INTEGRATED PHOTONIC DEVICE BY TOP DOWN FABRICATION PROCESSES

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Eagles meeting, Trento 18-19 october 2016

CNR IFN Institute for Photonics and Nanotechnologies

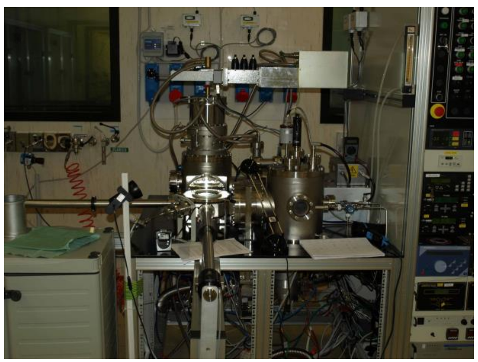
6 sites

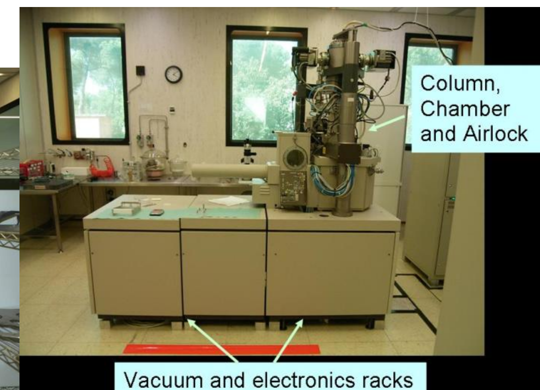
CNR IFN
Istituto di Fotonica e Nanotecnologie

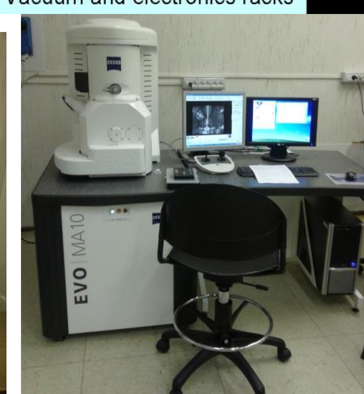
IFN- Rome site

IFN is a research institute of the Italian National Research Council (CNR)
IFN-Rome employs 12 permanent scientists, and 10 PhD/postdocs

- 250mq clean room
- Lithography (Electron Beam Lith., Photolith, Imprinting)
- Thin-film technology (sputtering, evaporators)
- Dry etching (RIE)
- MEMS (deep reactive ion etching, wet etching)







IFN- Rome Activities

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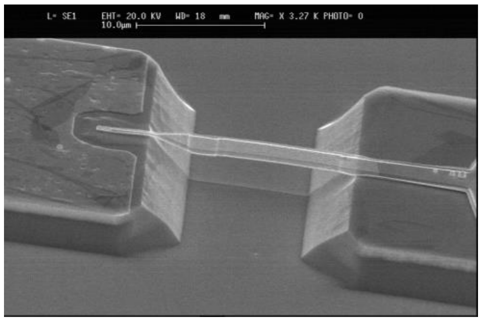
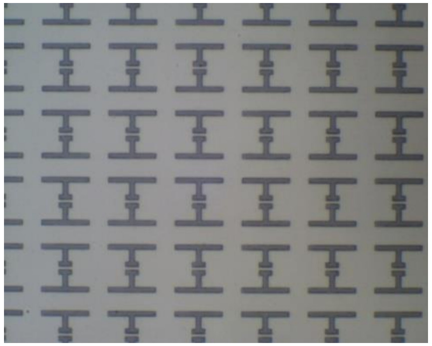
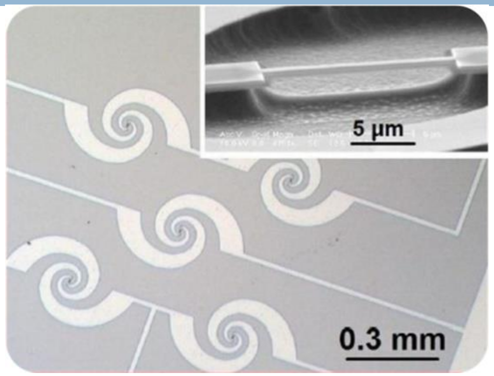
Sensing and Security



Schottky diode for electronic and photonic applications in the THz range



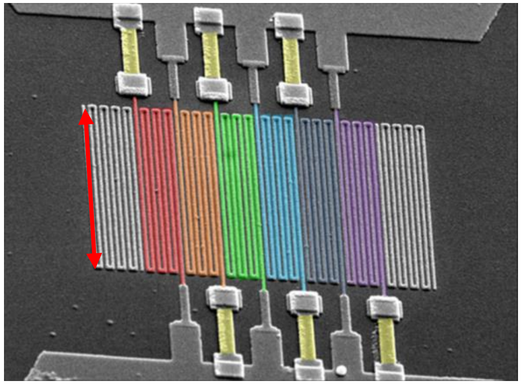
Metamaterial filters for the 1÷5 THz range



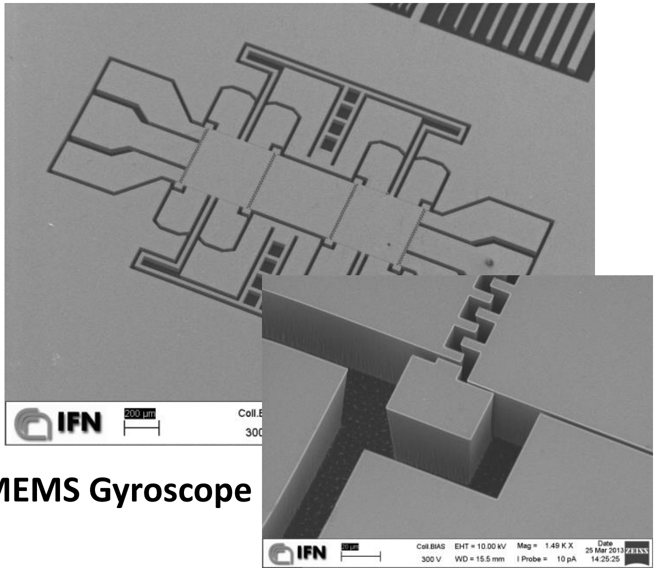
SHAB (Superconducting Hotspot Air-Bridge) detector for THz applications

Photonics

Photon number resolving detector



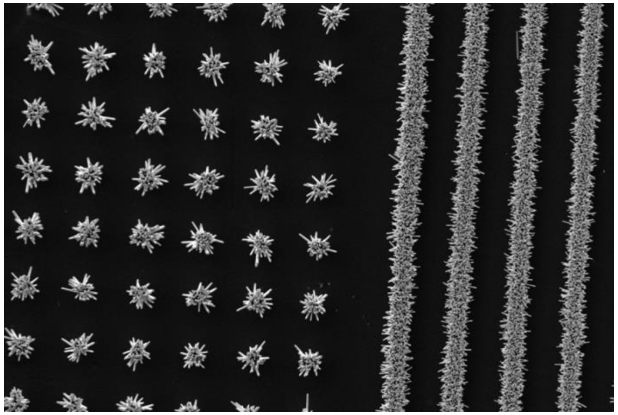
Aerospace



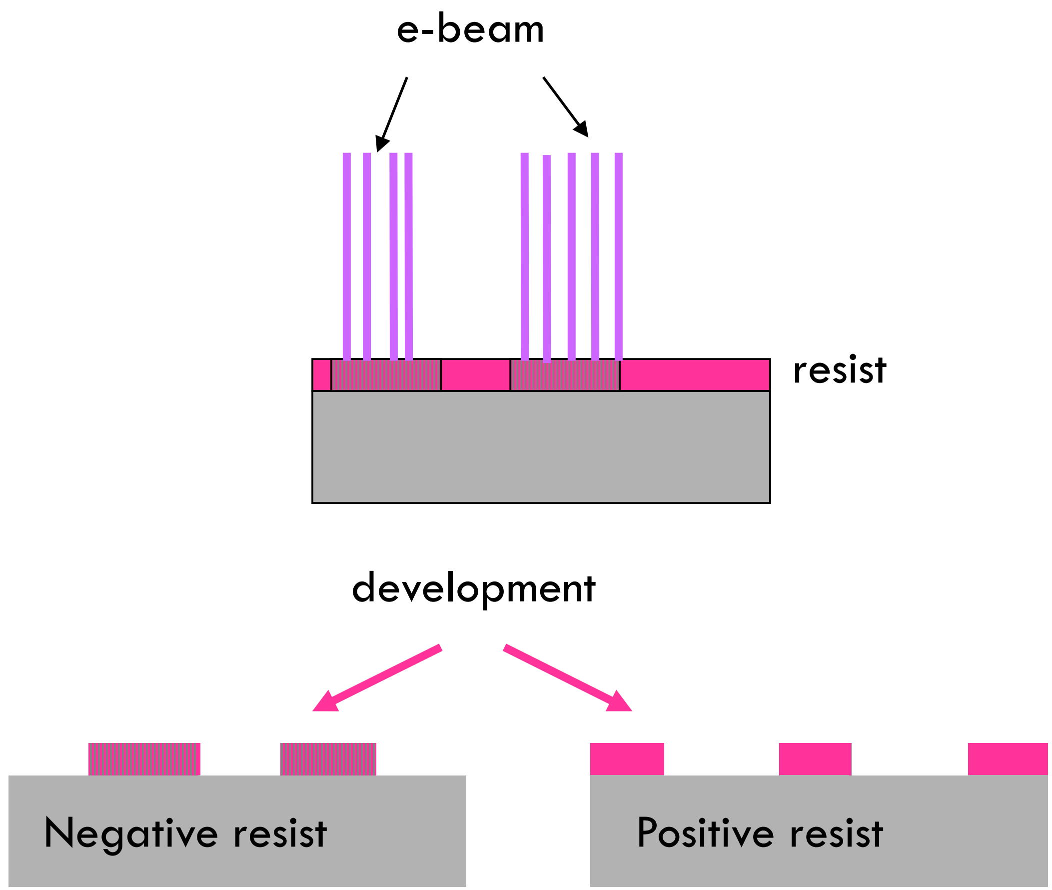
MEMS Gyroscope

Sensors and Energy Harvesting

Controlled growth of ZnO nanowires



Top down fabrication process



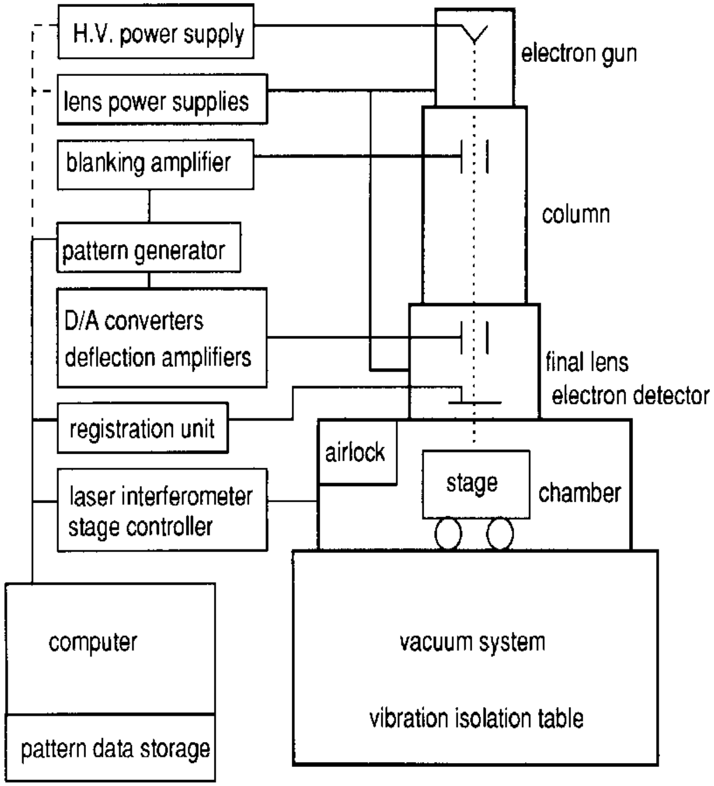
cross-linking the polymer chains together

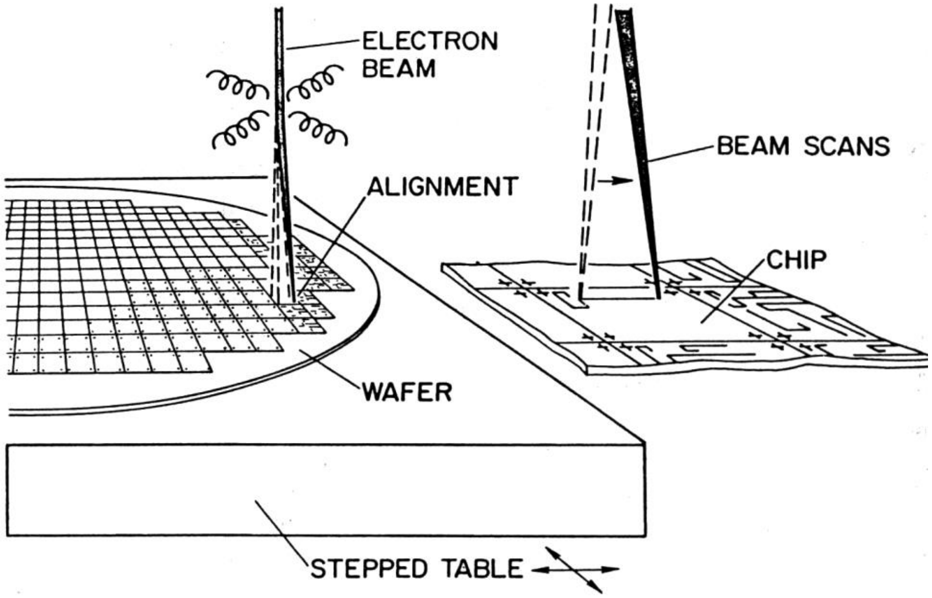
electron irradiation breaks polymer backbone bonds

Exposed area are not soluble

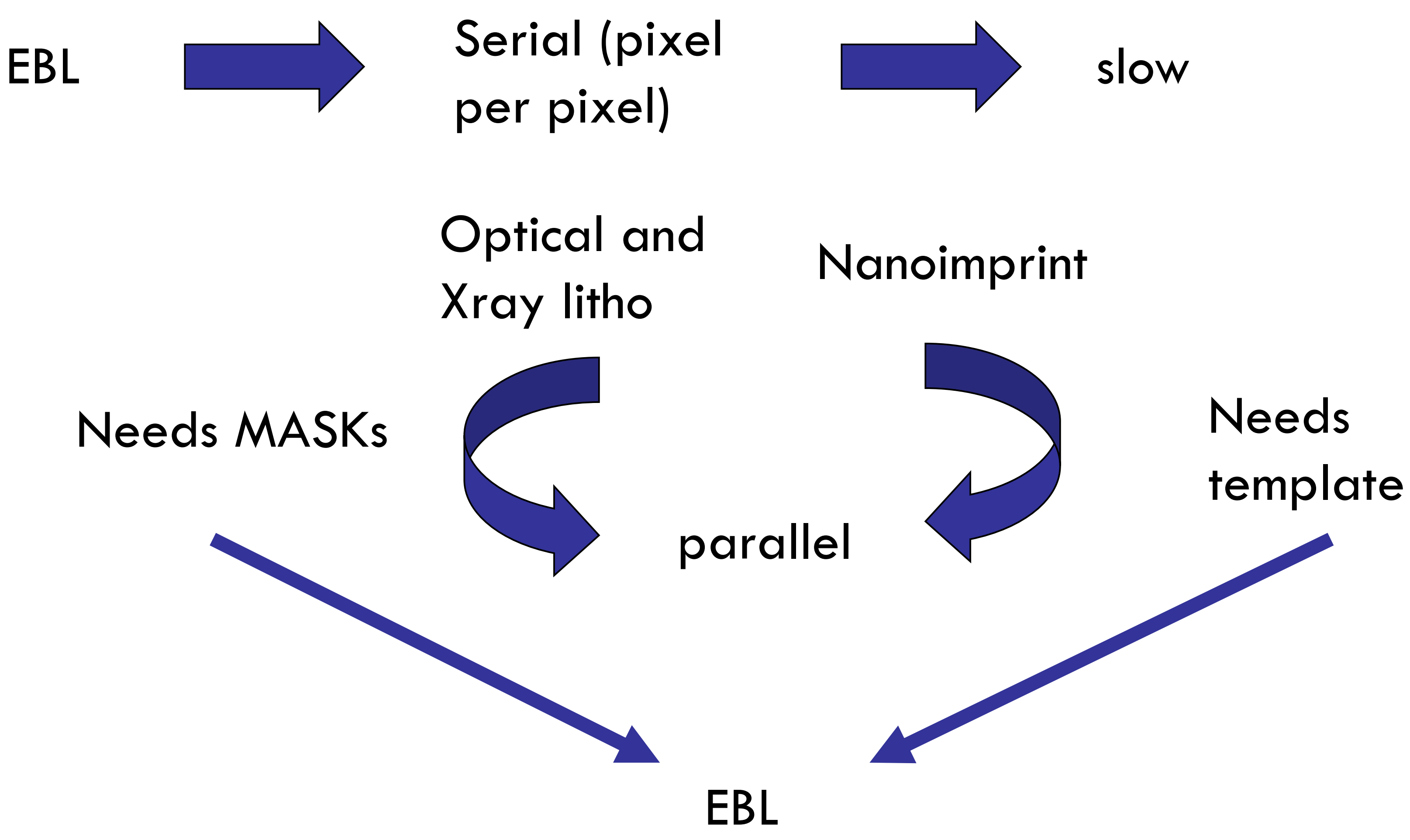
Exposed area are more soluble

Electron Beam Lithography

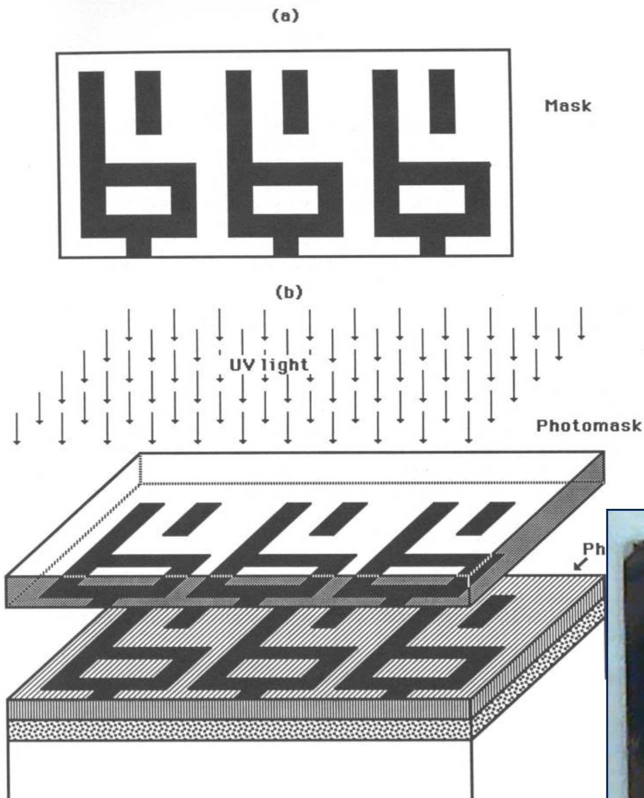




Comparison between different lithographies



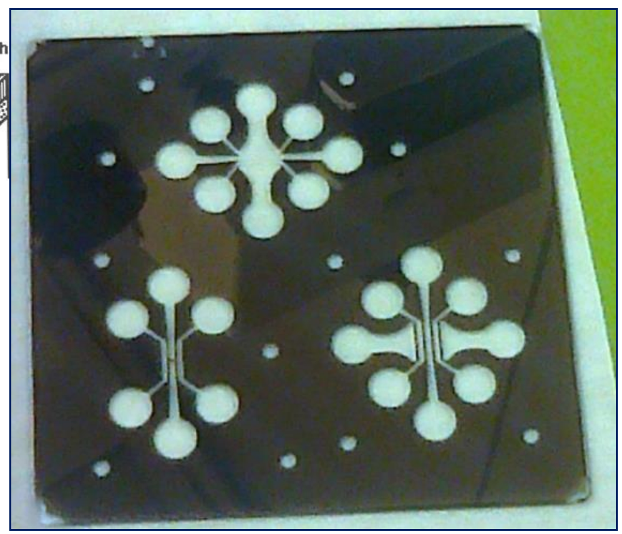
Optical Lithography



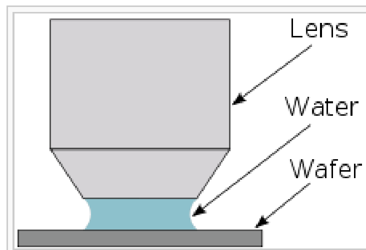
PARALLEL PROCESS

Need a Mask

- resist: sensitive to UV light (thickness: 100 nm- mms)
- mask: quartz and Cr film
- exposure: UV
- development

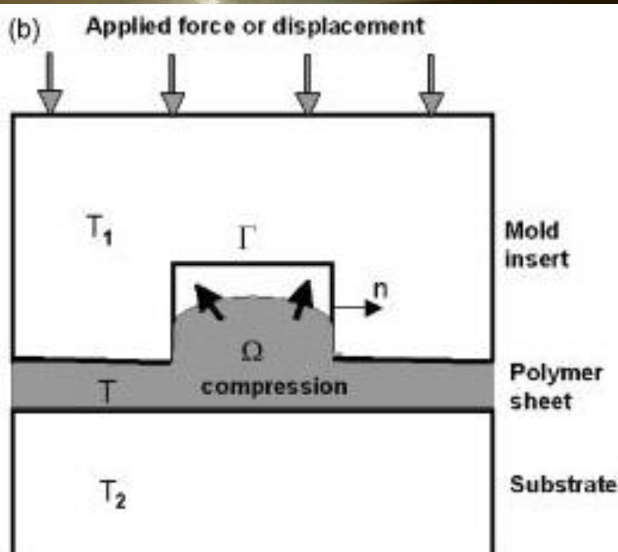


IMMERSION LITHOGRAPHY

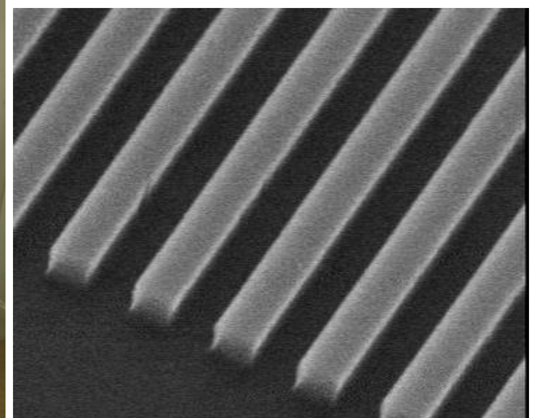


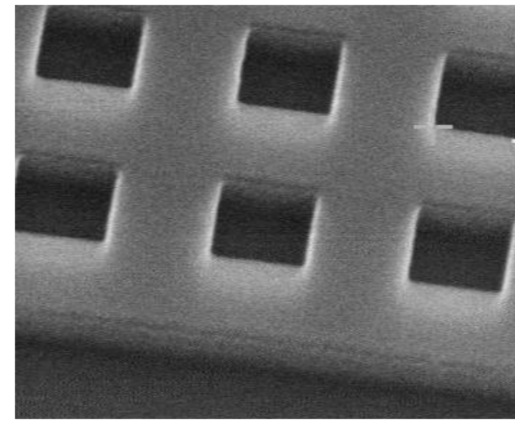
In immersion lithography, light travels down through a system of lenses and then a pool of water before reaching the photoresist on top of the wafer.

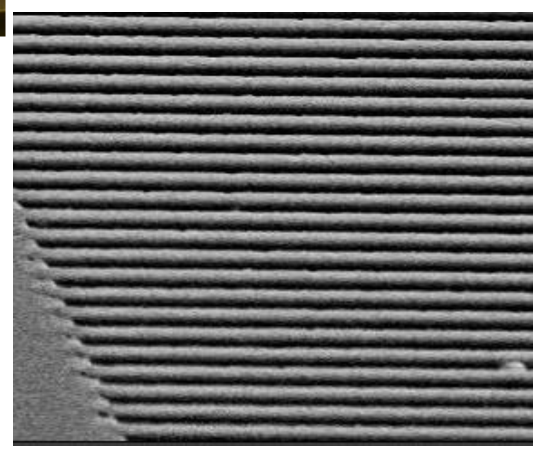
Nanoimprint

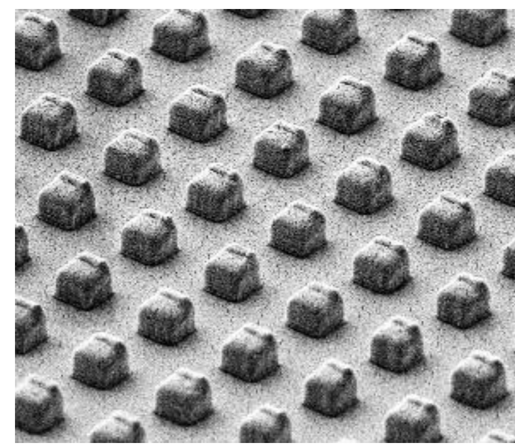


Si etched master





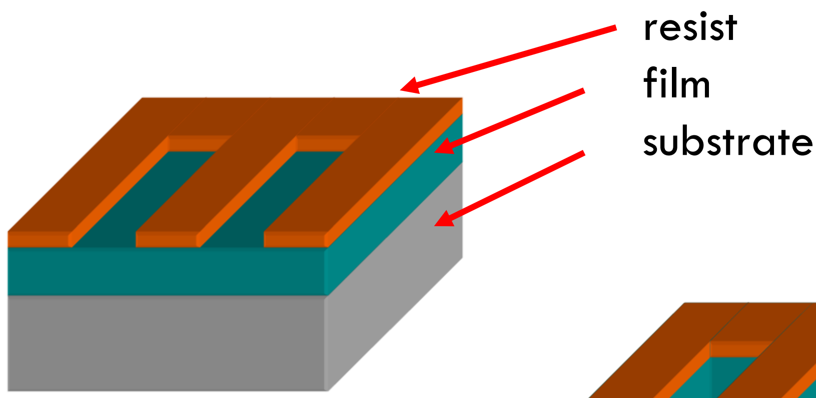




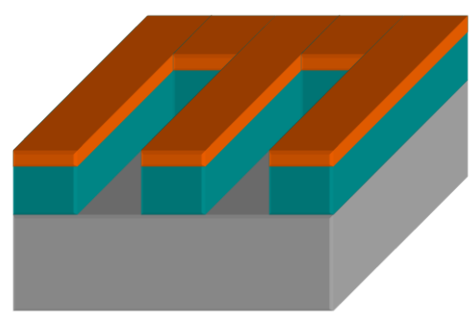
PS nanoimprinted petri

PE nanoimprinted coverslip

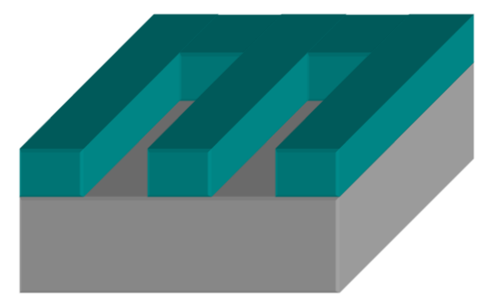
Top down fabrication process



development

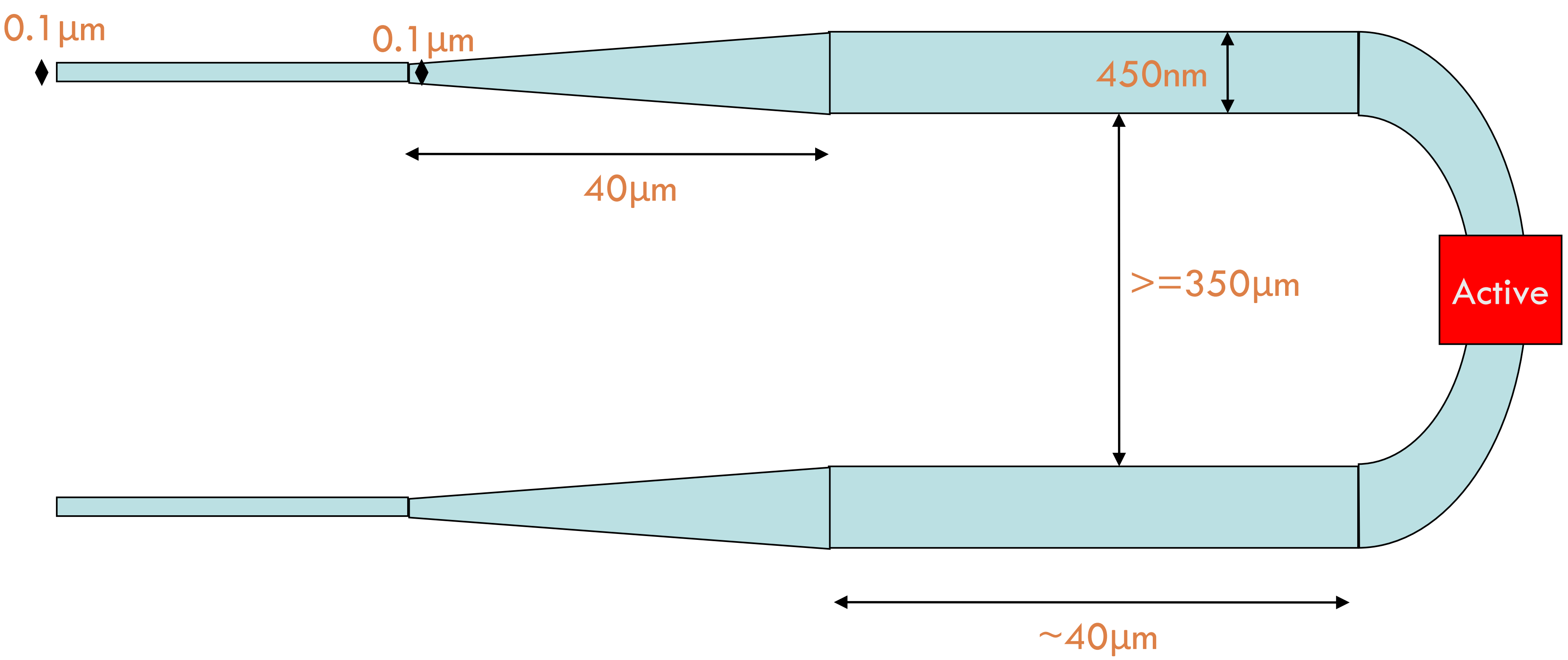


Selective etching of the film
through the resist mask



Stripping (resist removal)

Waveguide Fabrication Process: Design
General coupling Scheme



All optical modulator

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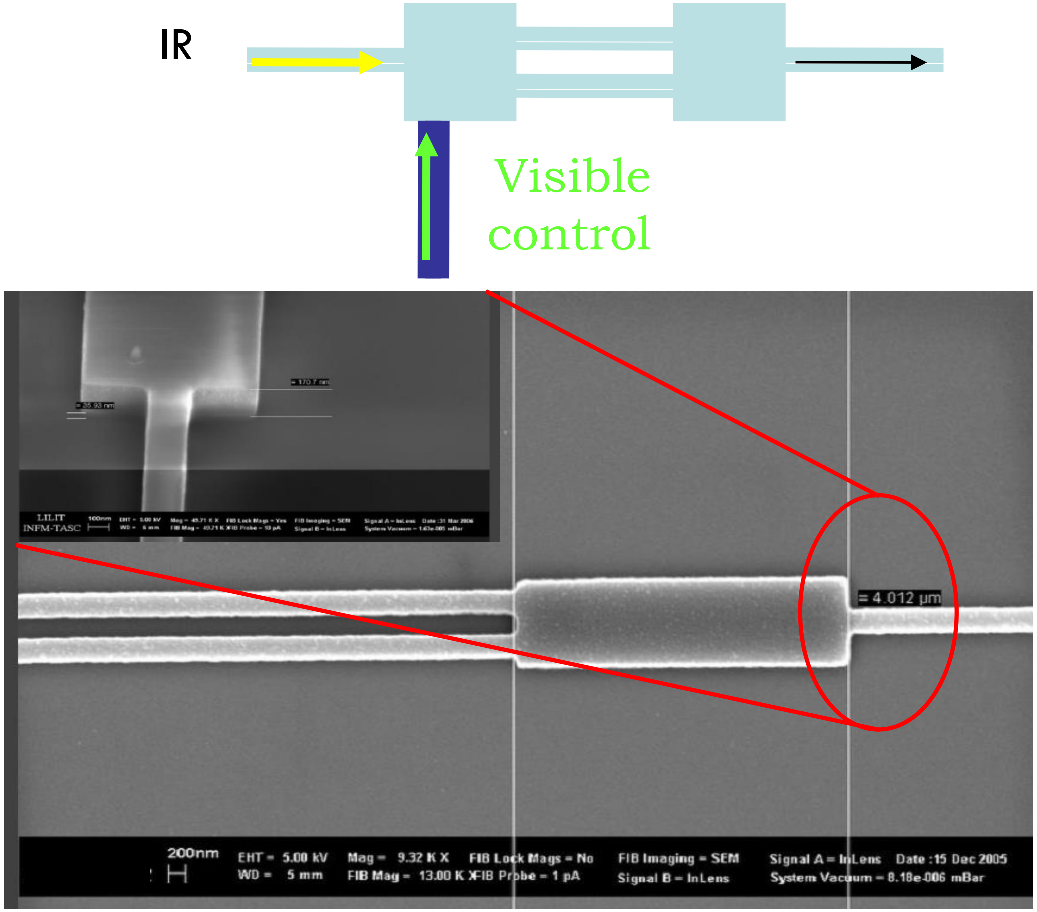
By illuminating the MZI structure with visible light, one varies the Si refraction index and Si absorption coefficient for an Infra-Red (IR) information beam passing through it.

- nano-scale device much smaller than in previous concepts using light induced Si absorption changes (device area of ~ 1µm2 instead of hundreds of square microns).
- Spatially non-uniform illumination (speckes) => obtain a high contrast modulator with better performance than a device based on direct illumination on a waveguide
- No high Finesse resonator, so our device is less sensitive to wavelength shifts and to spectral transmission and its operation rate is no longer connected to the time required for the optical response to reach steady state but rather to material related effects (although in general in Si, the free electron life time is usually longer than the life time of photons inside the resonator).



Collaboration with Bar Ilan University;
Prof. Zeev Zalevsky

All optical logic gate

ZrO 2 film (that was used as photo-resist) doped with QDs which have a significant gain factor over small interaction length

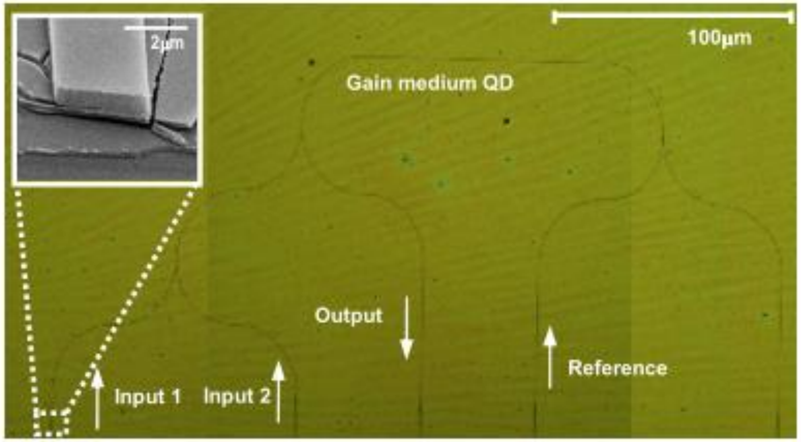


Figure 1. Microscope image of the fabricated nano photonic device. On the upper left corner one may see the SEM image of the fabricated QD waveguide.

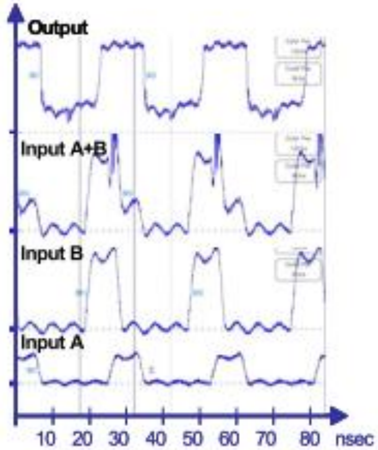
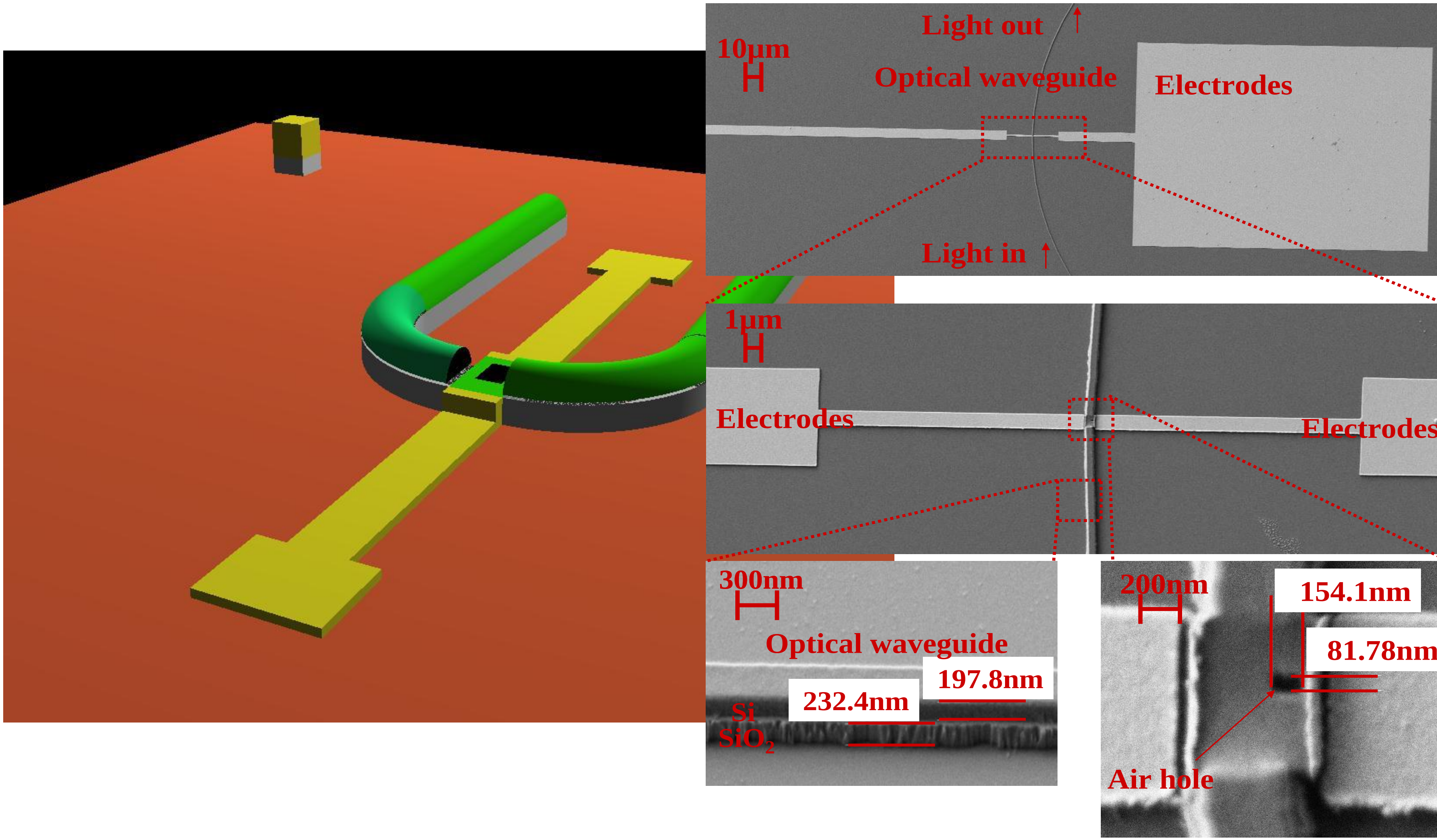


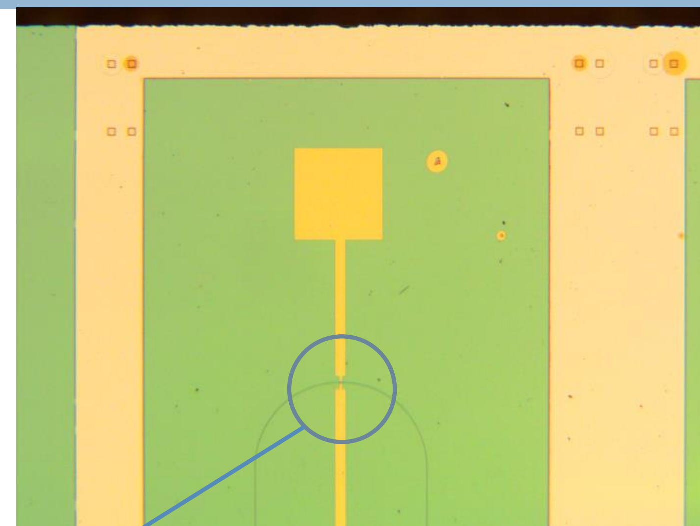
Figure 2. Experimentally obtained preliminary results for all-optical logic NOR gate (using SOA).

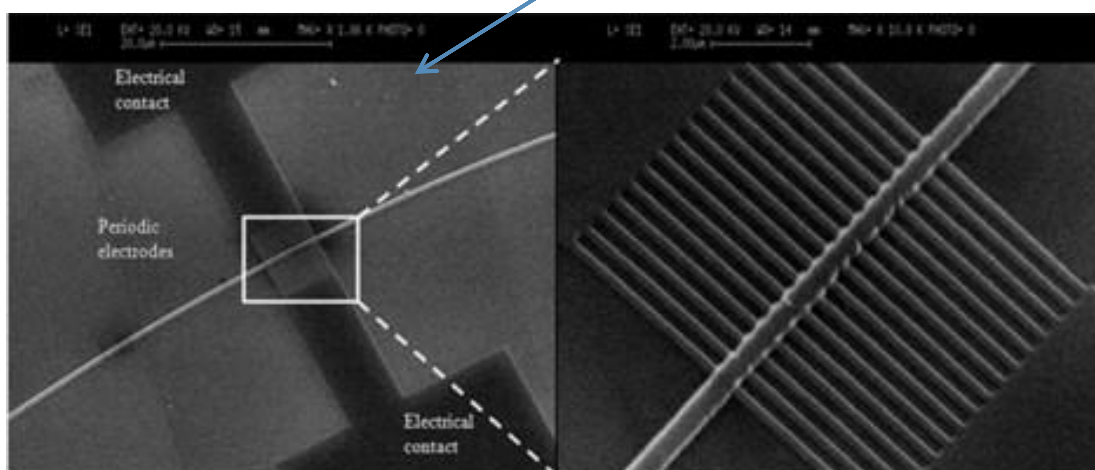
Electro-optical nano modulator on silicon chip 1



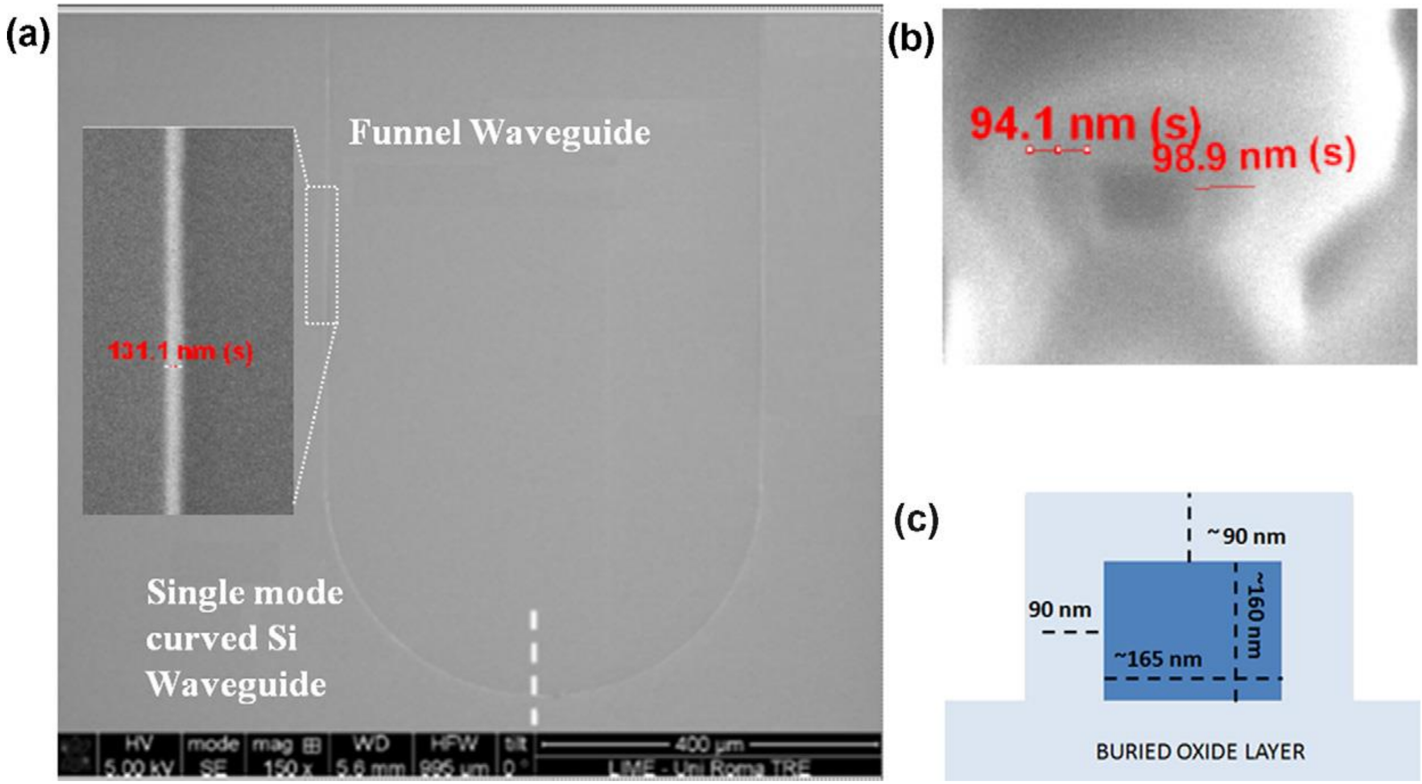
Electro-optical nano modulator on silicon chip 2

- Plasma dispersion effect in Silicon
- Array of periodically arranged Indium Thin Oxide (ITO) electrodes (like Bragg mirror) located along both sides of the optical core
- By applying voltage on the electrodes a periodic change in the free electrons is occurred along the optical core → change in refractive index



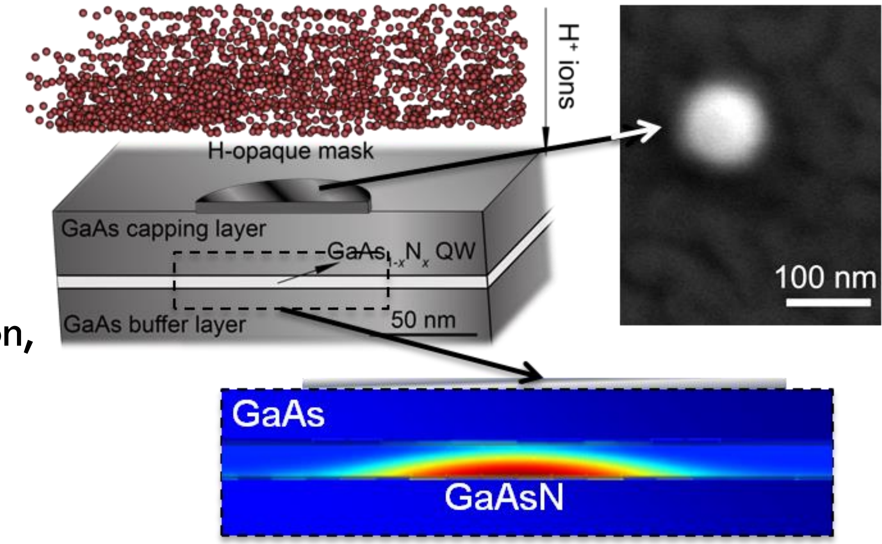


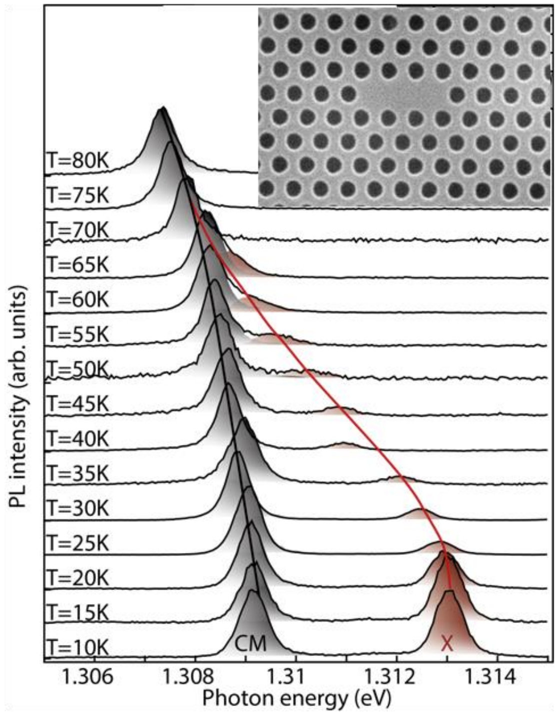
Waveguide fabrication



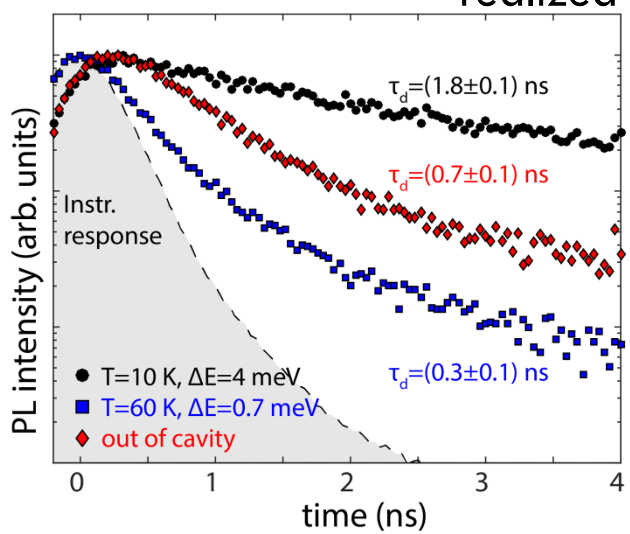
Nanophotonics for Quantum Information Technology

The spatial and spectral coupling between site-controlled single photon emitter quantum dot (QDs) and photonic crystal (PhC) nano-cavities is achieved by combining spatially selective hydrogen implantation in dilute nitrides (for QD fabrication) with photonic crystal fabrication, both using EBL techniques





Verification of ***Purcell Effect*** on a QD-PhC cavity system realized at IFN-CNR

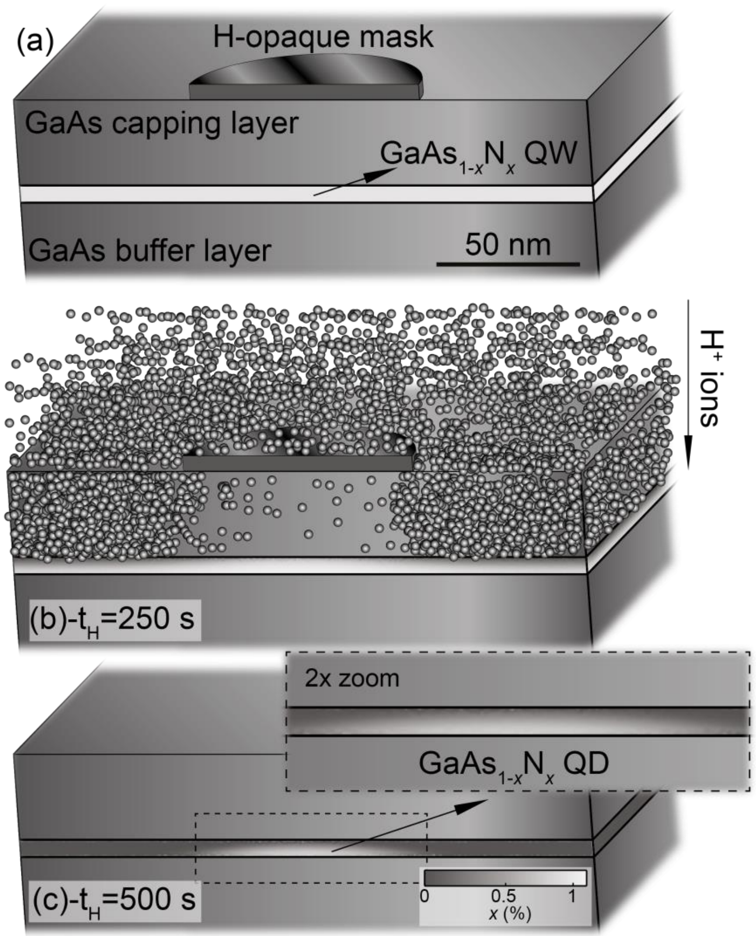


significant enhancement (inhibition) of the spontaneous emission rate for small (large) cavity mode-QD energy detuning

G. Pettinari *et al.*, *JAP* **115**, 012011 (2014)

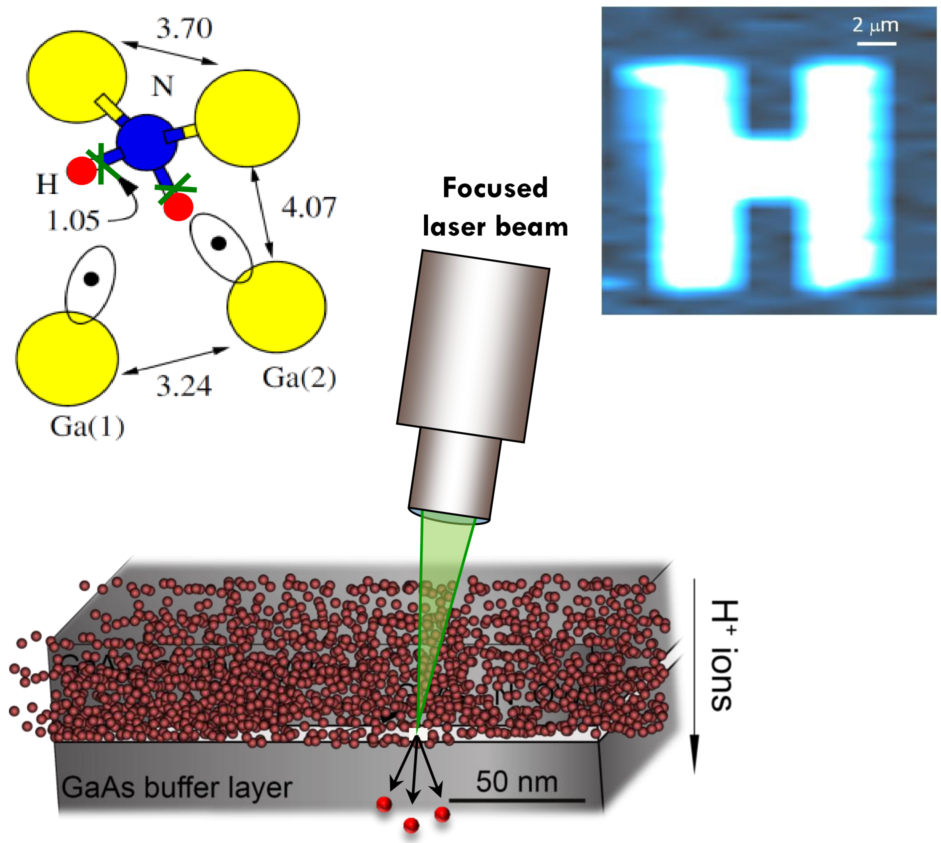
QD fabrication: Two strategies

QD by spatially selective hydrogenation



Direct band gap laser writing

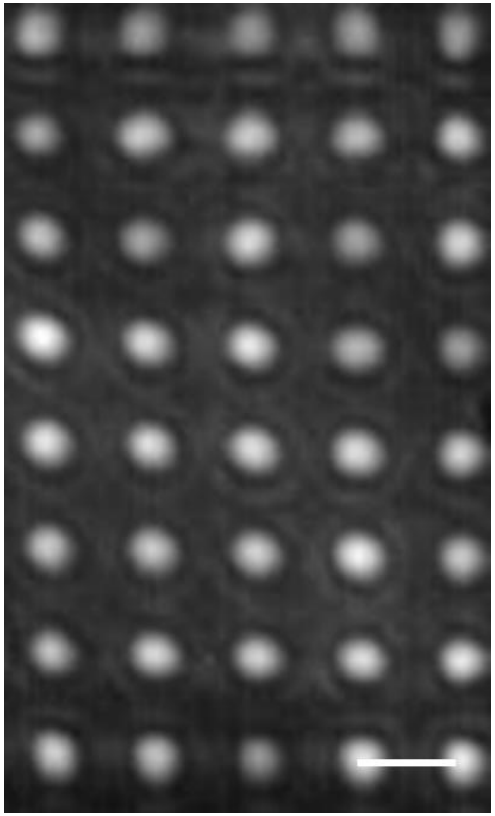
H removal by focused laser beam



N. Balakrishnan *et al.*, *PRB* **86**, 155307 (2012)

QD properties

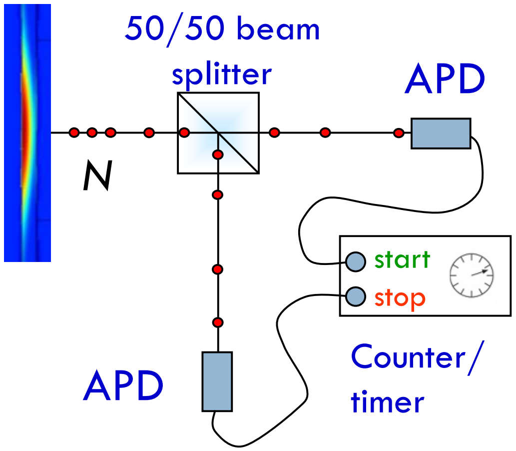
For sufficiently small mask sizes, can quantum confined effects be observed



R. Trotta *et al.*, *Adv. Func. Mat.* **22**, 1782 (2012)

G. Pettinari *et al.*, *JAP* **115**, 012011 (2014)

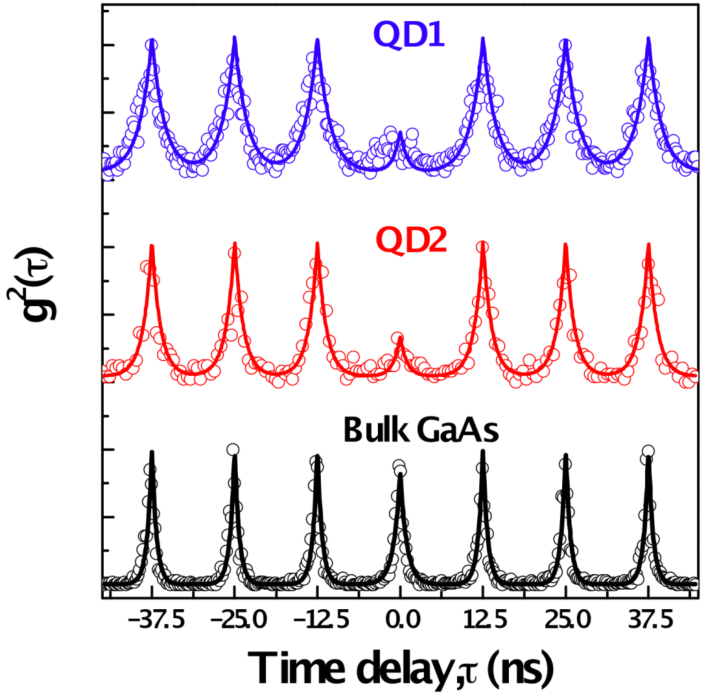
Hanbury-Brown-Twiss setup



$$g^2(\tau) = \frac{\langle I(t)I(t+\tau)\rangle}{\langle I(t)\rangle^2}$$

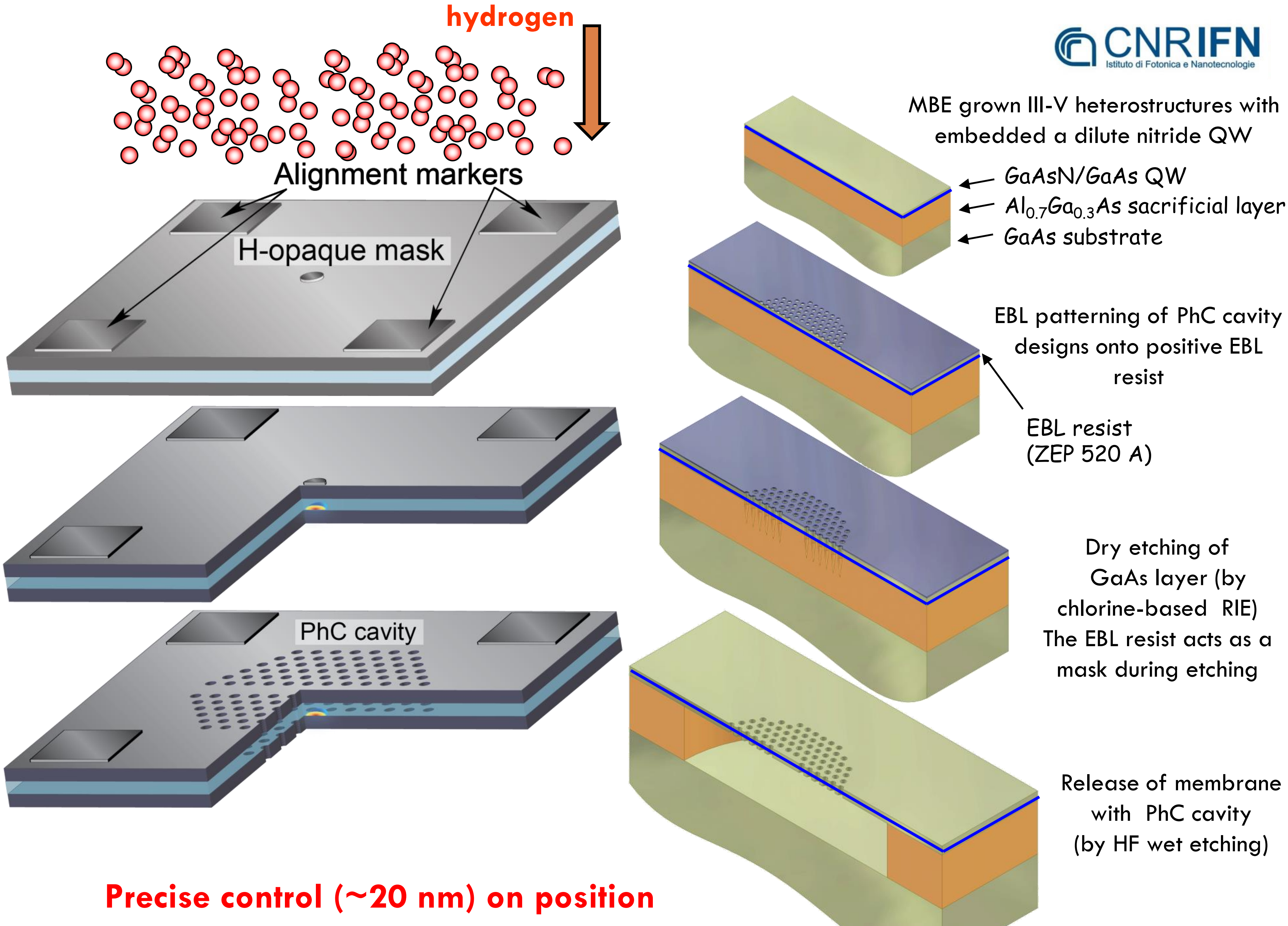
$$g^2(0) = 1 - \frac{1}{N}$$

Time-domain autocorrelation

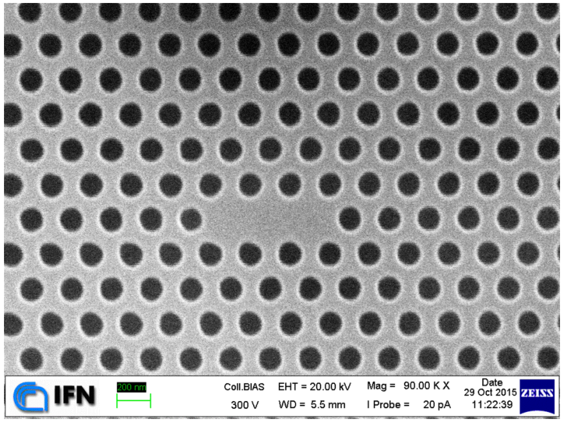


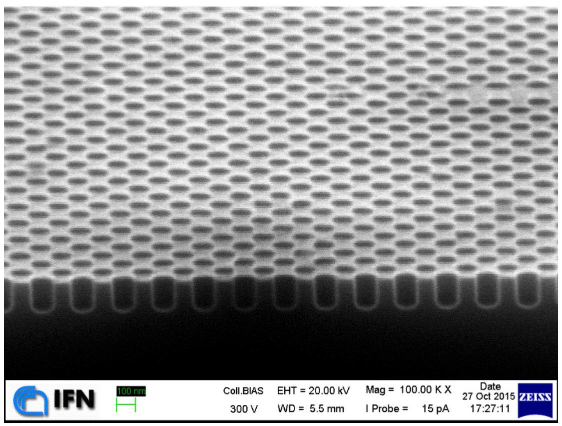
Single photon emission

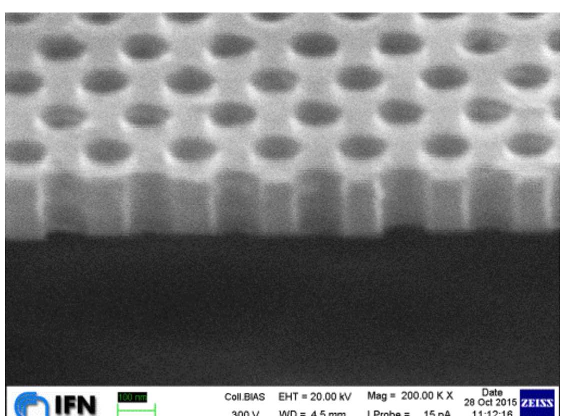
S. Birindelli *et al.*, *Nano Letters* **14**, 1275 (2014)

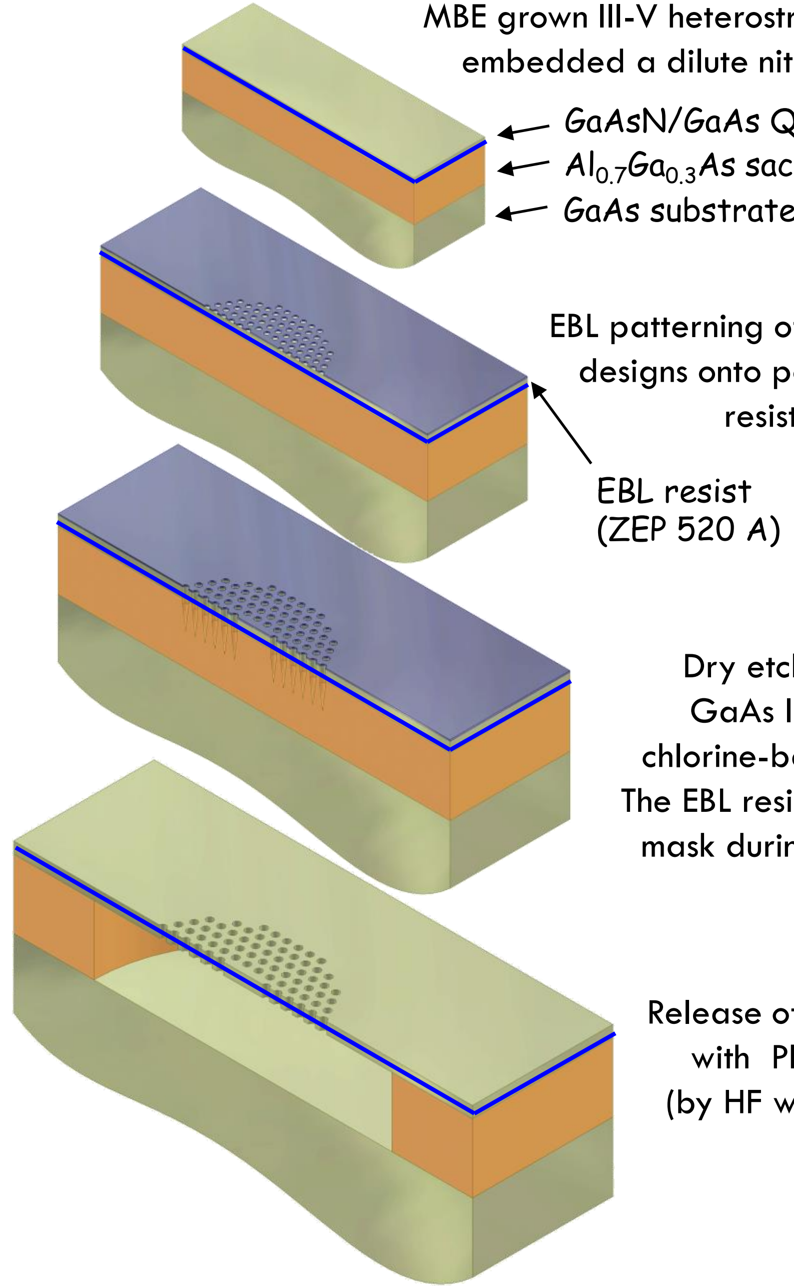


hydrogen
Alignment markers
H-opaque mask
PhC cavity
Precise control (~20 nm) on position
MBE grown III-V heterostructures with embedded a dilute nitride QW
GaAsN/GaAs QW
$Al_{0.7}Ga_{0.3}As$ sacrificial layer
GaAs substrate
EBL patterning of PhC cavity designs onto positive EBL resist
EBL resist
(ZEP 520 A)
Dry etching of GaAs layer (by chlorine-based RIE)
The EBL resist acts as a mask during etching
Release of membrane with PhC cavity
(by HF wet etching)









MBE grown III-V heterostructures with embedded a dilute nitride QW

EBL patterning of PhC cavity designs onto positive EBL resist

Dry etching of GaAs layer (by chlorine-based RIE) The EBL resist acts as a mask during etching

Release of membrane with PhC cavity (by HF wet etching)

THANK YOU FOR YOUR ATTENTION

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