/cm²

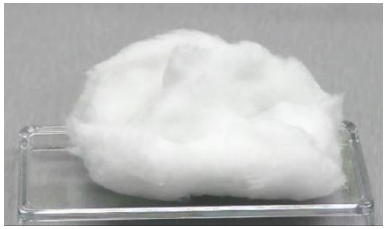
Fresnel lens



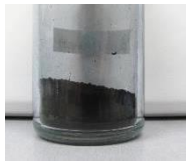
TiN NPs in water
0.1 vol%
(Bottom: 29.5 °C)

S. Ishii, et al, J. Phys. Chem. C 120, 2343 (2016)

Solar water evaporation

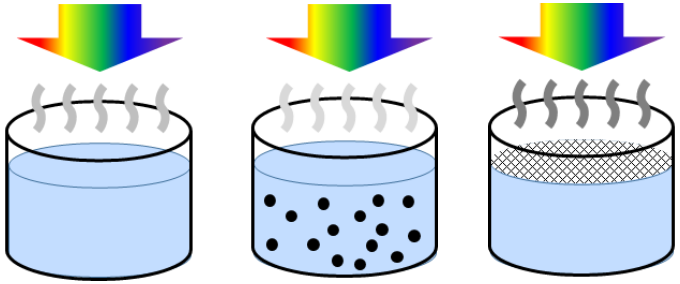


Ceramic wool

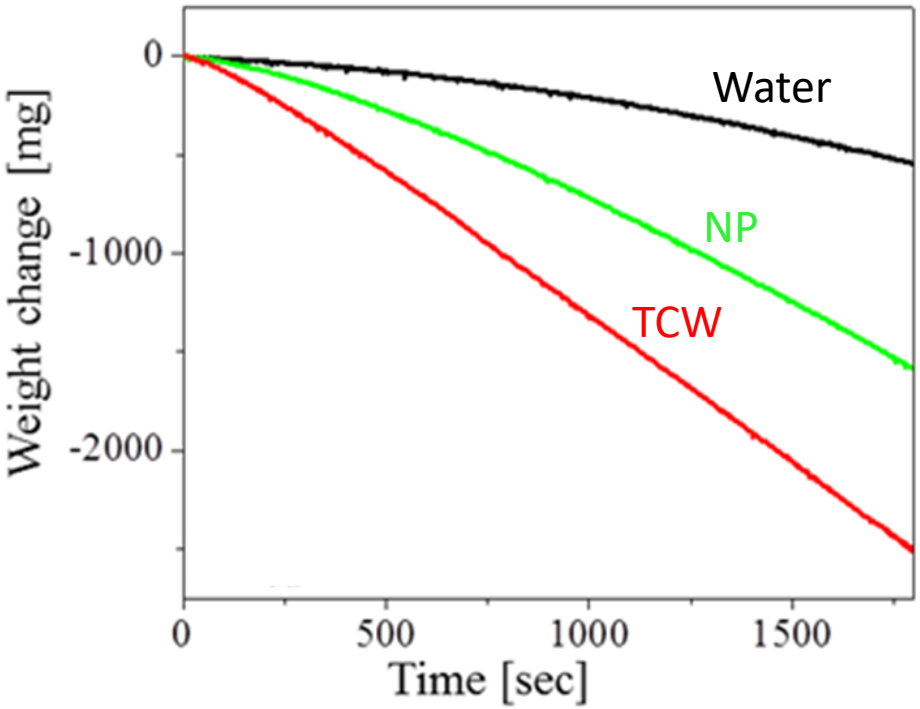


TiN NPs

Composite (TCW)



M. Kaur



Capillary force of TCW improved evaporation

M. Kaur, SI, et al, ACS Sustain. Chem. Eng. (2017)

Photothermal chemical reaction

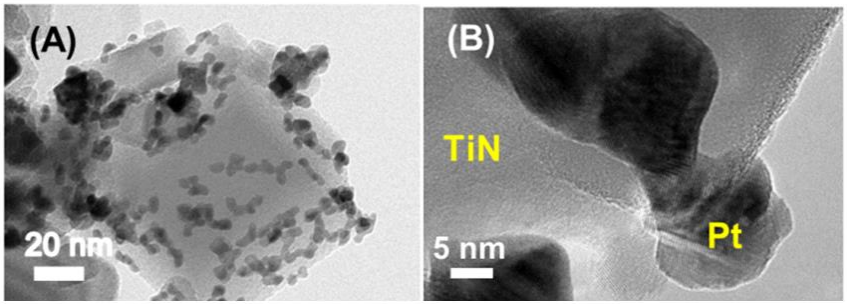
H. Abe &
O. Anjaneyulu

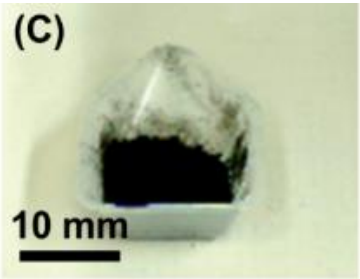
Oxidation of CO

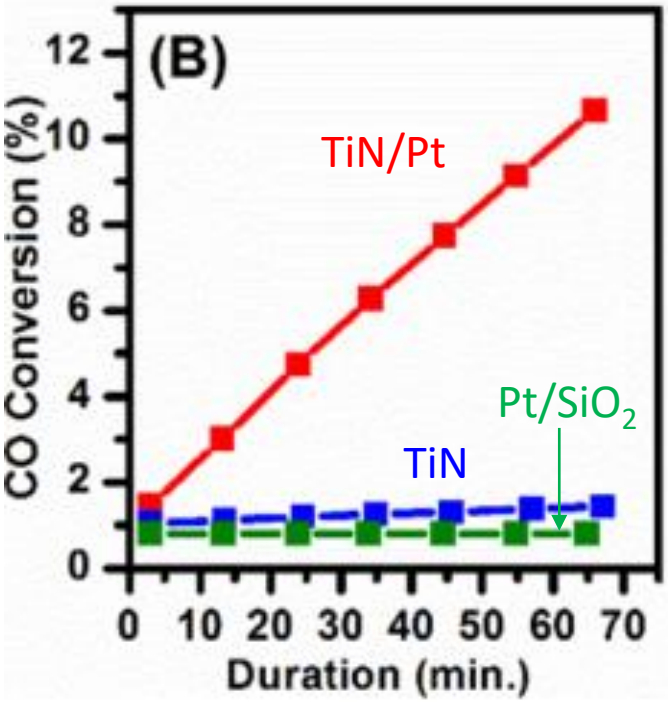
- Conventional: heat >200 degC
- Ours: Pt-coated TiN NPs + focused sunlight

$$CO + 1/2\ O_2 \rightarrow CO_2$$

TiN + Pt

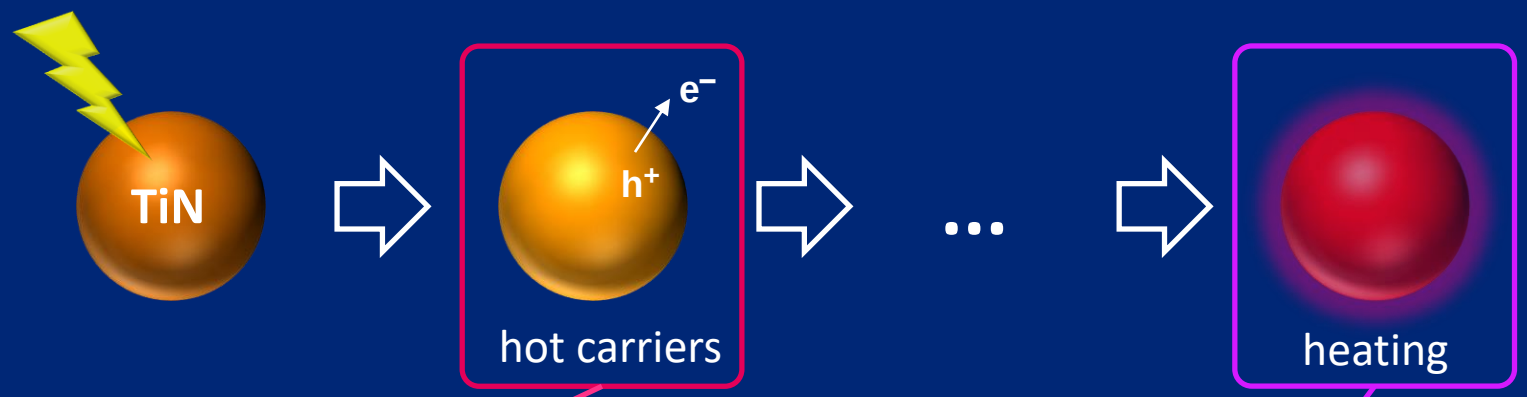


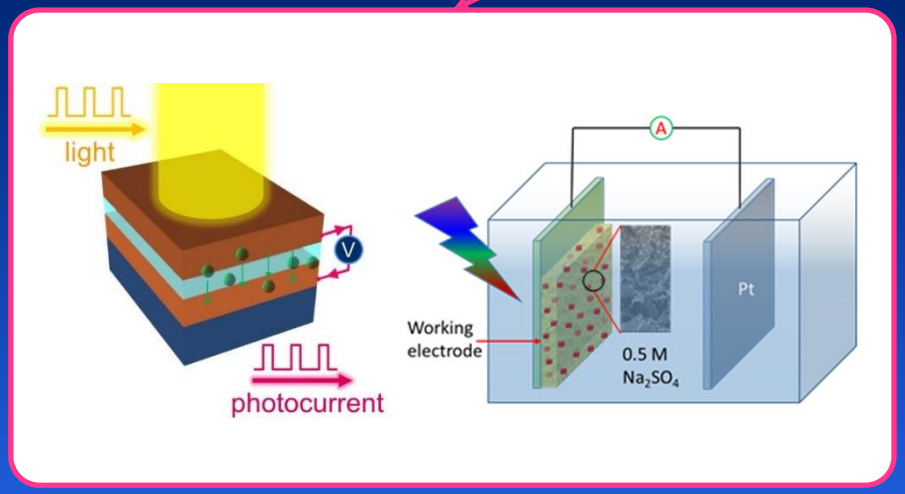


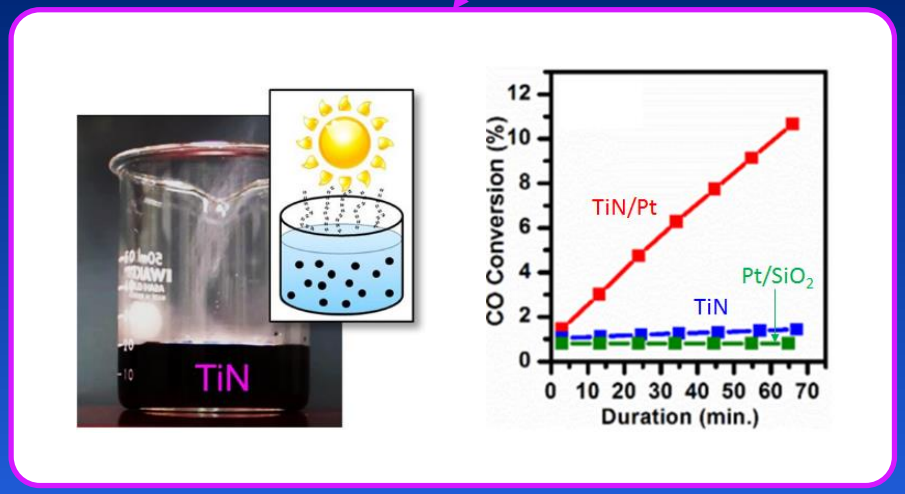


O. Anjaneyulu, S. Ishii, et al, RSC Adv. (2016)

Hot carrier engineering w/ TiN







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