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About Omics Group Conferences

Dielectrophoretic fabrication and characterization of ZnO NW photoconductors and MOS photodiodes

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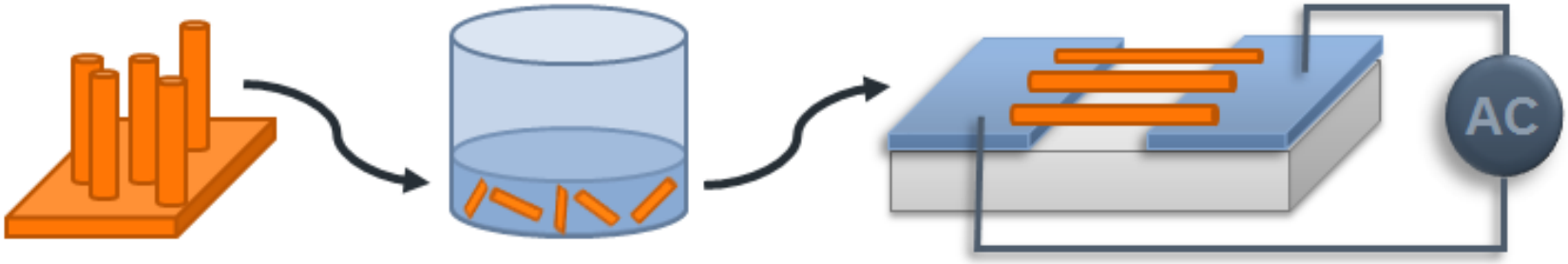

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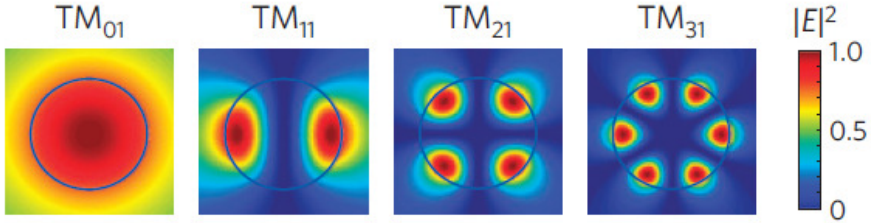
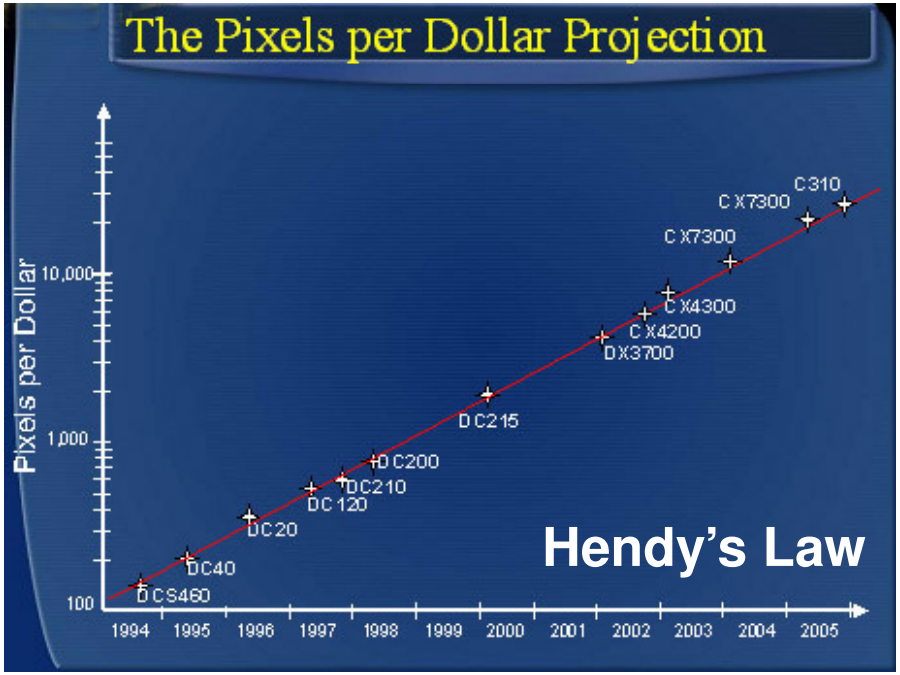
Optics-2014 – Philadelphia, Sep 8-10, 2014

NANOWIRE PHOTODETECTORS

- High crystal quality
- Enhanced light absorption (optical resonances)
- Tunable optical properties (absorption edge) as a function of NW diameter
- Near-ballistic transport (reduced scattering rate)
- Polarization sensitive detection
- Single photon detection (superconducting NWs)



L. Cao et al., Stanford Univ., Nature Mat., 8, 643 (2009)



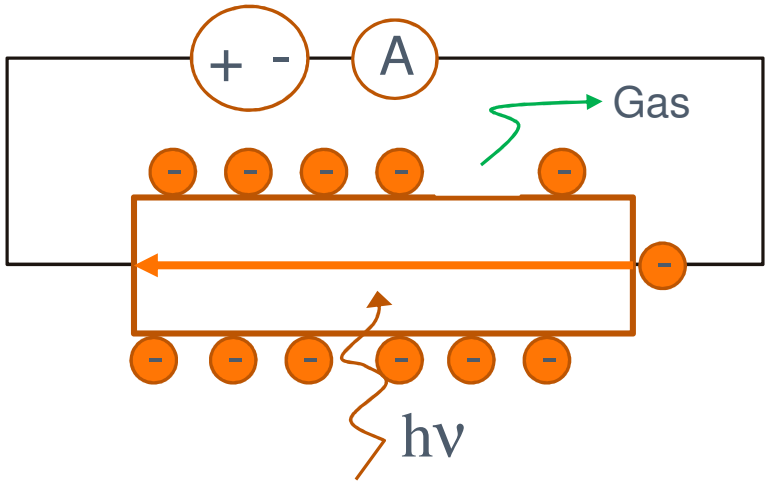
PHOTOCONDUCTIVE GAIN

As surface to volume ratio is increased, reported photoconductive gains seem to enlarge:

- Surface effects (carrier trapping)
- Gas adsorption/desorption processes

Ej: graphene, C nanotubes, metal oxide NWs,…

ZnO NW photoconductor



$$R = \frac{I_{ph}}{P_o} \propto \frac{Nq}{h\nu}$$

$$N\uparrow, R\uparrow, EQE >> 100\%$$

but…

τ (relaxation time) $\uparrow\uparrow$

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TECHNICAL CHALLENGE:
Reliable and fast processing methods for high throughput fabrication of NW devices.

Common bottom-up approaches

- electric or magnetic fields
- fluid flows
- Langmuir-Blodgett technique
- bubble-blown films
- mechanical printing

… but creating high-density NW arrays in an efficient and scalable manner remains challenging.

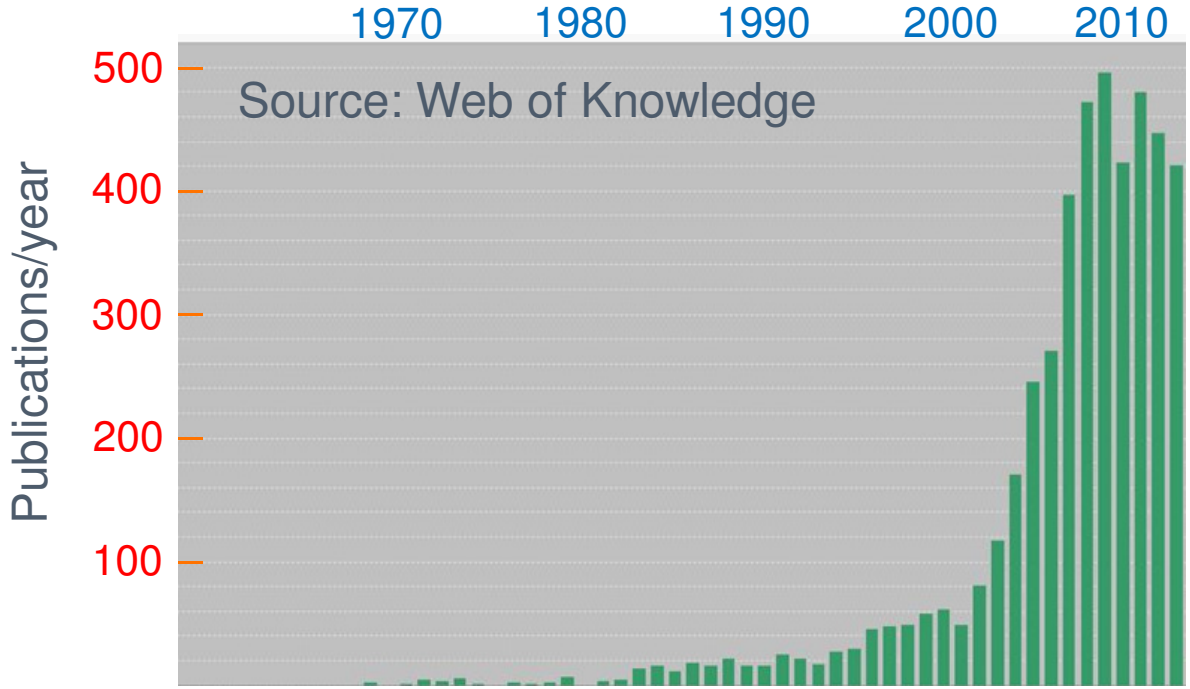
Dielectrophoresis (DEP)

Dielectrophoresis describes the movement of a particle in a non-uniform electric field.

1950s First studies by Prof. Herbert Pohl.

1980s, 90s Widely used in biochemistry to separate cells and study their dielectric properties.

Last decade Manipulation of inorganic nanostructures.



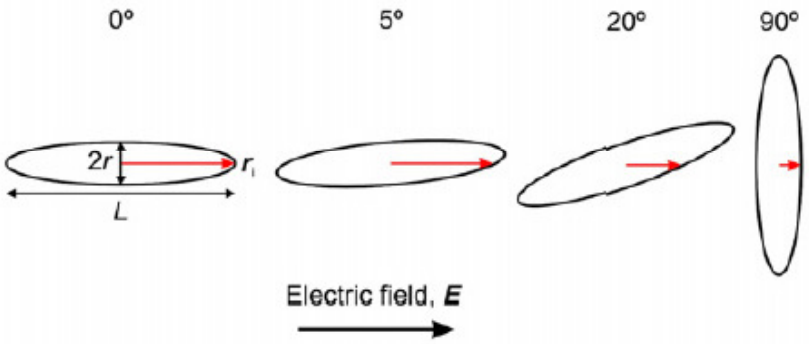
Dielectrophoresis (DEP)

Dielectric permittivity of the solvant

Clausis-Mossotti factor

Dielectrophoretic Force (AC signal)

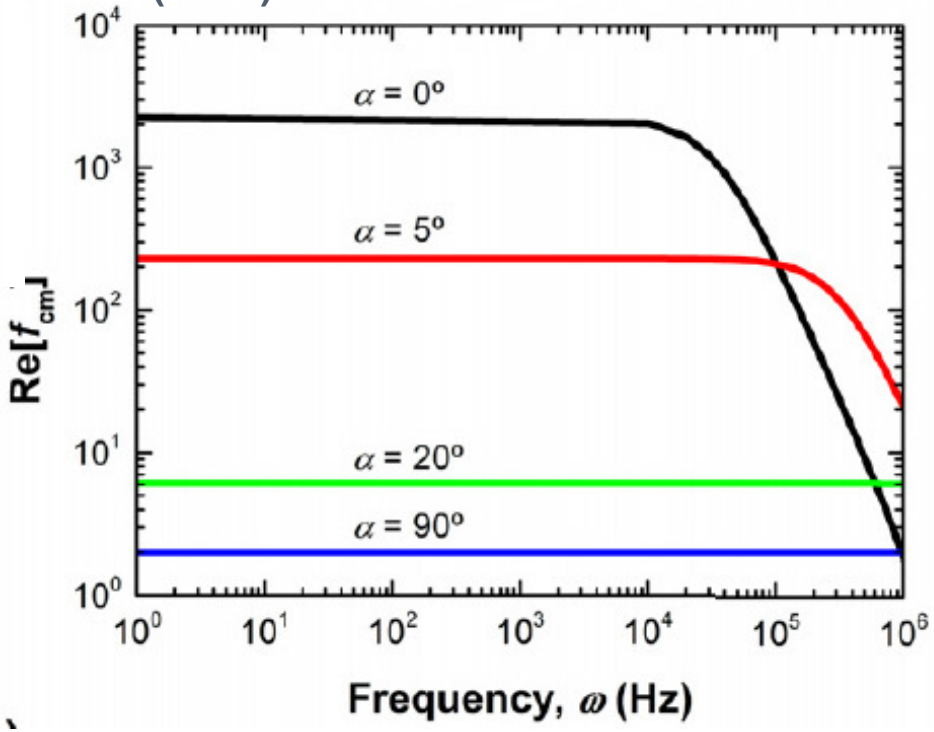
$$\langle F_{\mathrm{DEP}} \rangle = \frac{1}{2} V_{NW} \varepsilon_{\mathrm{m}} \, \mathrm{Re}\{K\} \nabla E_{rms}^2$$



$$K_{long\ axis} = \frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_m^*}$$

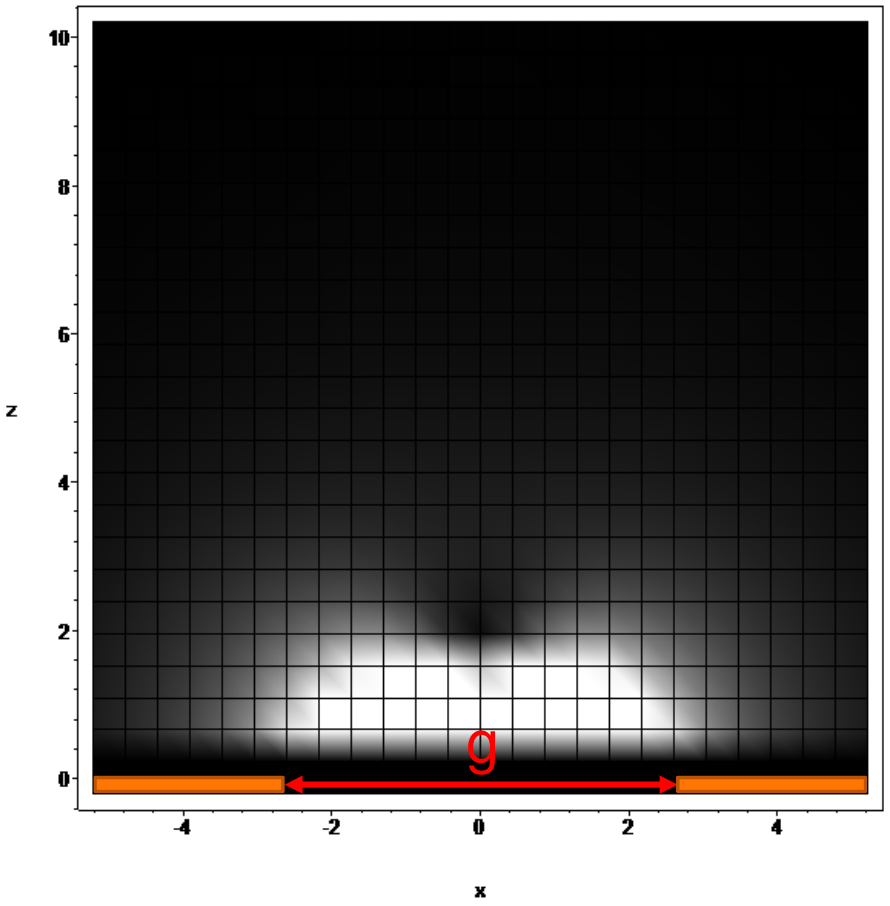
$$K_{short\ axis} = 2\frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + \varepsilon_m^*}$$

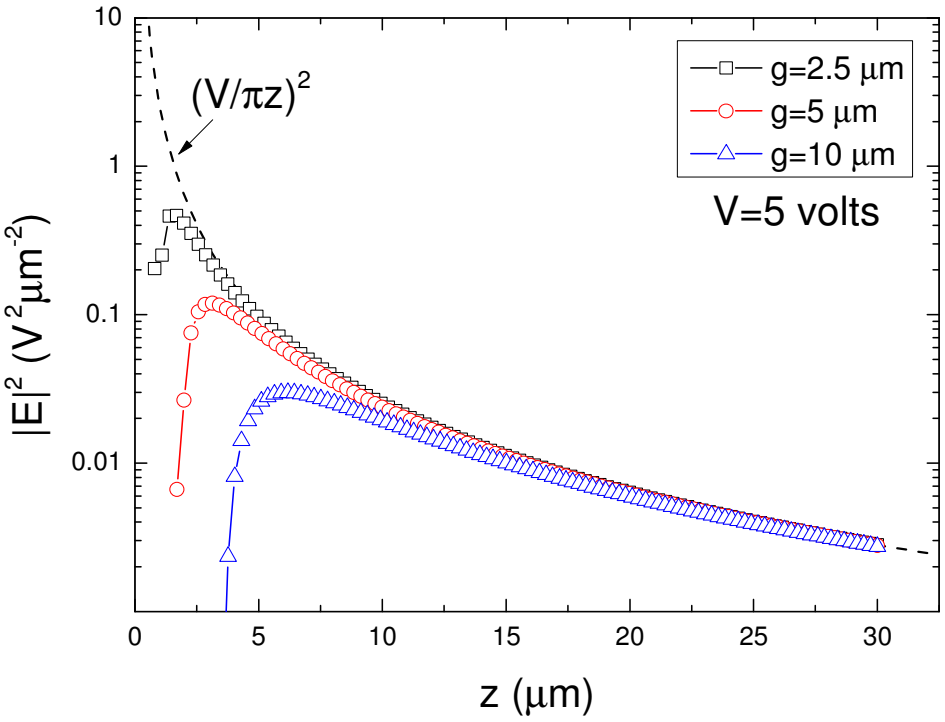
C. García et al., Nanotechnology 24 (2013) 415702



DEVICE FABRICATION
DEP attractive force

$|E|^2$





$|E|^2$ decays as $1/z^2 \Rightarrow F_{DEP}$ decays as $1/z^3$

Maximum trapping distance ≈ 50-100 µm

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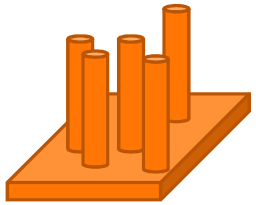
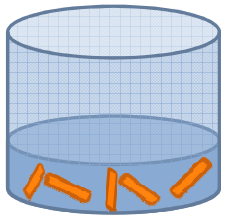
DEVICE FABRICATION:

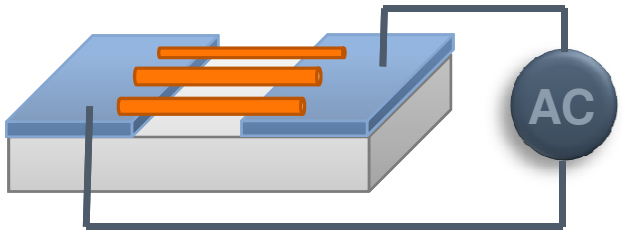
1. ZnO NW Growth



2. Preparation of NW dispersions



3. Dielectrophoresis (DEP)



DEVICE CHARACTERIZATION:

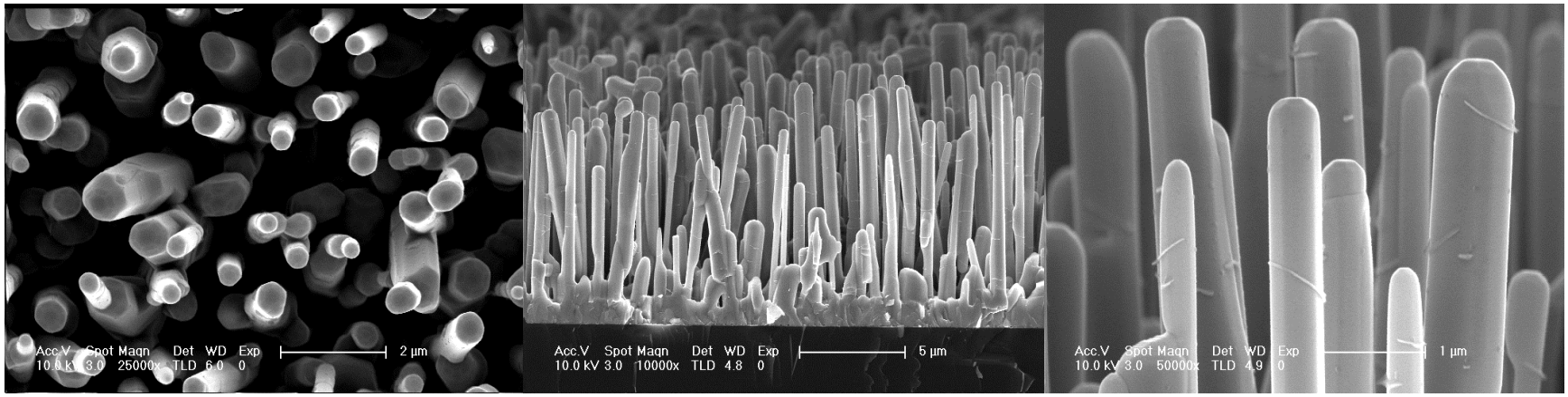
1. NW photoconductors
2. NW MOS photodiodes

ZnO NANOWIRES
Vapor Phase Transport

- Substrate= Si(100) / precleaned in HF:H_2O (1:10)
- Zn film nucleation layer (t=20-100Å)
- Source: (ZnO,Zn)/graphite powder $ZnO(s) + C(s) \rightarrow Zn(g) + CO(g)$
- Carrier gas: Ar flux(0-400 sccm)/O_2 flux(10-100 sccm)

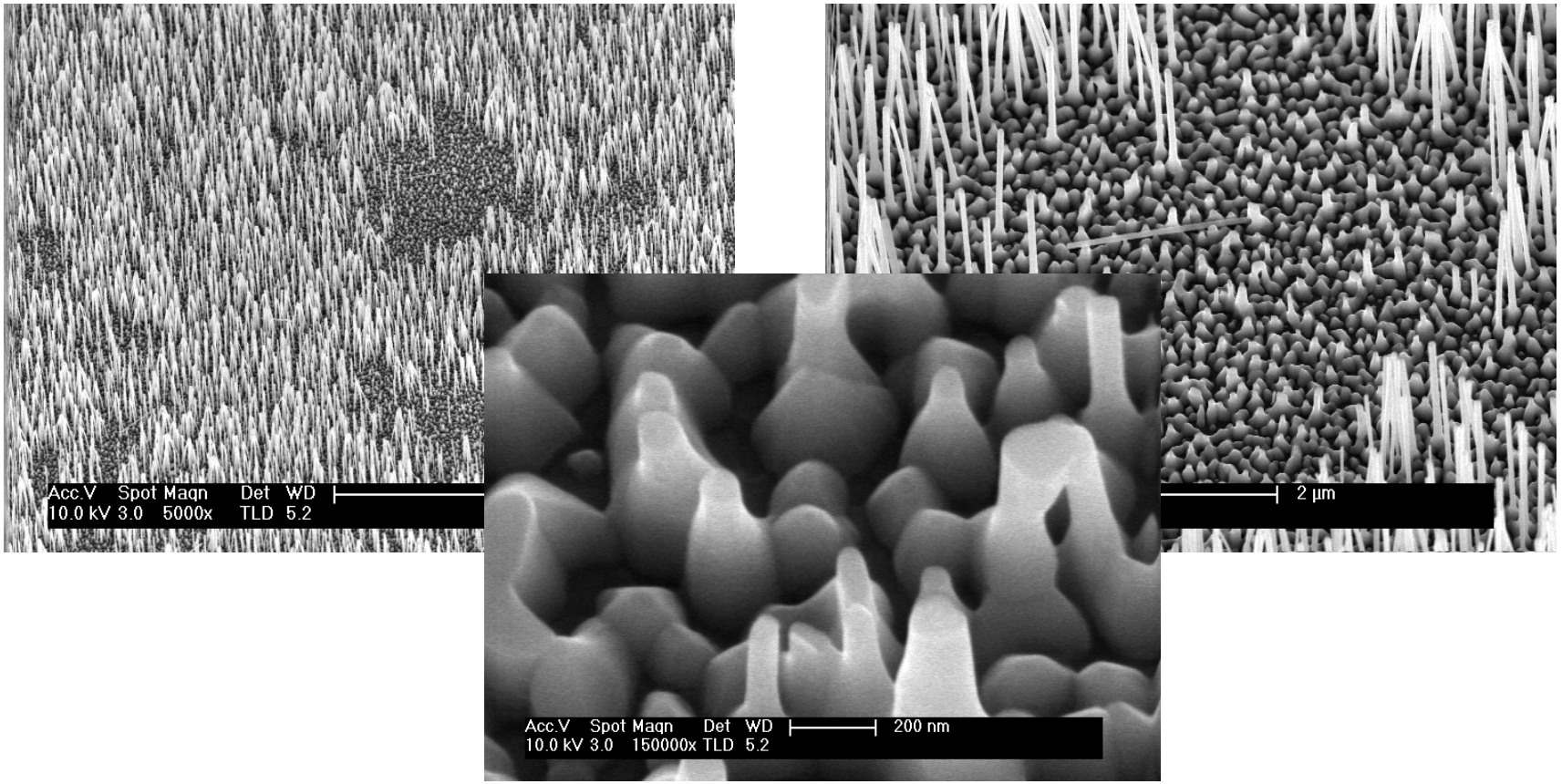
Diameters = 100-500 nm
Lengths = 5-20 μm

preferential orientation: [0001]

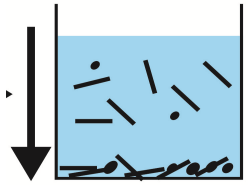


ZnO NANOWIRES
Transfer process

Donor substrate ⇒ ethanol dispersion
US cavitation

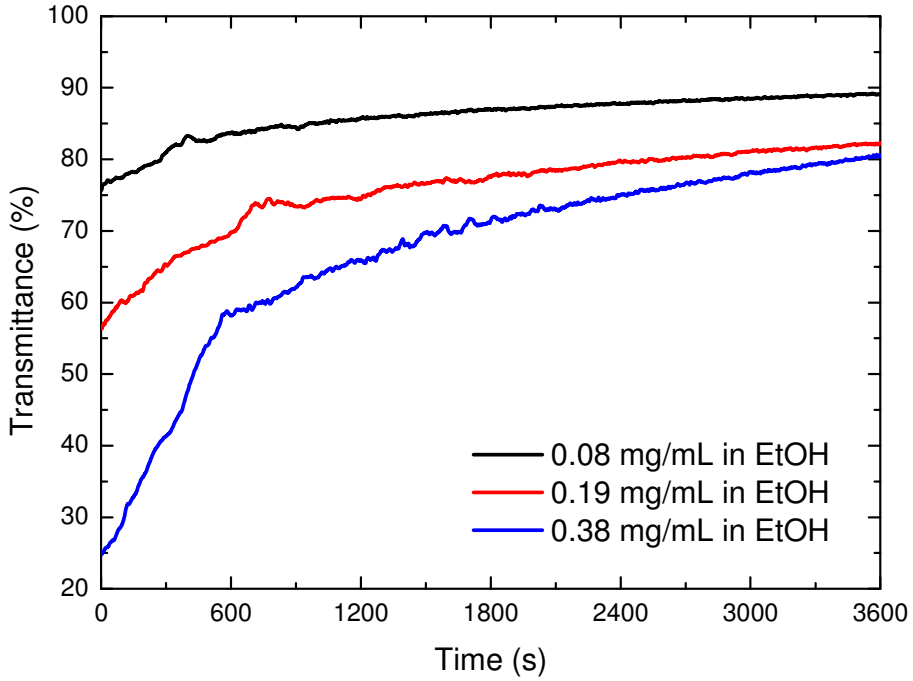


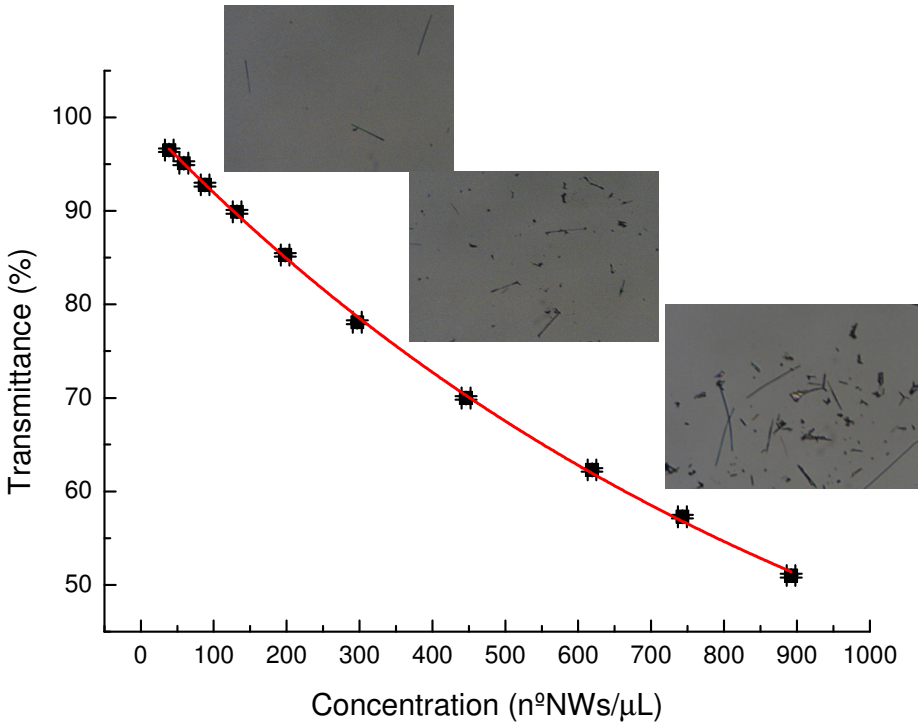
ZnO NANOWIRES
Filtering process



1h

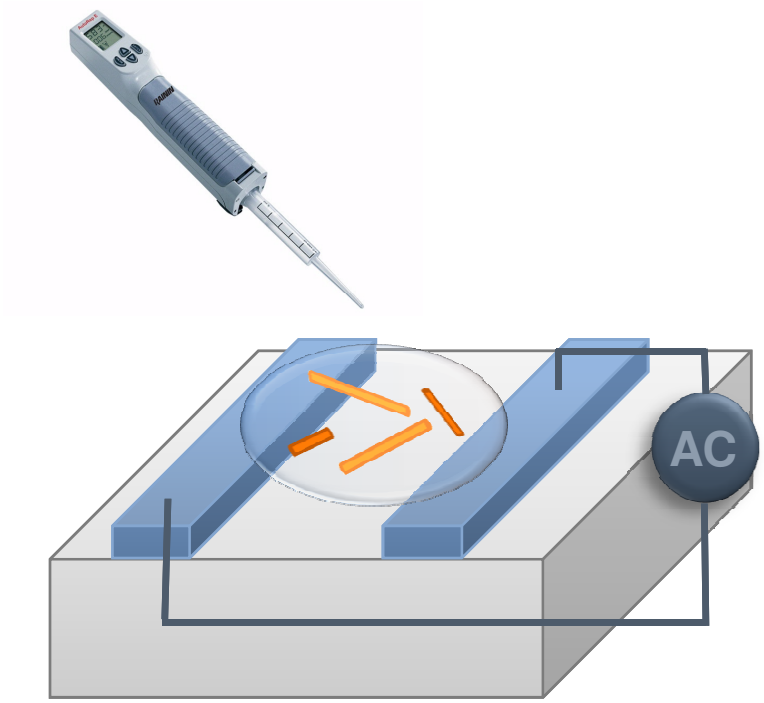
Filtering process based on sedimentation



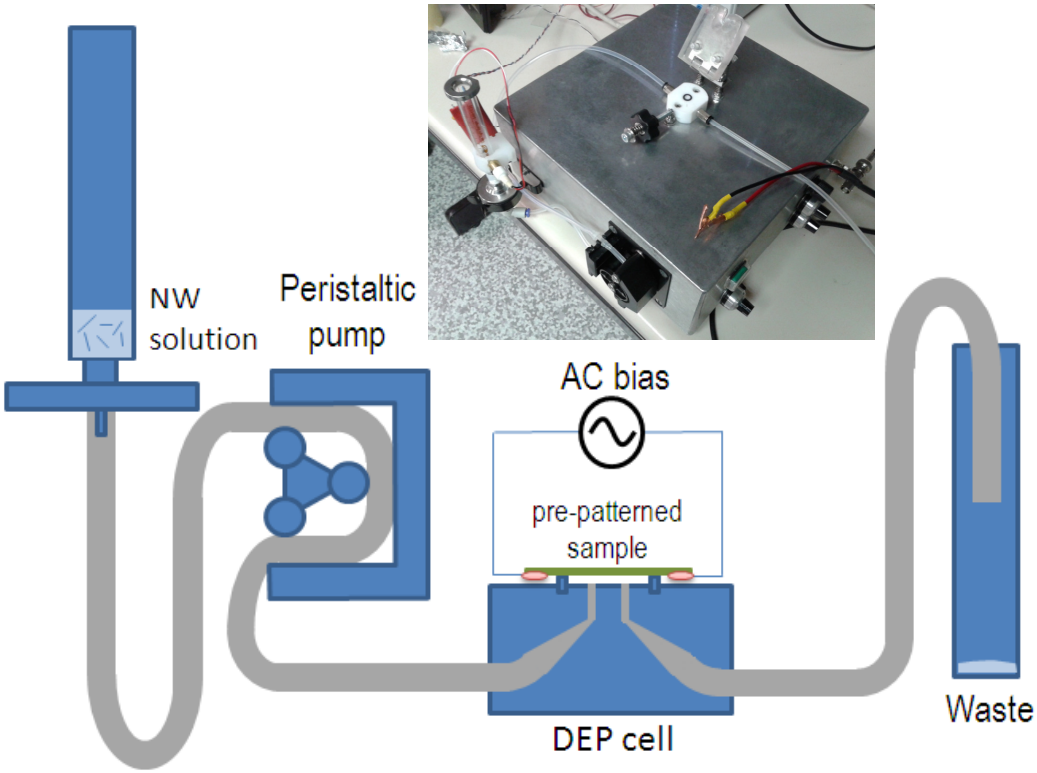


DEVICE FABRICATION
Dielectrophoresis

Droplet DEP



Continuous-flow DEP system



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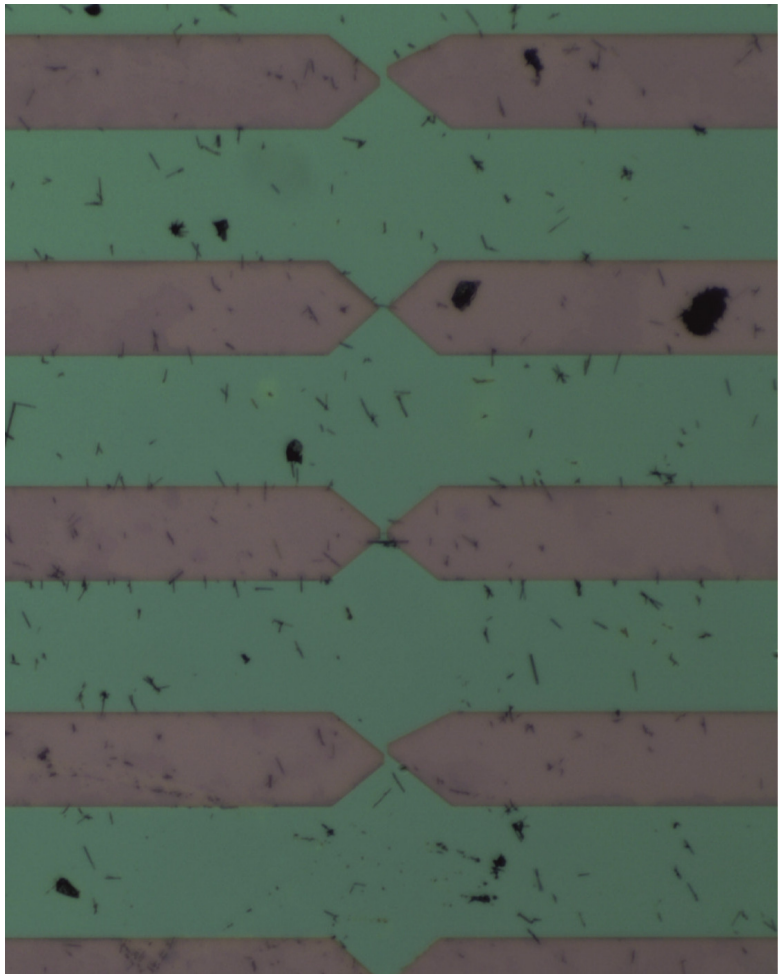
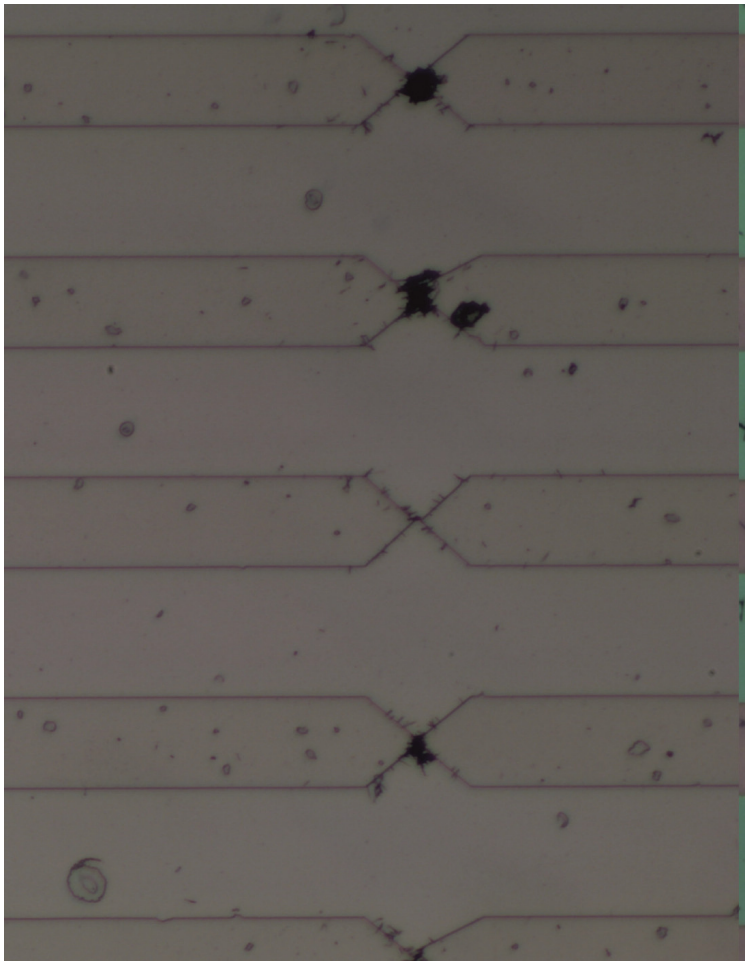
Droplet DEP



Continuous-flow DEP system



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C. García et al., Nanotechnology 24 (2013) 415702

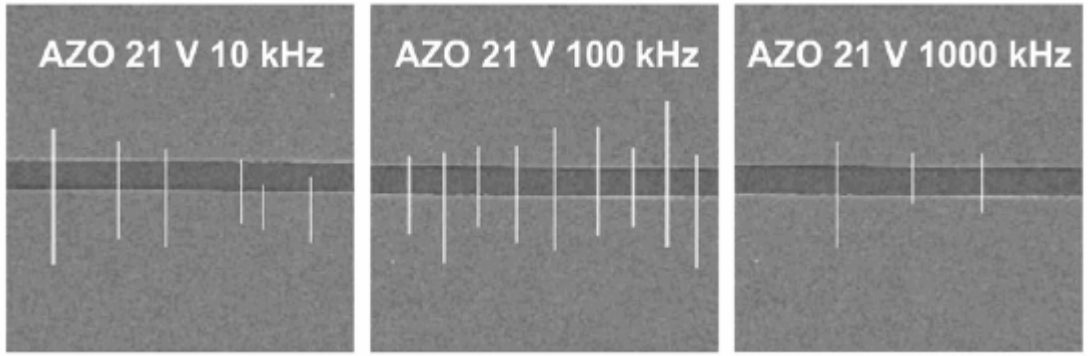
Receiver chip substrate:

- **SiO_2/Si**
- **Glass**
- **Printed Circuit Boards**

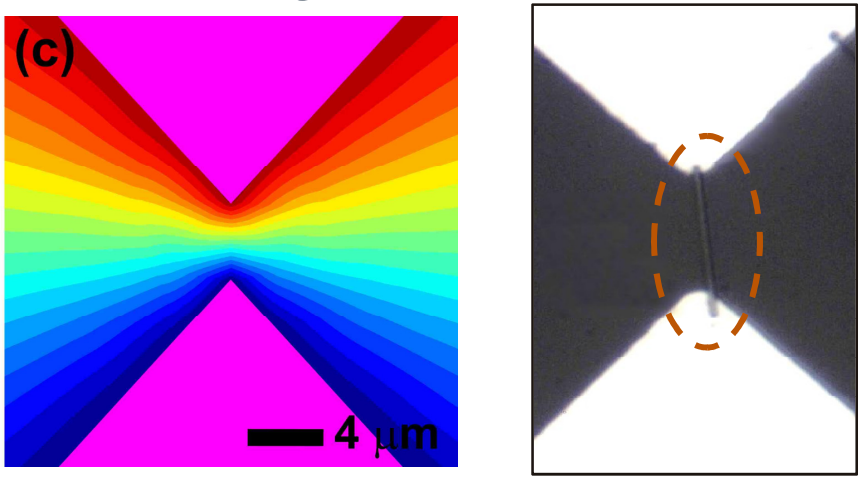
Metal electrodes

- **Al**
- **Au**
- **Al-doped ZnO (AZO)**
- **Cu**

multiNW devices



single NW devices



COMSOL multiphysics

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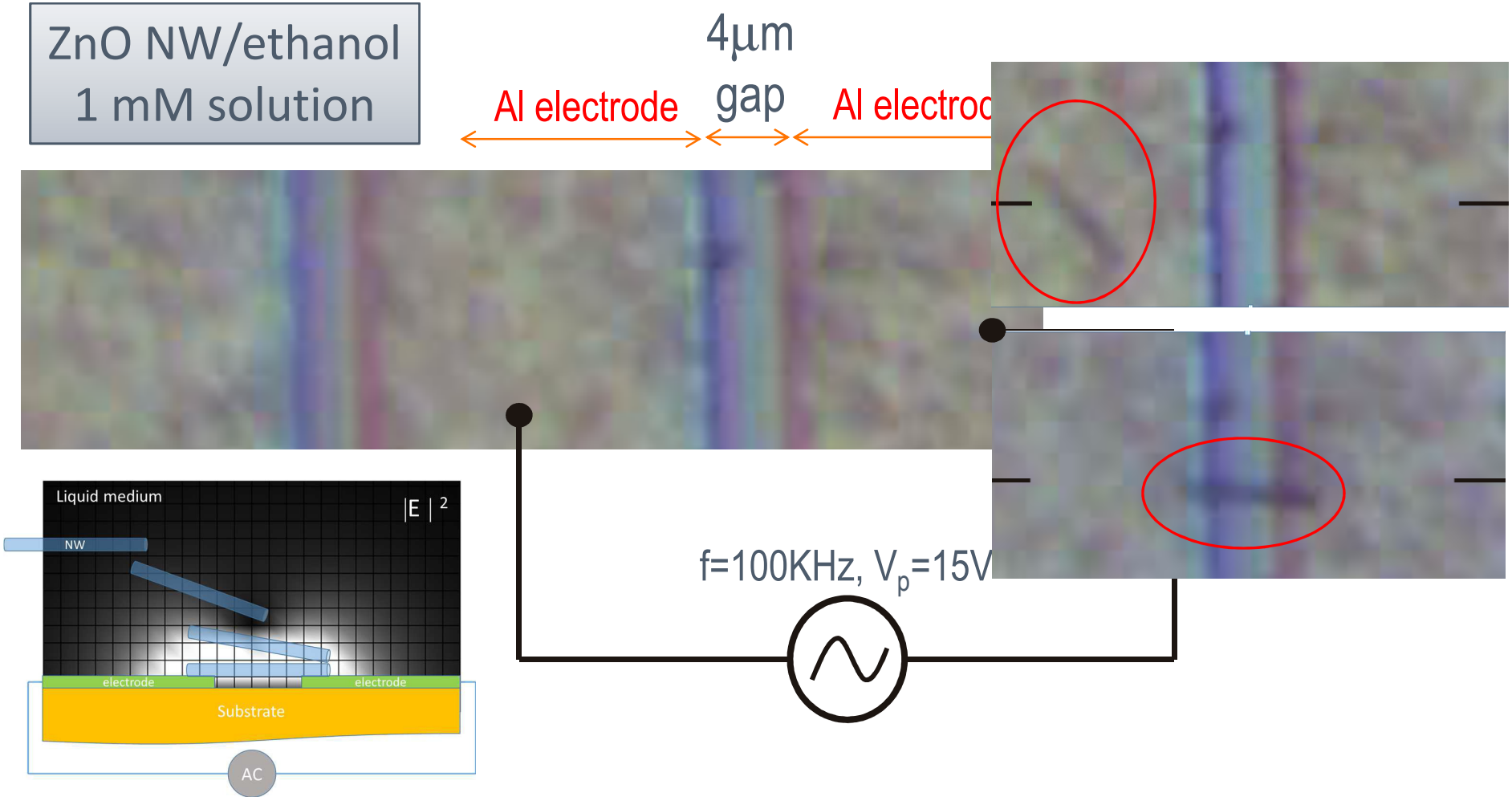
ZnO NW/ethanol
1 mM solution



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DIELECTROPHORESIS

Size selectivity

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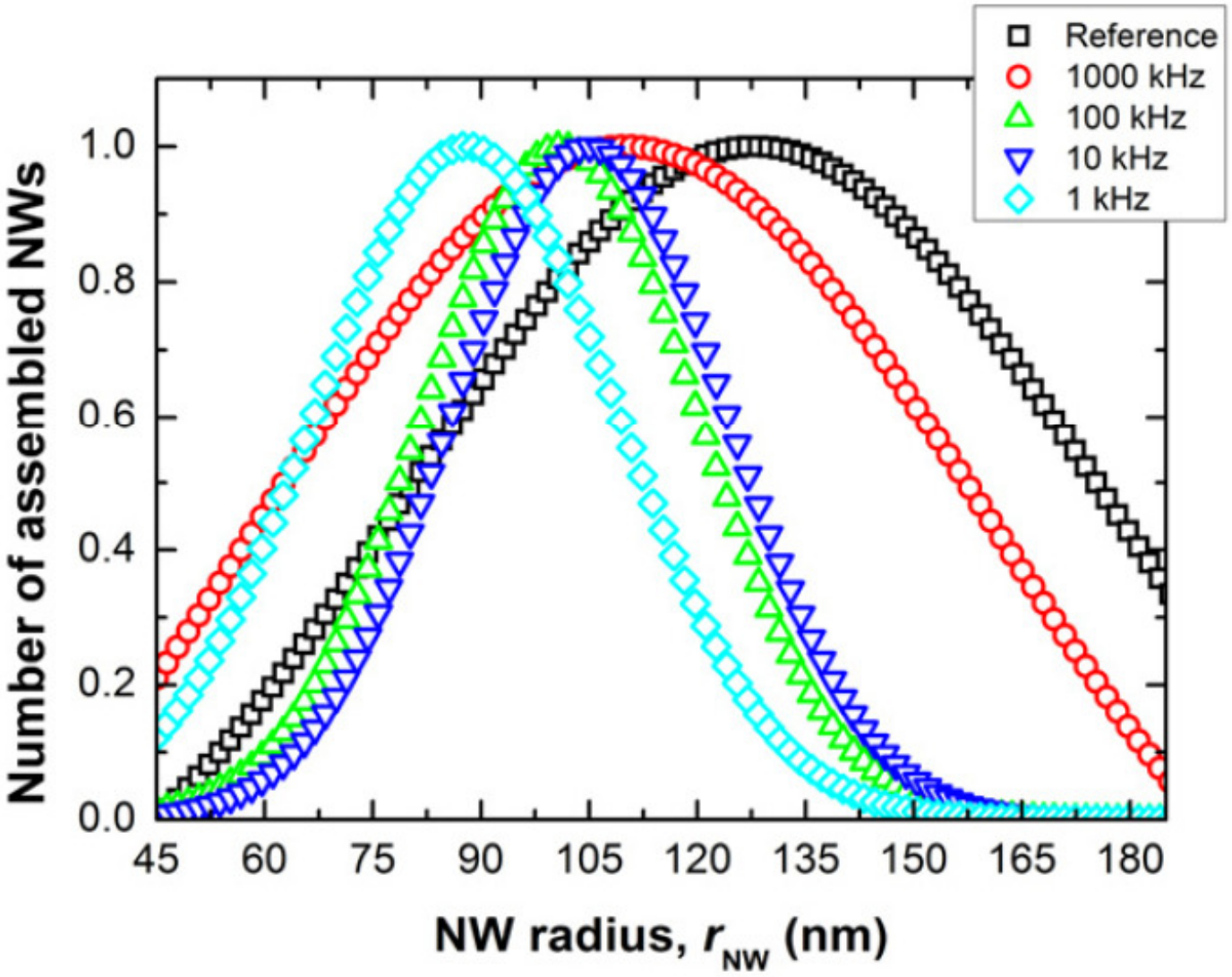

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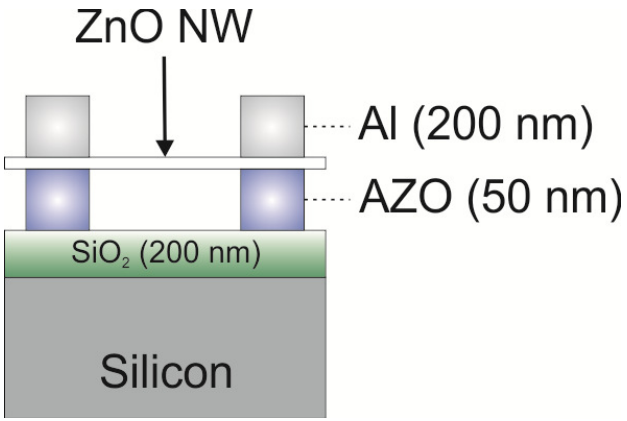
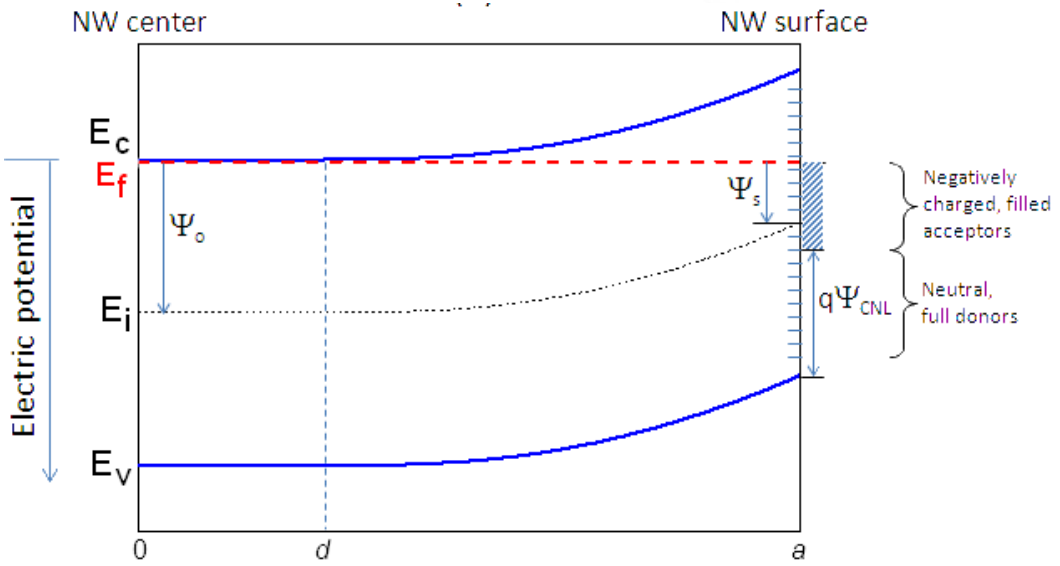
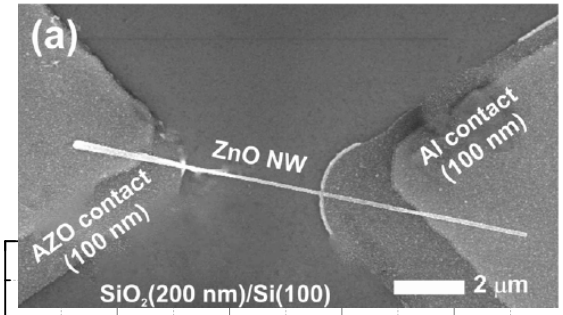
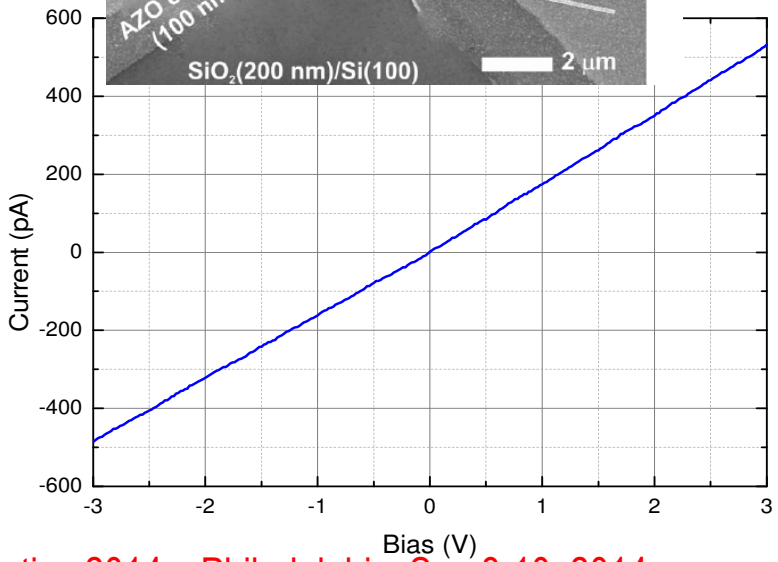
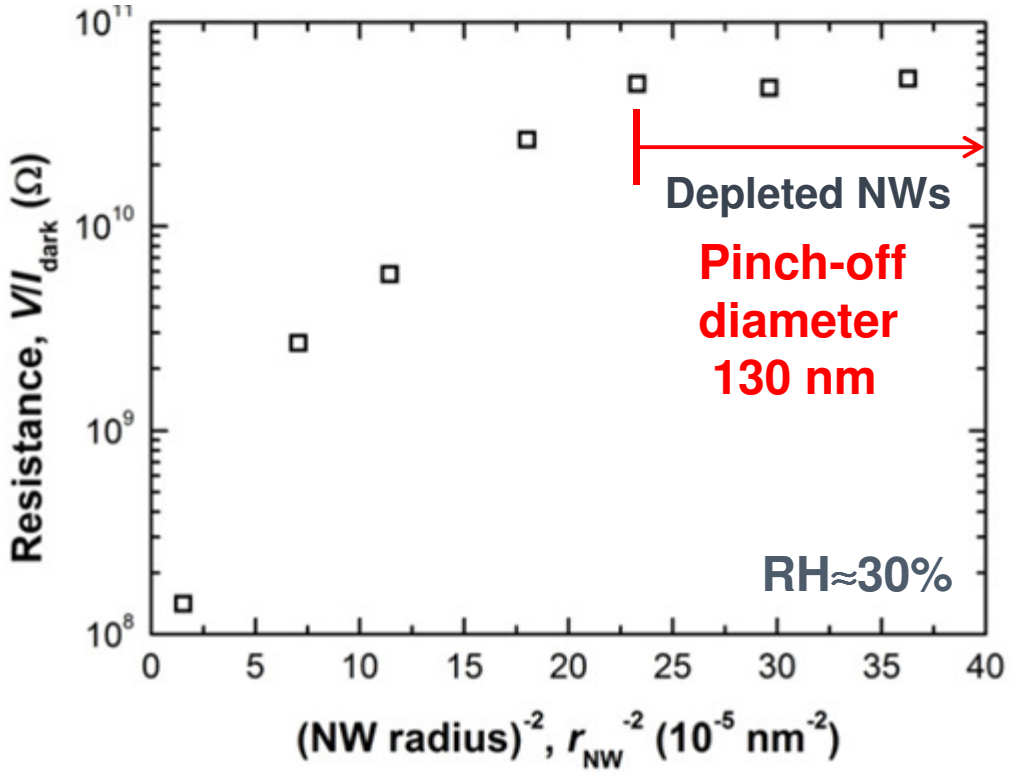
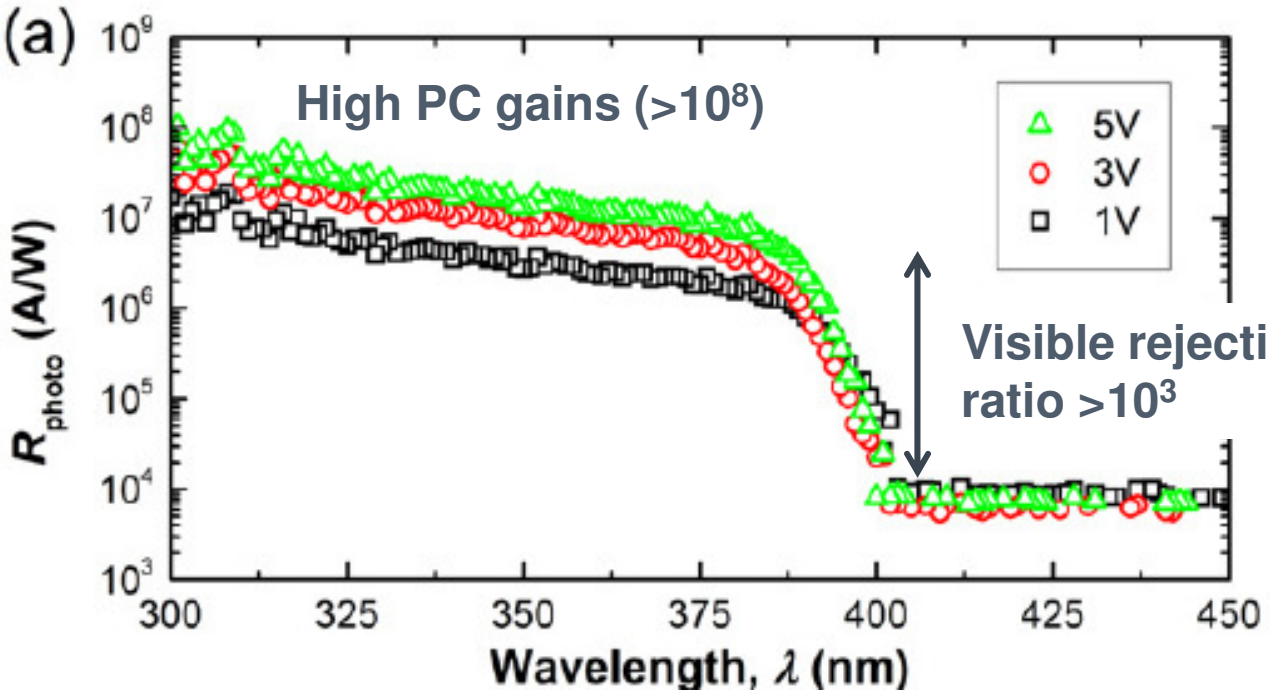


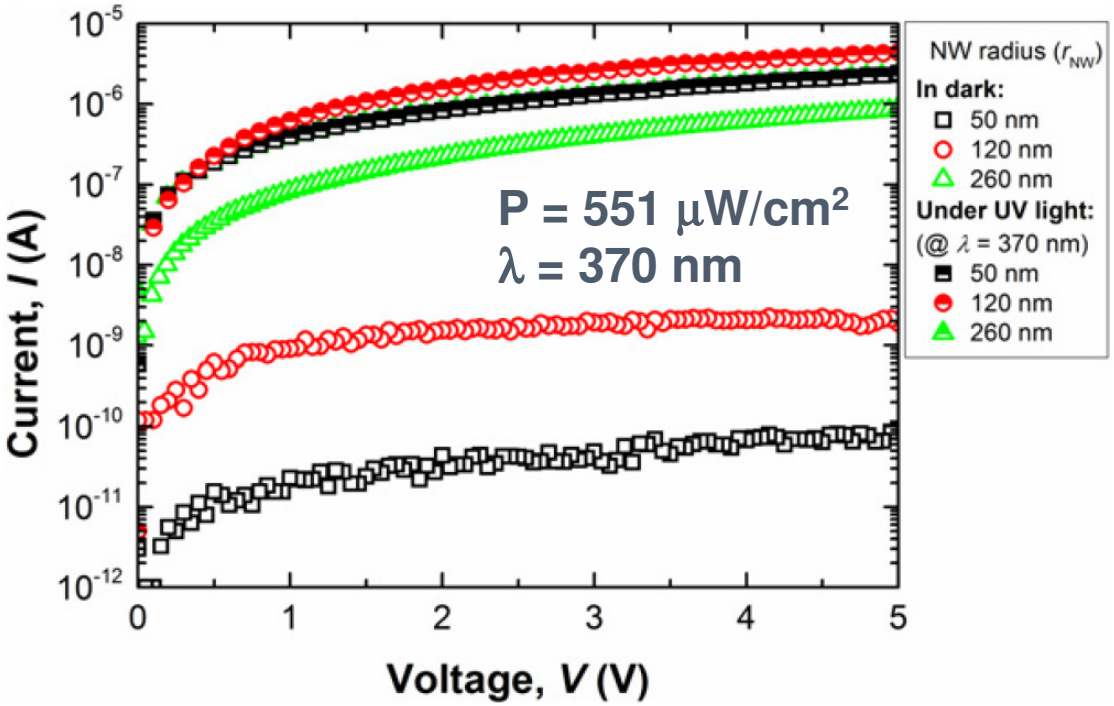


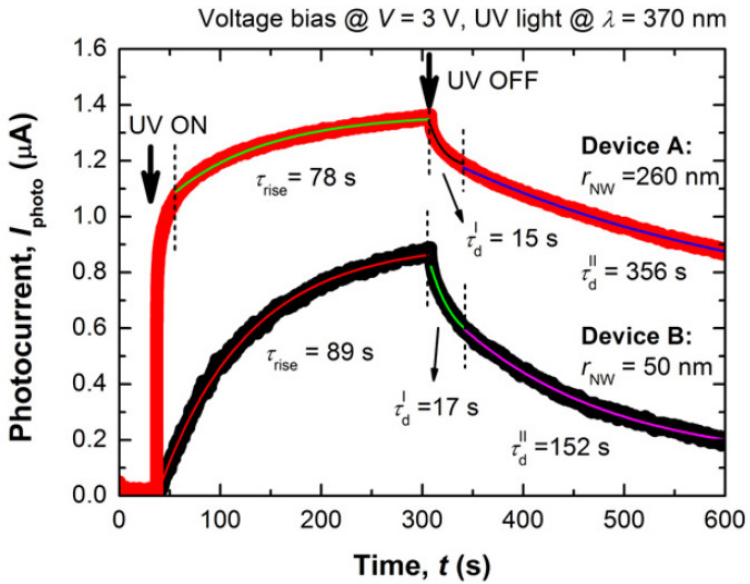




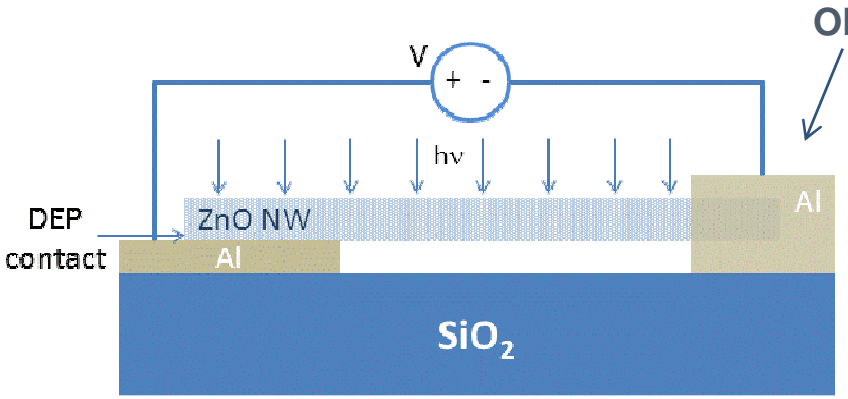


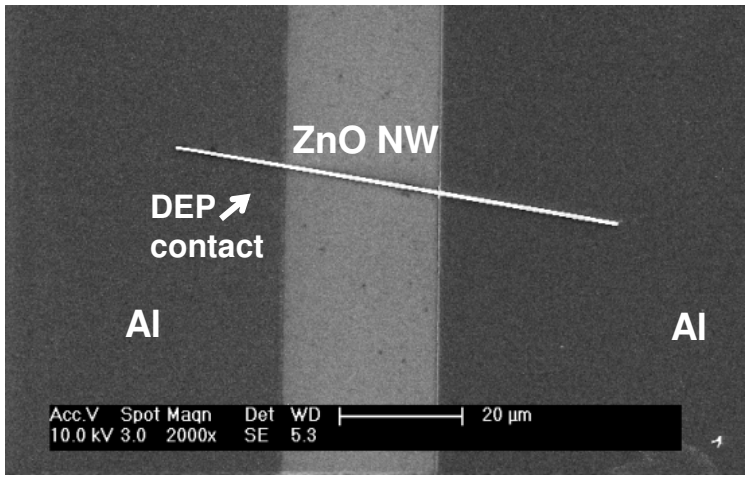

(a)
High PC gains (>10⁸)
5V
3V
1V
Visible rejection ratio >10³
R_photo (A/W)
Wavelength, λ (nm)

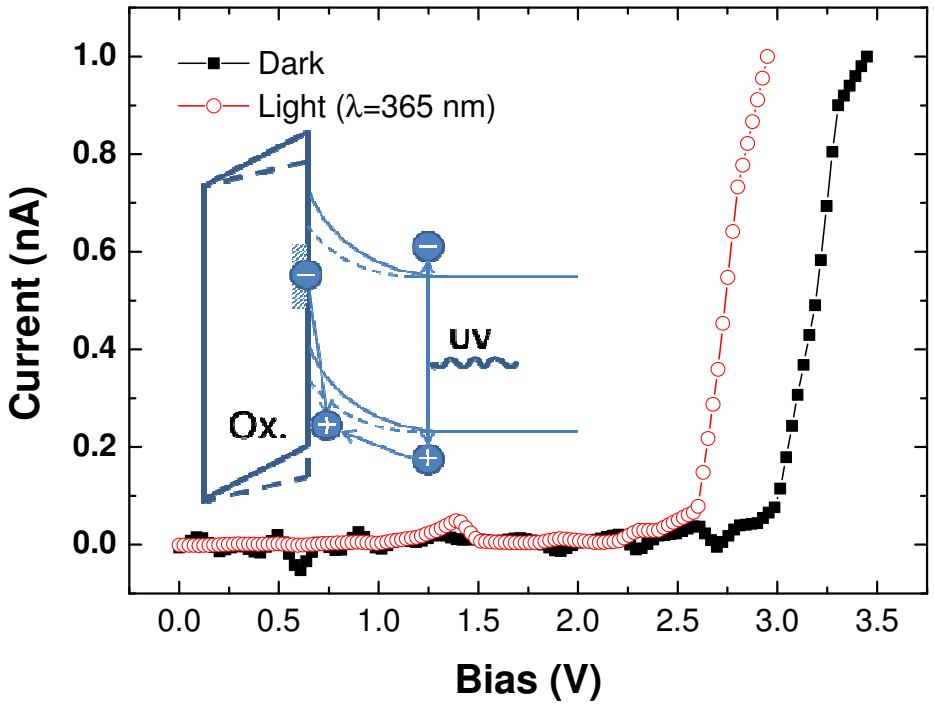

NW radius (r_NW)
In dark:
50 nm
120 nm
260 nm
Under UV light:
(@ λ = 370 nm)
50 nm
120 nm
260 nm
P = 551 μW/cm²
λ = 370 nm
Current, I (A)
Voltage, V (V)


Voltage bias @ V = 3 V, UV light @ λ = 370 nm
UV ON
UV OFF
τ_rise = 78 s
τ_d^I = 15 s
τ_d^II = 356 s
Device A:
r_NW =260 nm
τ_rise = 89 s
τ_d^I =17 s
τ_d^II =152 s
Device B:
r_NW = 50 nm
Photocurrent, I_photo (μA)
Time, t (s)

SINGLE NW DEVICES
Blocking contacts







J. L. Pau et al., Proc. of SPIE 8987 (2014)

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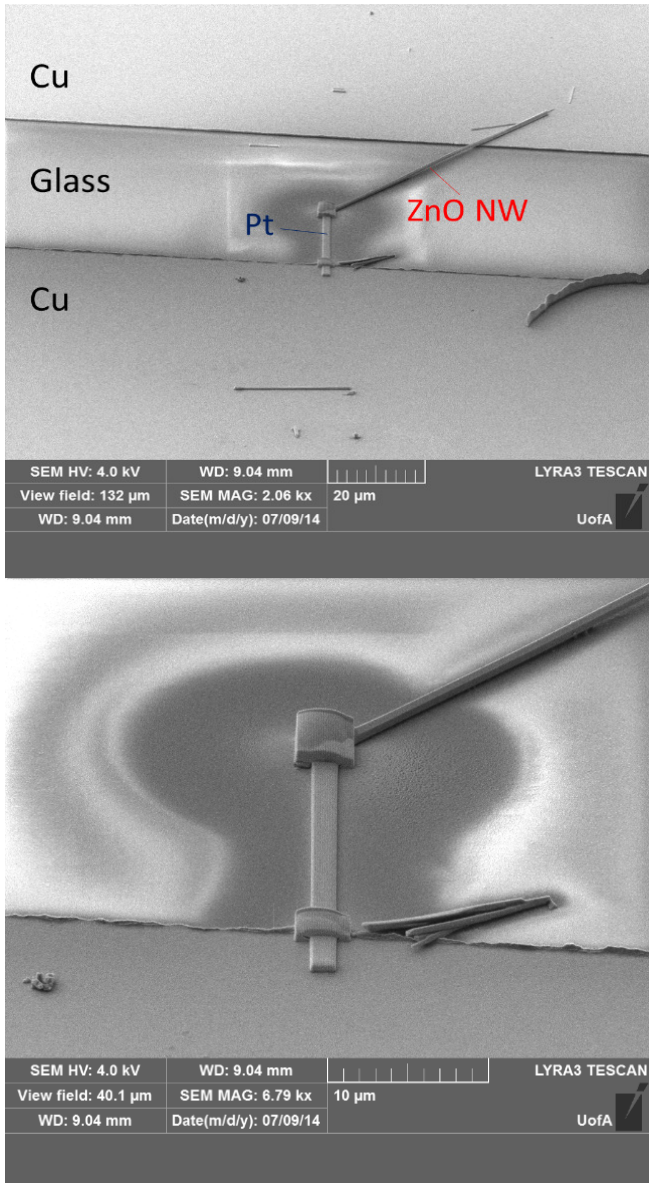
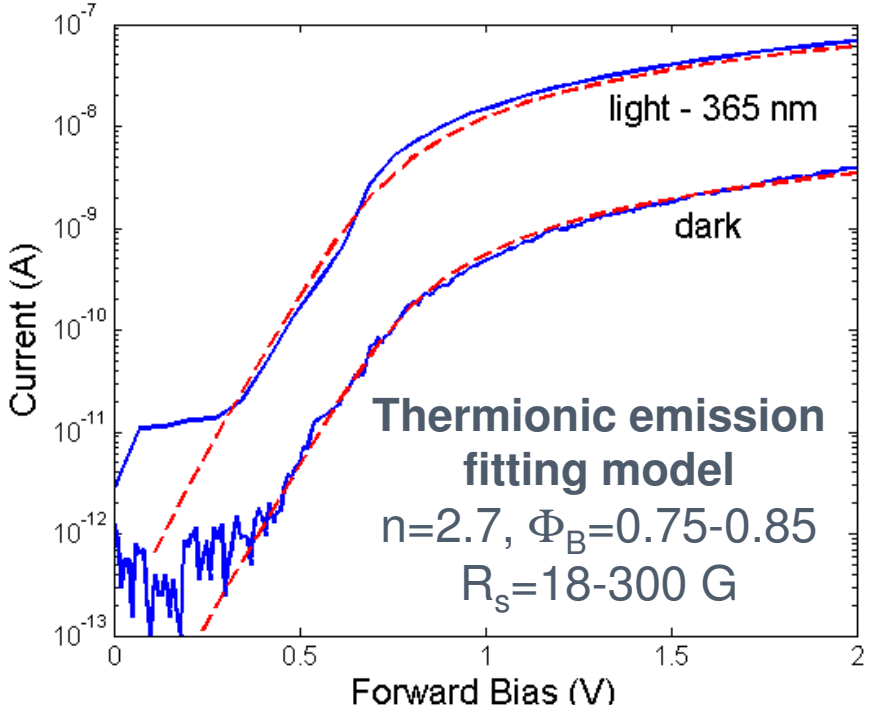
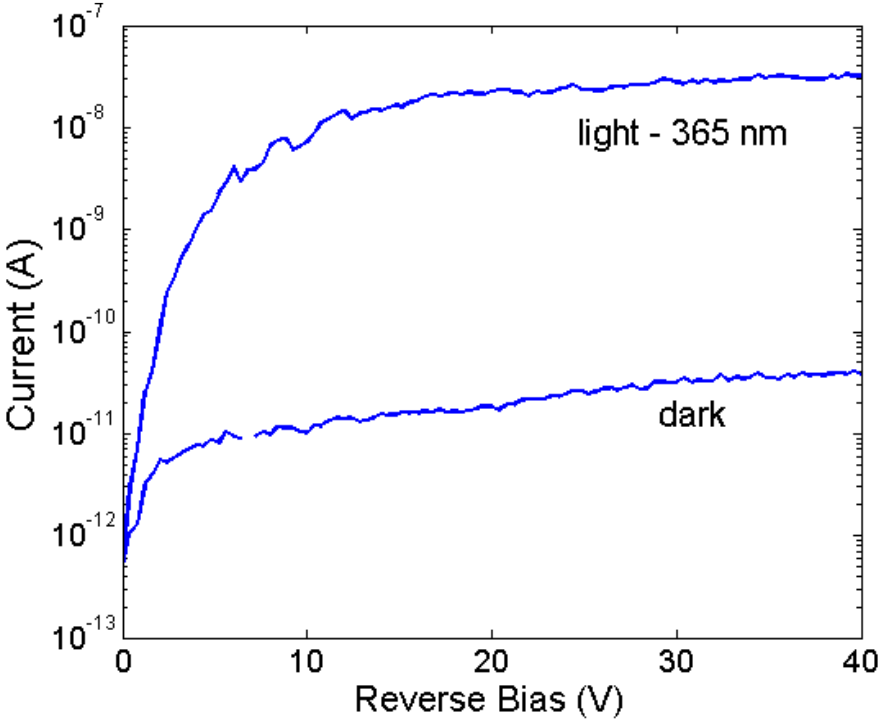
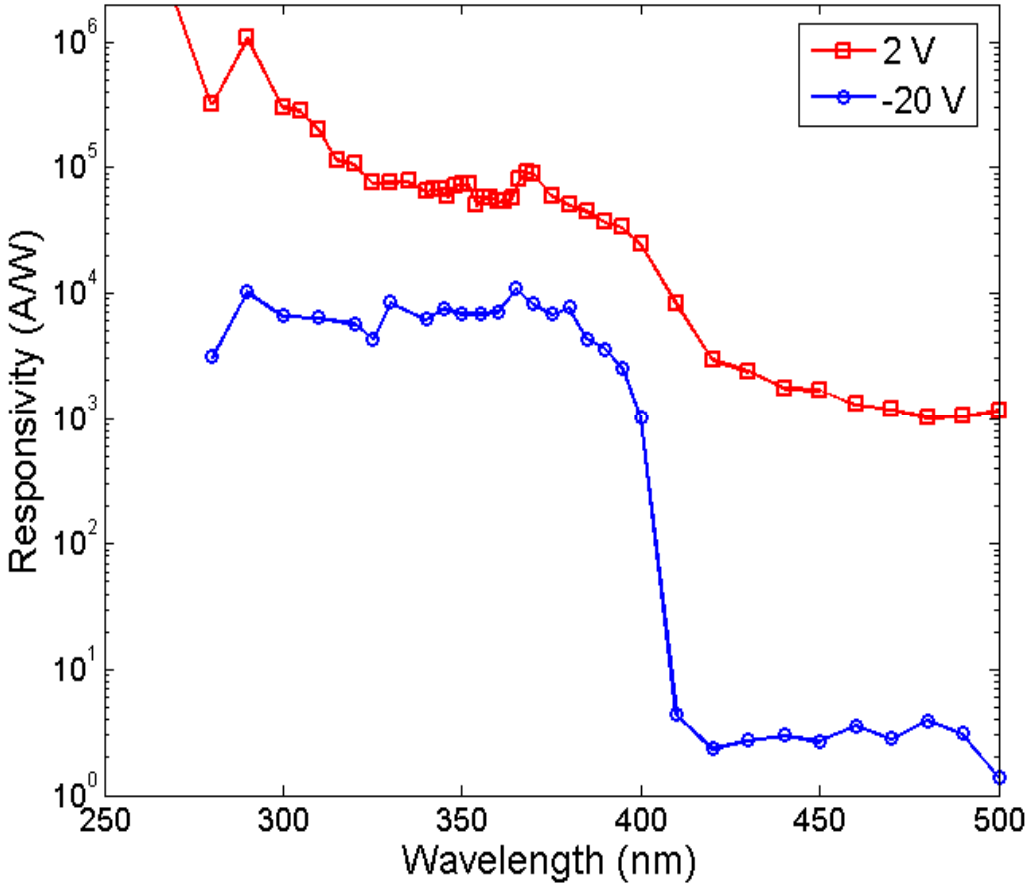








Detection range: 390-280 nm

Responsivity:

2V: 10^5 A/W

-20V: 10^4 A/W

Gain=10^4-10^5

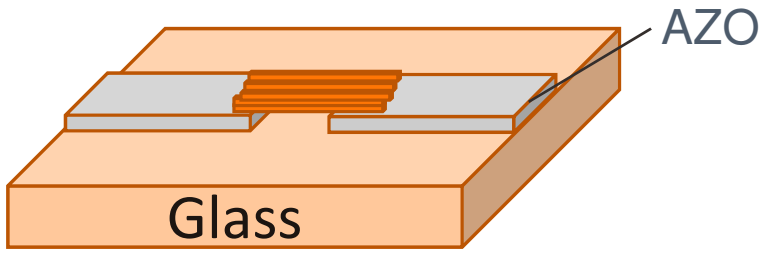
UV/visible contrast:

2V: 10^2

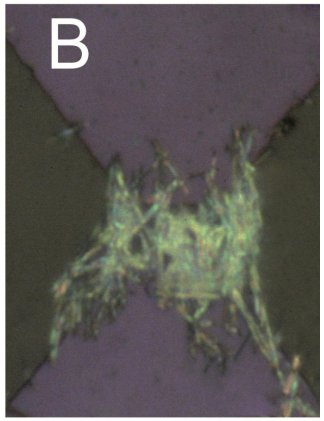
-20V: >10^3

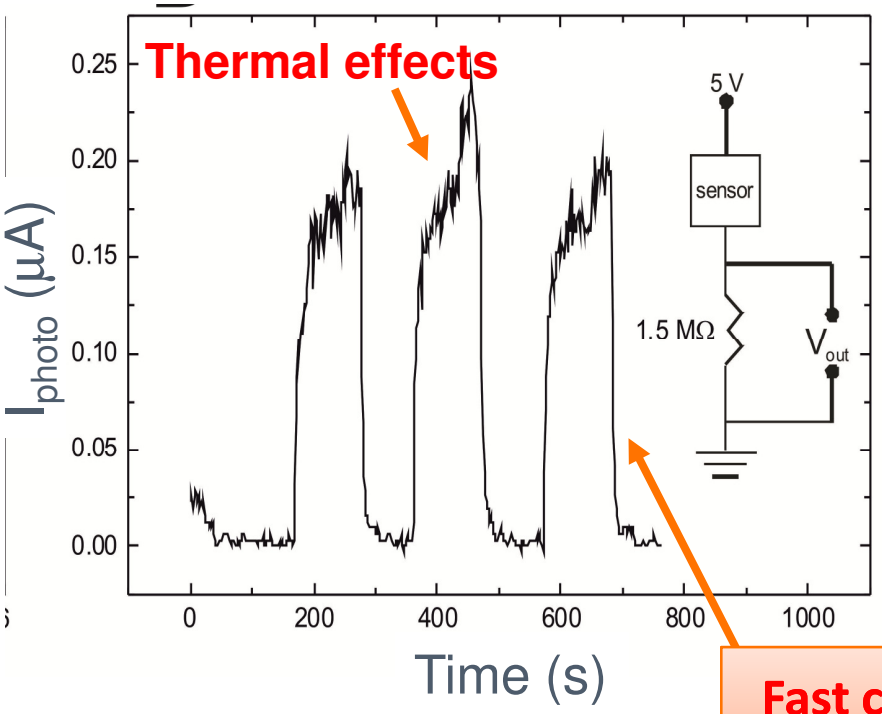
MULTI-NW DEVICES

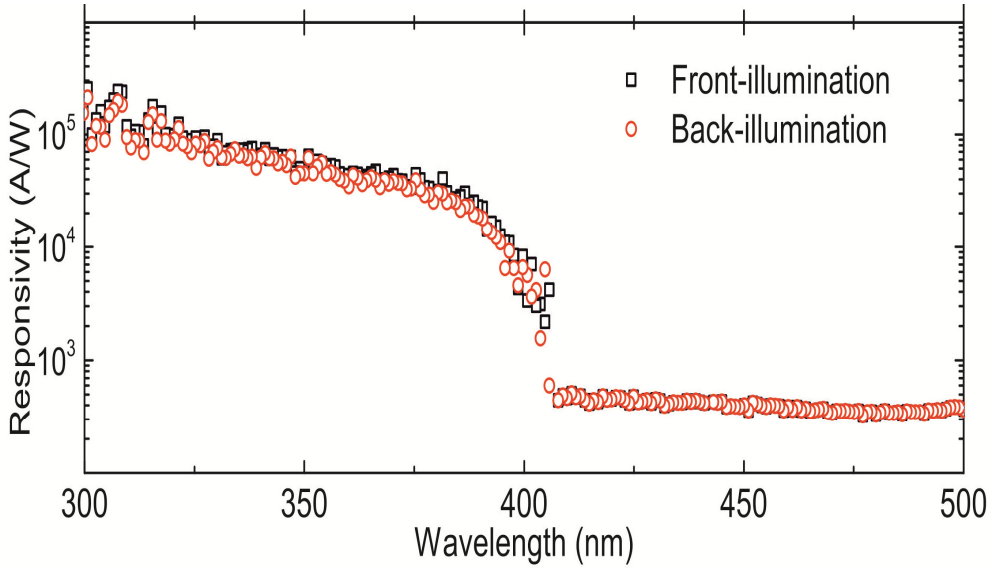
Blocking contacts



Fully transparent sensors







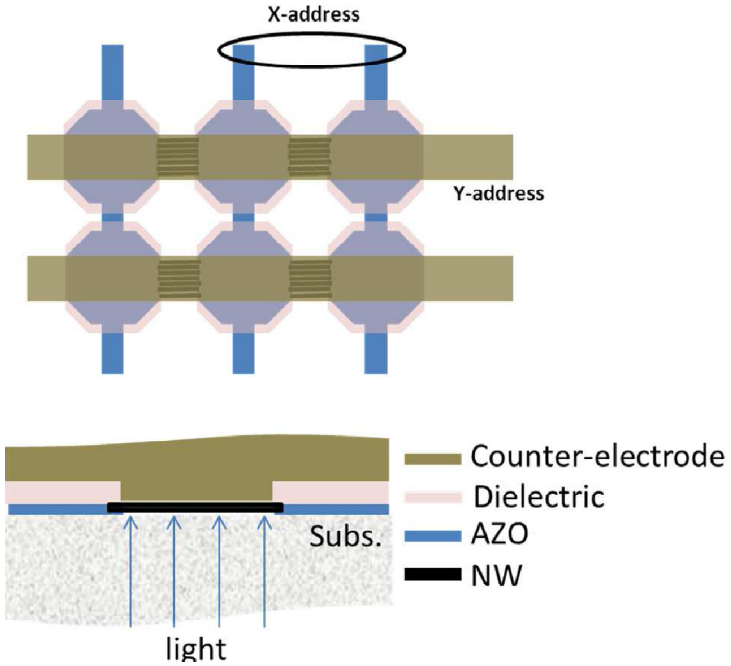
Fast current shutdown (<5% of the signal reached in <1s)

CONCLUSIONS and PROSPECTS

- DEP systems for NW integration developed
- Industrially scalable procedure for the fabrication of single NW and multi NW devices
- UV-visible photodetectors based on contacts formed by DEP have demonstrated to present fast response and very low leakage currents.

FUTURE WORK:

- Addressable arrays
- Heterogenous DEP - combining different NW technologies.



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(JdIC post-doc) A. Redondo
(Technicians) E. Ruiz, P. Rodríguez
(Faculty) J. Piqueras

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