Open Discussion Topic:

Digital Society Trends: Challenges on Large Scale Use of QNM Technologies

Moderator:

Victor Ovchinnikov, Helsinki University of Technology, Finland

Panel:

H. Joerg Osten, Leibniz University of Hannover, Germany

Sylvain Martel, Ecole Polytechnique de Montreal (EPM), Canada

Ivano Ruo-Berchera, INRIM, Italy

Vladimir Privman, Clarkson University, USA

Igor Sokolov, Clarkson University, USA

List of questions for the panel members and the audience to address in connection with their favorite QNM technologies:

1. How advanced is this QNM technology beyond theoretical designs and basic experimental research, to engineering and manufacturing possibilities?

2. What are the perspectives and timeline for "conveyer line" manufacturing of actual products. What about the reproducibility and cost issues?

3. Regulatory challenges, health risks, and environmental impacts.

Some details of what do these items mean are given next.

The audience is welcome to add questions or suggest modifications.

V. Priman

Challenges posed by the failure of the “technician” engineering paradigm: the expectation that a technician can make any device as long as it is well-designed by an engineer. QNM technologies are still primarily at the basic-science stage of research and development.

This applies to quantum technologies in particular, but actually is a main challenge for any nanotechnology. There is a gap between molecular-level design and actual experimental and even more so, manufacturing realization.

A related challenge is the “conveyer-line” set of issues with QNM designs: reproducibility, cost, etc. (Nanomanufacturing is now a separate NSF program.)

Regulatory challenges: no nanoparticles should be allowed in air or water.

Related: health risks and environmental impacts.

I. Sokolov

1. How advanced is this QNM technology beyond theoretical designs and basic experimental research, to engineering and manufacturing possibilities?

Self-assembly

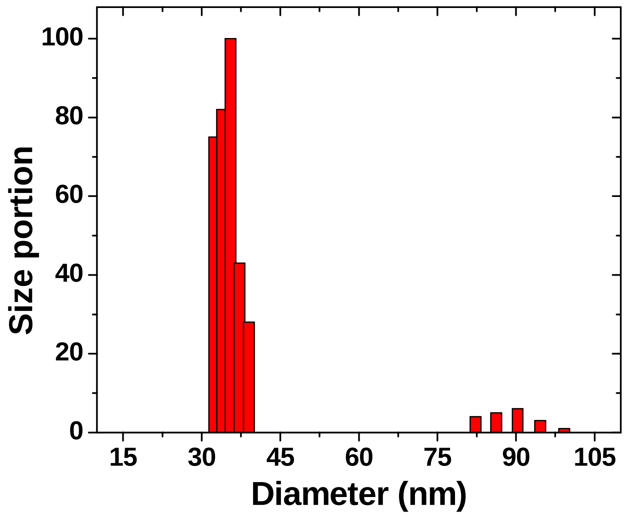
2. What are the perspectives and timeline for "conveyer line" manufacturing of actual products. What about the reproducibility and cost issues?

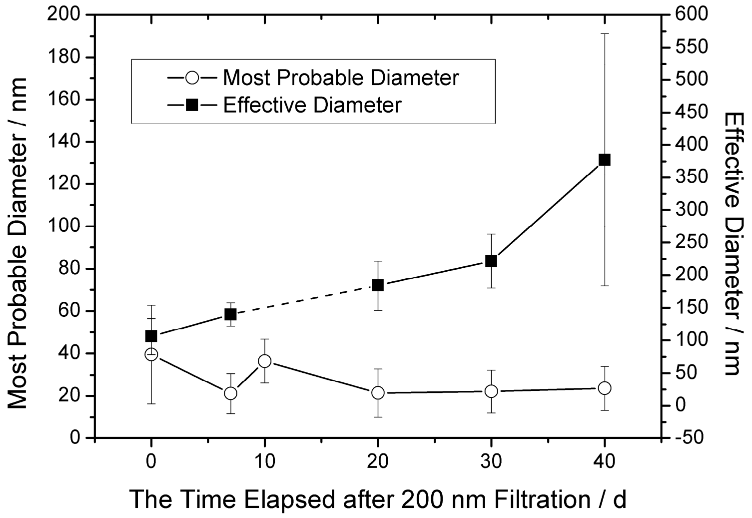
Very near..

3. Regulatory challenges, health risks, and environmental impacts.

Silica examples

Example: Mass production of ultra-bright fluorescent silica nanoparticles





S. Martel

QNM TECHNOLOGIES 1/3

- How advanced is this QNM technology beyond theoretical designs and basic experimental research, to engineering and manufacturing possibilities?
  - General theoretical designs and basic experimental research concentrate on the small (nano- micro-) scale independently or without too much effort on the interfacing aspect with the macro-scale.
  - For better and more useful engineering possibilities, constraints and characteristics at the macro-scale must be studied in parallel with the nano-scale with the aim to interface adequately both scales and to exploit the physical properties for both scales to complement each others.

S. Martel

QNM TECHNOLOGIES 2/3

- What are the perspectives and timeline for ‘conveyer line’ manufacturing of actual products. What about the reproducibility and cost issues?
  - Depending on products, conveyer line approach is questionable, exploiting self-assembly is more likely for higher throughput and lower cost. But self-assembly is limited, could potentially be more appropriate by complementing it with some minimum level of controlled assembly. Trade-off between the two approaches will be required for cost issue.
  - Reproducibility for many nanoscale components at the present time is not very good (e.g. commercial nanoparticles of specific diameter may vary substantially, also formation of clusters, etc…)

S. Martel

QNM TECHNOLOGIES 3/3

- Regulatory challenges, health risks, and environmental impacts:
  - Issue on health risks (e.g. nanoparticles) are mostly based on the fact that some have been used for a relatively long time (e.g. Iron –Oxide particles) and everything seems OK so far so it should be OK to continue.
  - Much more research is needed to understand how the body (immune system) reacts, for instance a material compatible at a large scale is not automatically compatible when implemented at the nano-scale. The surface of the nano-components is also important, etc. A lot of unknowns, so difficult at the present time to impose regulations without slowing down research but at the same time protecting patients. This is a real regulatory challenges at the present time.

Surface plasmon resonance in large scale arrays of silver nanocrescents

V. Ovchinnikov

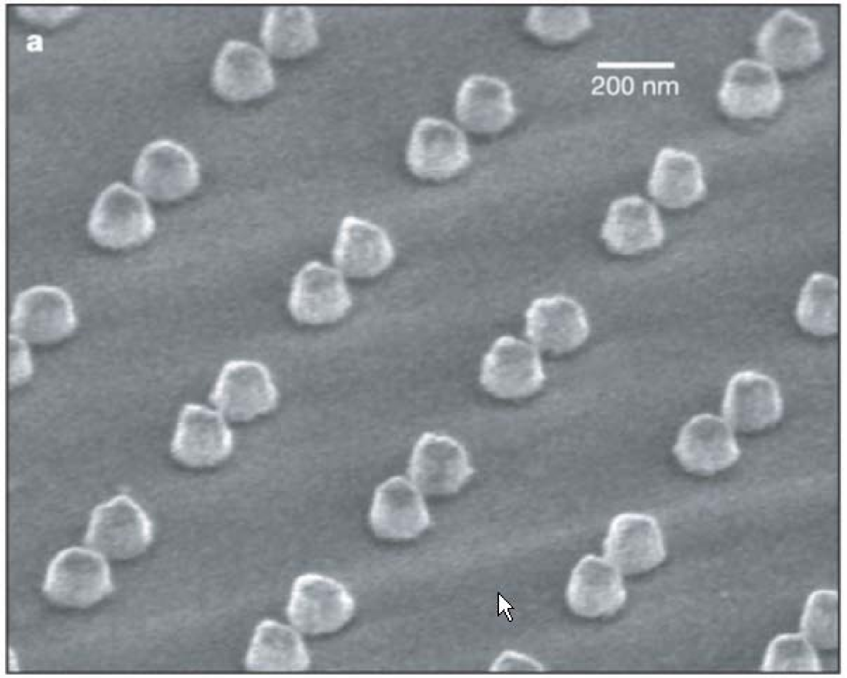
MICRONOVA Nanofabrication Centre
School of Science and Technology
Aalto University
Espoo, Finland

Motivation

- Fabrication of metal nanostructures with desired shapes and orientations, for nanoscale shaping of electromagnetic fields, e.g. in near-field optics and SERS applications
- Development of magnetic and left-handed metamaterials operating at optical wavelengths
- Reliable fabrication technique of large-sized metamaterials for effective integration of plasmonic nanostructures in real-world applicable devices
- Experimental verification of unusual properties, e.g. second-harmonic generation or magnetic resonance

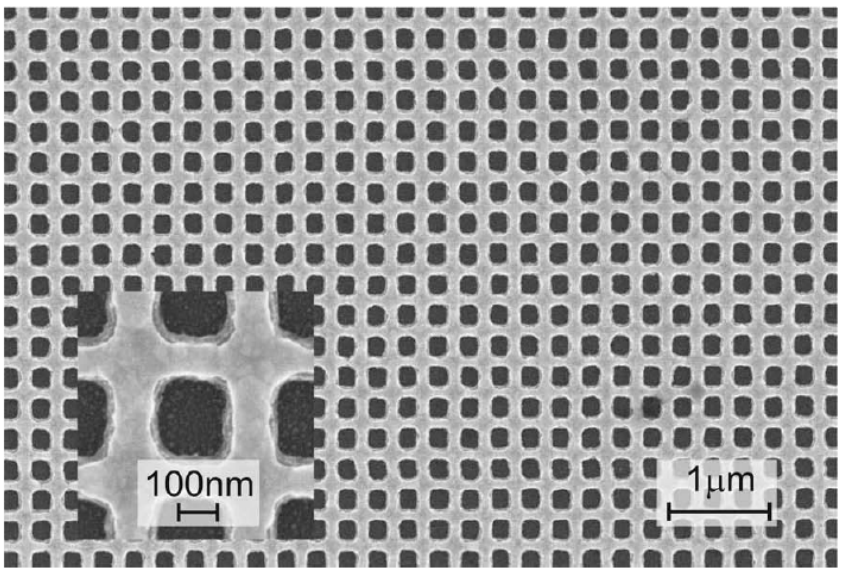
Ordered arrays

500 nm magnetic resonance. Au/glass, separation s = 140 nm, height h = 90 nm and average diameter d = 110 nm, area 0.1 mm^2



A.N. Grigorenko *et al*., Nature **438**, 335 (2005)

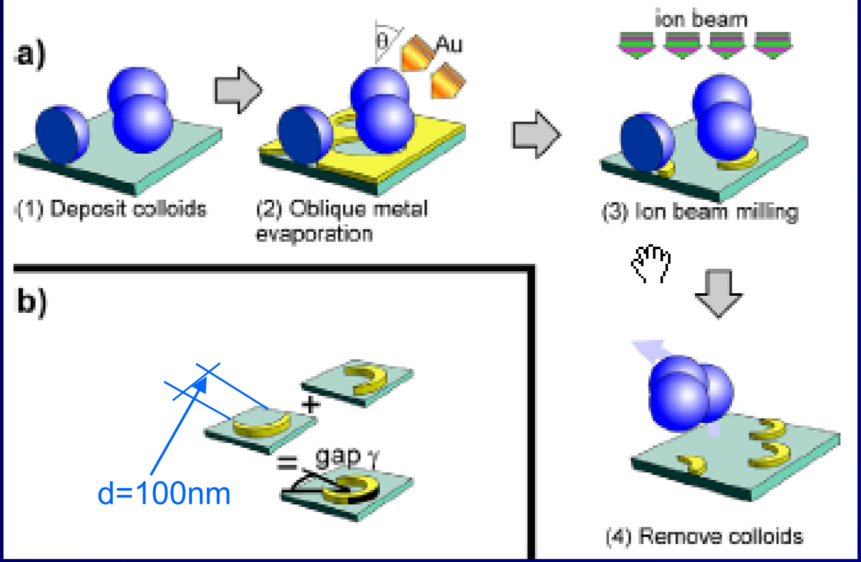
Negative index of refraction at **780 nm**. Stack Ag-MgF$_2$-Ag 97 nm / ITO 5nm / glass, area 100x100 um

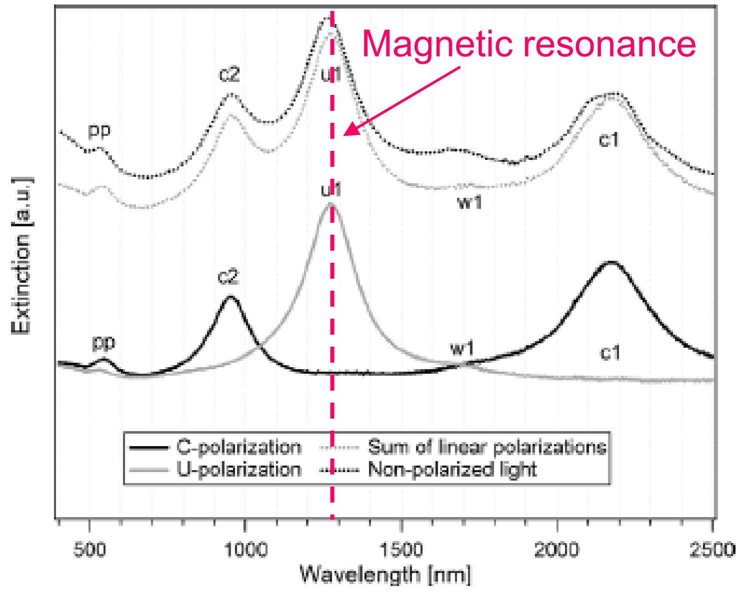


G. Dolling *et al*., Opt. Lett. **32**, 53 (2007)

Partly disordered arrays

Only separation between nanospheres is disordered, diameter is the same





1300 nm magnetic resonance. Au/glass, opening γ = 120º, Au thickness h = 20 + 20 nm and colloid diameter d = 150 nm, area 0.1 mm^2

H. Rochholz *et al*., New Journal of Physics, **9** (2007) 53

Comparison of the fabrication methods

Electron beam lithography

- Time-consumable, hours
- Small-area samples, 0.1×0.1 mm^2
- Limited resolution, min size > 50nm
- Limited structure height, max 100 nm

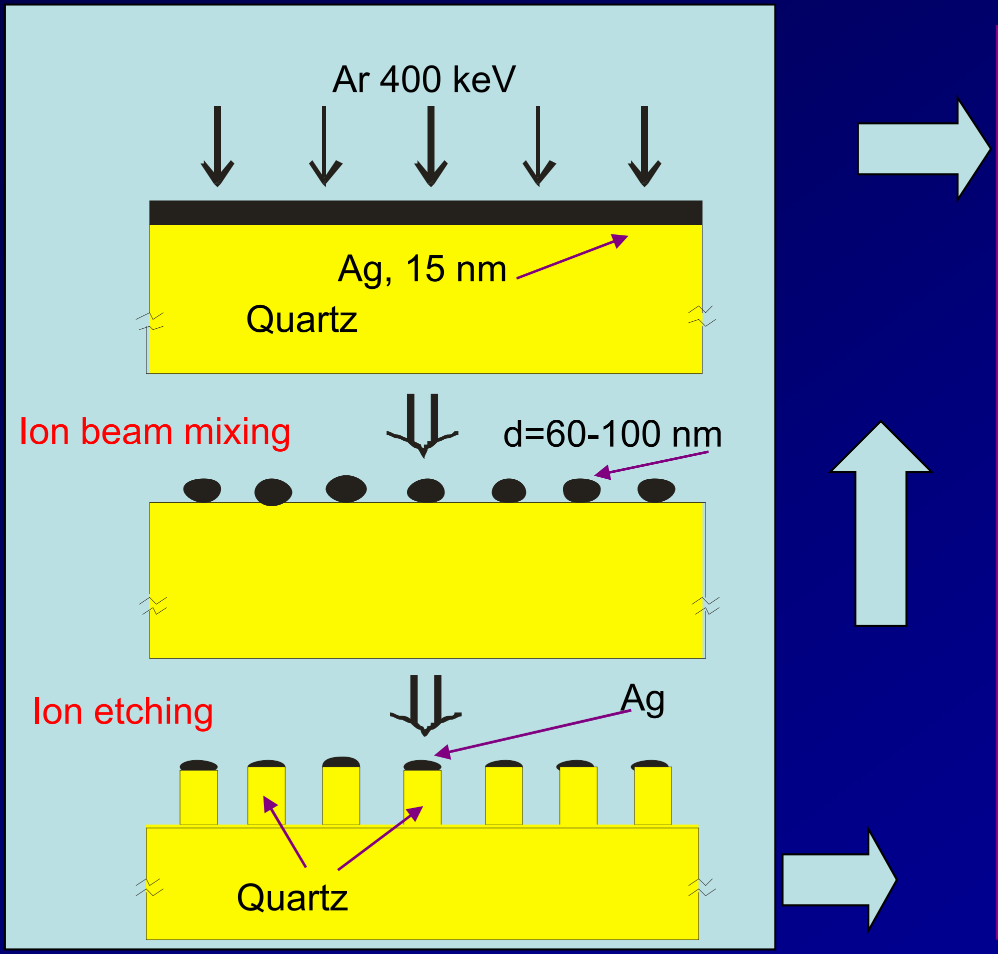
Nanosphere lithography

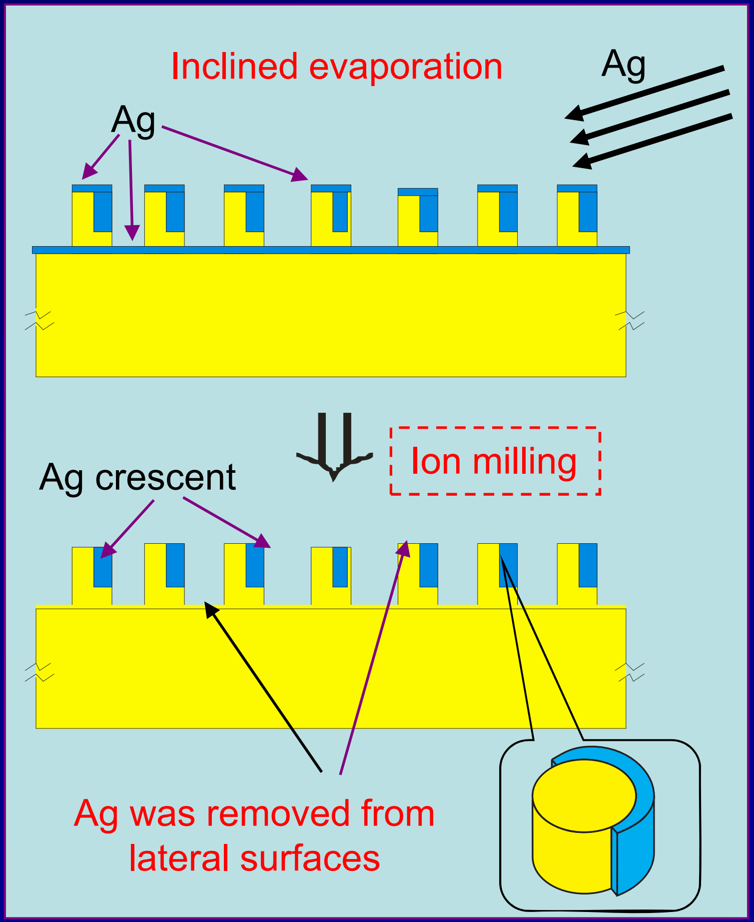
- Bad reproducibility
- Bad uniformity on large-area substrates
- Structure diameters > 60 nm
- Limited structure height, max d / 3

Fabrication of nanocrescent array

Formation of nanopillars using Ag surface islands as etching mask

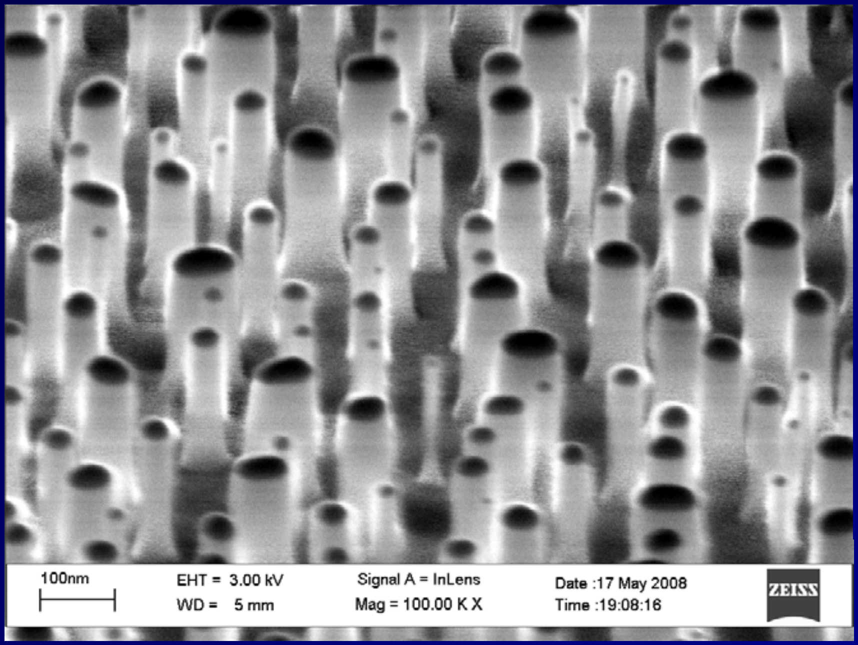
Fabrication of Ag nanocrescents by inclined evaporation and ion milling





Ag crescents with SiO_2 core

SiO_2 nanopillars

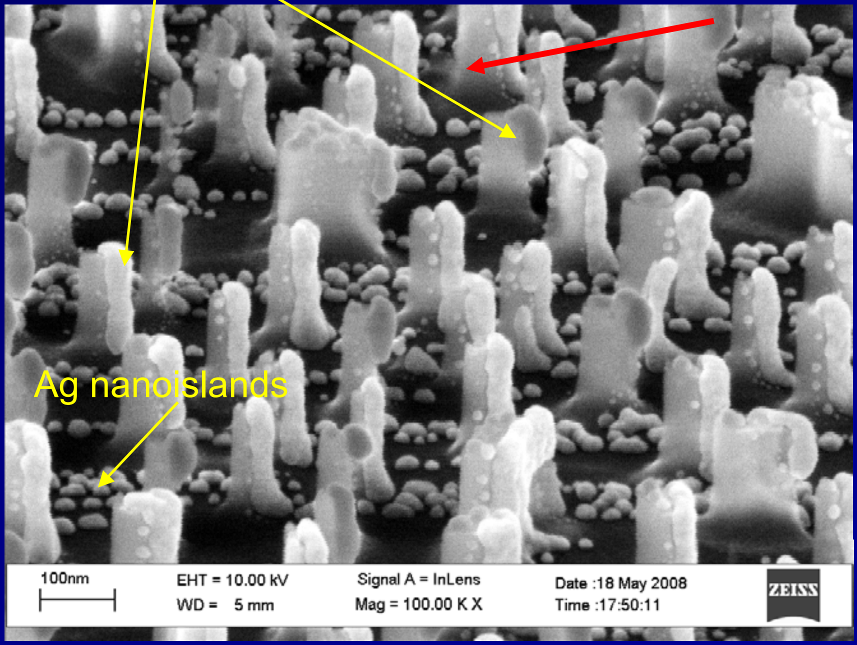


Height 170 nm, diameter 75 nm

SiO_2 nanopillars partly covered by Ag

Sidewall covered by
Ag fully and partly

Direction of
deposition



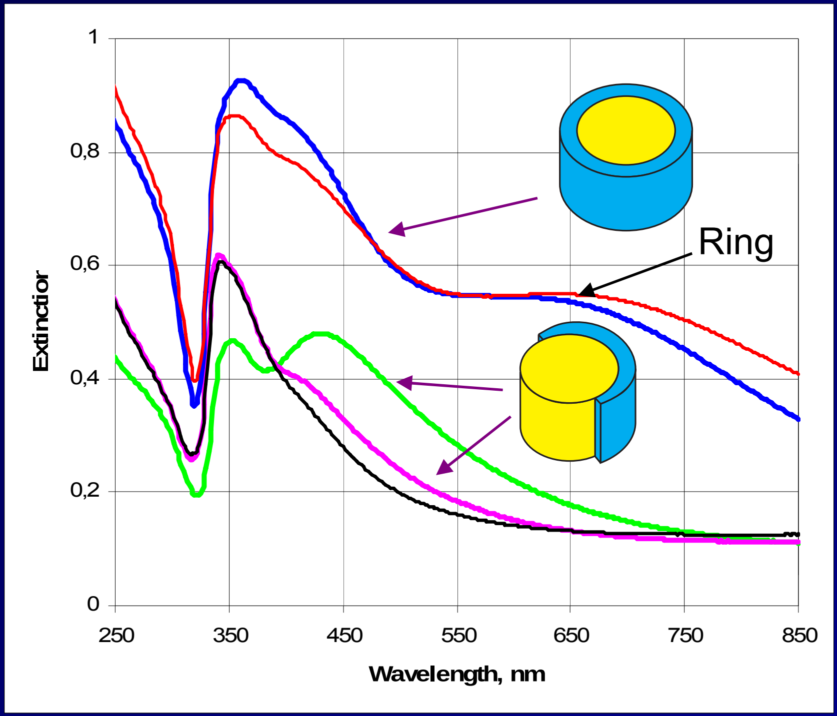
Ag nanoislands

Inclined evaporation of Ag (20 nm) at 75º

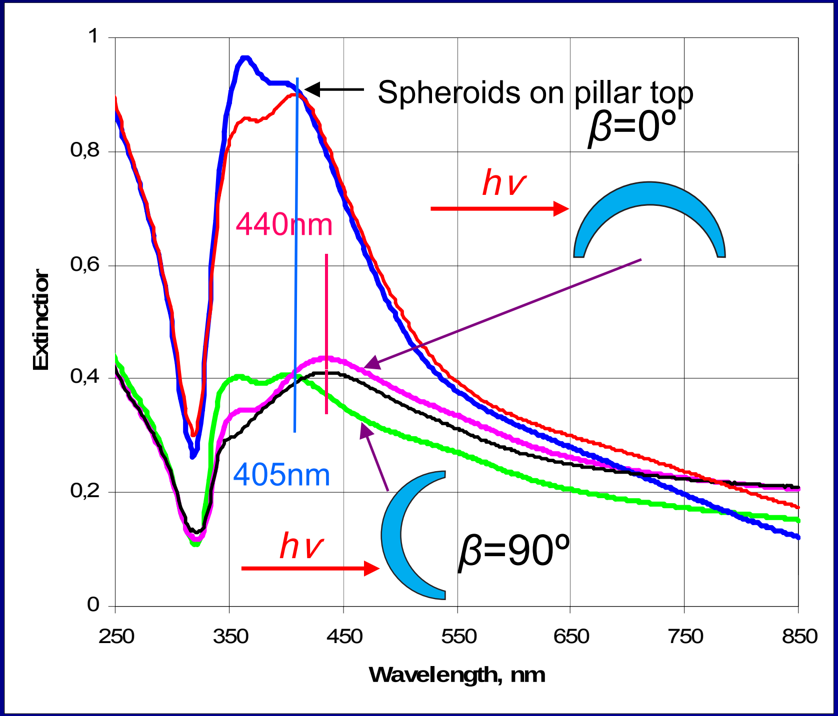
60º incidence. Extinction variation with the nanocrescent shape and orientation

Only 440 nm peak is unique property of the crescent structure

s-polarization



p-polarization

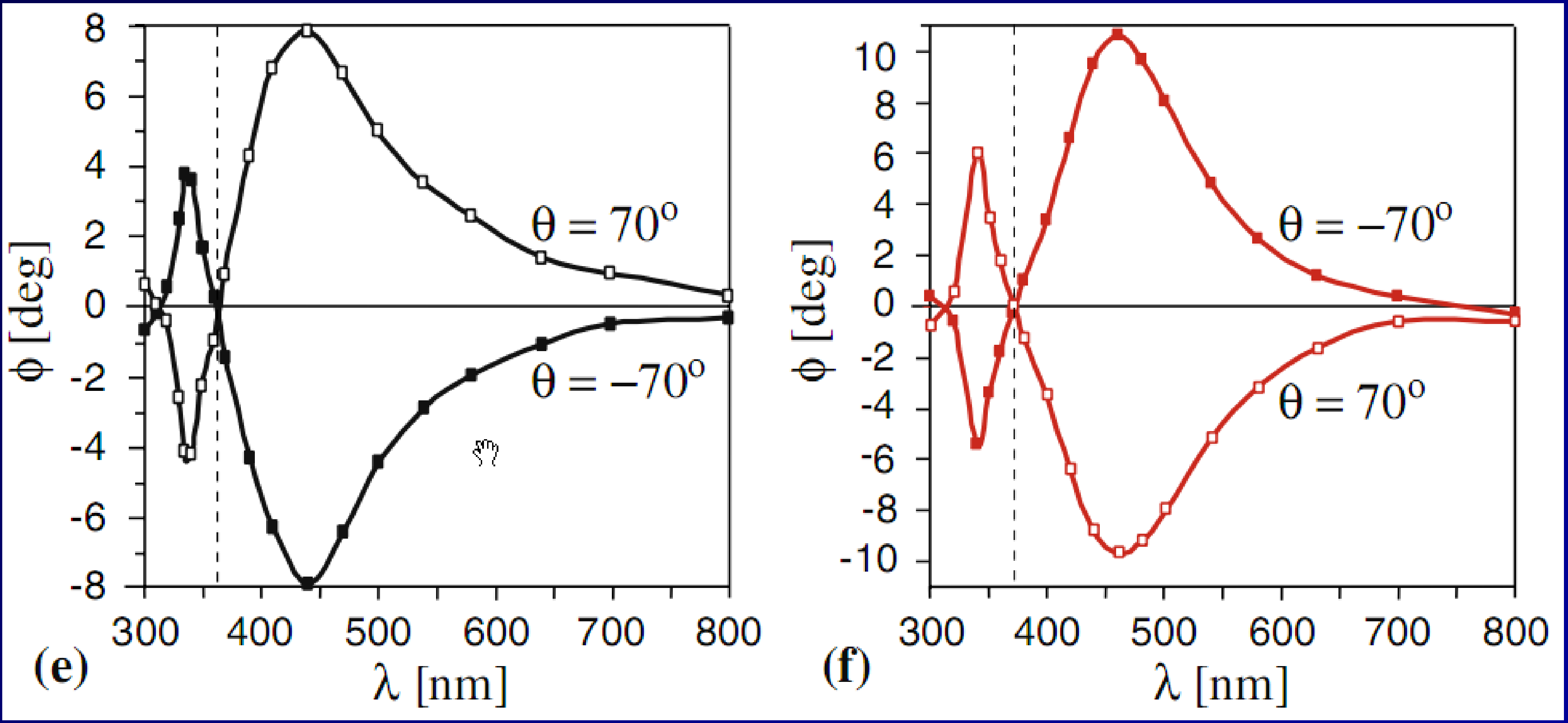


Red and black lines demonstrate effect of ion beam milling

The same colour notation on both figures

Polarization-rotation spectra

An array of silver nanocrescents on 50nm long nanopillars. Spectra were measured for two angles of incidence θ



Summary

- Disordered arrays of metal nanocrescents can be synthesized on large-scale surfaces by proposed method
- The arrays show significant optical anisotropy with respect to both direction of incidence and polarization of illuminating light
- In conjunction with observed optical properties, our structures make promise to demonstrate magnetic response at 440 nm. It is shorter, than predicted minimum 750 nm
- Plasmonic properties of arrays can be controlled by pillar height and material and by shape and dimensions of the split-ring resonators

Perspectives of quantum technologies

Applications of entangled state of light produced by Parametric Down Conversion to:

Quantum Cryptography
Quantum Metrology
Quantum Imaging

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Quantum Technologies

- Quantum Computers: promising extraordinary revolution by lowering the class of computational problems from exponential to polynomial. Far future (number 15 as been factorized by a quantum computer).

- Quantum Teleportation: to destroy a “System” in a place and reconstruct the same System with its complete quantum properties in an other place. Far far future (now just simple properties, as the photon polarization, particle spin can be transported in the lab).

- Quantum Cryptography: commercialization stage. Quantum Key Distribution systems are nowadays are commercialized by several Company.

- Quantum Metrology: Entangled source of photons are used in the National Metrology Institutes (as INRIM, NIST, NPL, ...) for the absolute calibration of detectors and these methods compete in terms of uncertainty with traditional ones in the single-few photon regime.

- Quantum Imaging: possibility of surpassing the limits imposed by the classical light in the imaging, either in terms of resolution or in terms of noise. We demonstrated that the limit of sub-shot- noise can be beaten in the image of weak absorbing object. Application to biomedical imaging.

Why … Quantum Cryptography is needed?

Symmetric Cryptosystems

ONE-TIME PAD

Today is the only secure cryptosystem!

OTP allows unconditionally secure transmission over public channels once Alice and Bob share unconditionally secure secret Key (a random string of bits).

Key bits cannot be reused without compromising security of the system (the length of the key should equal the length of the message)

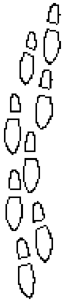
PROBLEM: Key Distribution

Same Key for encrypting and decrypting

0 0 0 1 1 1 0 0 0 1 1 1 0 Message

1 0 1 1 0 1 1 0 0 1 0 0 0 XOR Key to get

1 0 1 0 1 0 1 0 0 0 1 1 0 Ciphertext



Key distributed secretly beforehand

Ciphertext transmitted on a public channel

1 0 1 0 1 0 1 0 0 0 1 1 0 Ciphertext

1 0 1 1 0 1 1 0 0 1 0 0 0 XOR Key again to get

0 0 0 1 1 1 0 0 0 1 1 1 0 Message

SOLUTION 1:
Trusted Couriers
SECURITY LEVEL:??

SOLUTION 2:
Classical Symmetric Cryptosys.
(e.g. Block Ciphers, AES)
SECURITY LEVEL:COMPUTATIONAL

SOLUTION 3: QKD
SECURITY LEVEL: UNCONDITIONAL

How … does Quantum Cryptography work?

BB84 protocol [Charles H. Bennett and Gilles Brassard (1984)]

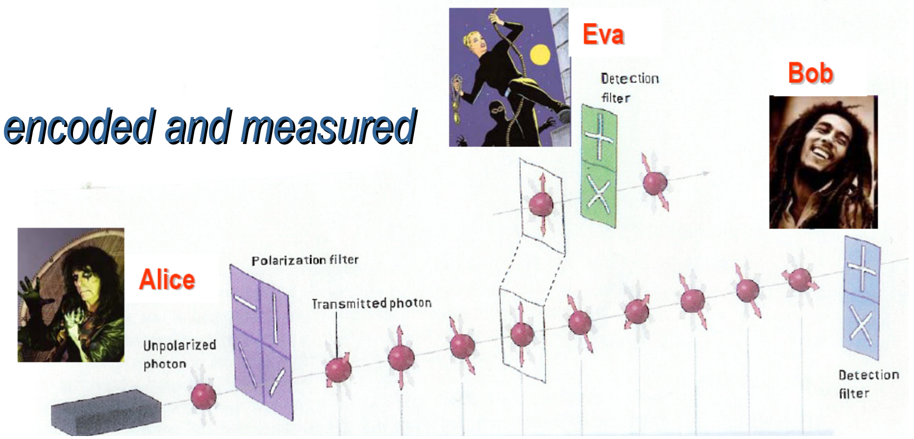
Basis	0	1
+	↑	→
×	↗	↘

Step 1: *Alice sends Bob a string of polarization encoded photon*

Step 2 : *Bob measures the string of encoded photons using random bases (rectilinear or diagonal).*

Step 3 : *Alice and Bob publicly compare the bases they encoded and measured in, and discard all results where they do not match.*

The result is the Shared Secret Key



Alice's random bit	0	1	1	0	1	0	0	1
Alice's random sending basis	+	+	×	+	×	×	×	+
Photon polarization Alice sends	↑	→	↘	↑	↘	↗	↗	→
Bob's random measuring basis	+	×	×	×	+	×	+	+
Photon polarization Bob measures	↑	↗	↘	↗	→	↗	→	→
PUBLIC DISCUSSION OF BASIS								
Shared secret key	0		1			0		1

How … does Quantum Cryptography work?

QUANTUM CHANNELS: Single-Mode fibers @ Telecom Wavelength

Adv.s: Lower attenuation

Disv.s: Decoherence (***Geometric phase, Birefringence, PMD, Chromatic Dispersion***)

PHOTON SOURCES: Faint Laser Pulses

Adv.s: Coupling Efficiency, Bandwidth, Costs

Disv.s: Poissonian Statistics (***Nonzero probability of having more than one photon per pulse***)

(**Alternatives:** *Heralded Single-PS based on PDC, Quantum Dots, Impurities in Diamond, …*)

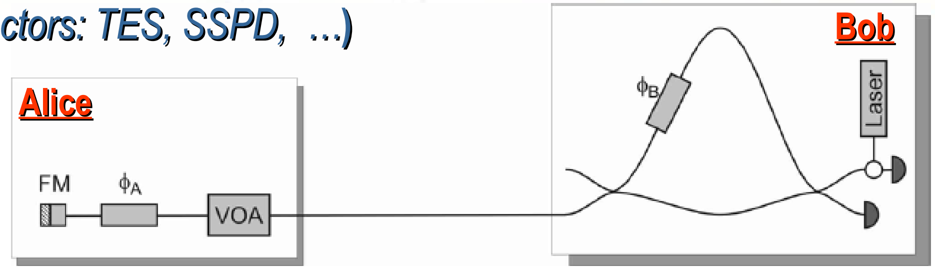
PHOTON DETECTORS: APD operating in Geiger mode

Adv.s: , Room Temperature Operation

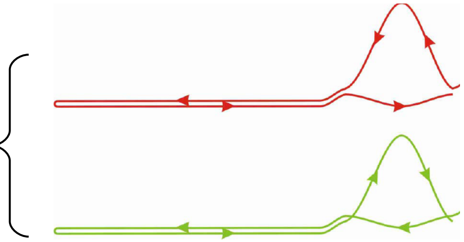
Disv.s: Dark counts (***Gated mode***), On/Off Detection

(**Alternatives:** *Superconducting Detectors: TES, SSPD, …*)

Real World QKD



The two interfering paths



QKD in the Real World

Who … is selling QKD devices?

id Quantique

MagiQ

SmartQuantum Complete Quantum security.

quintessencelabs

Who … has research program on QKD?

TOSHIBA Leading Innovation >>>

hp invent

MITSUBISHI ELECTRIC Changes for the Better

NEC Empowered by Innovation

NTT

ELSAG DATAMAT

…

NIST and several others Public Research Institution and Universities all over the world …

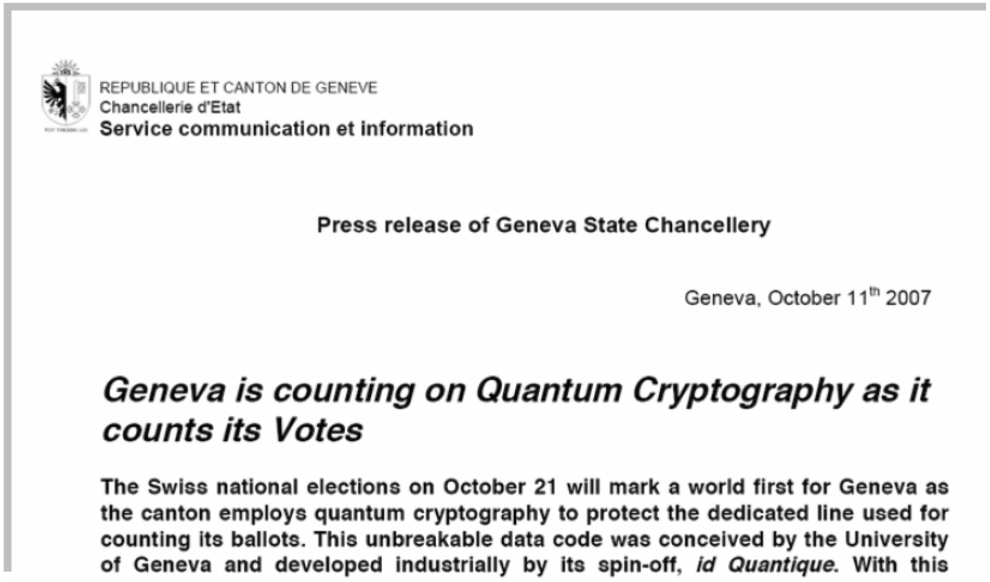
Who … is using QKD devices?

2004 - World's first bank transfer using QKD in Vienna.

2004 - DARPA QKD Network in Massachusetts.

2007 - QKD used in Geneva for Swiss elections.

2008 - World's first computer network protected by QKD implemented in Vienna.



REPUBLIQUE ET CANTON DE GENEVE
Chancellerie d'Etat
Service communication et information

Press release of Geneva State Chancellery

Geneva, October 11th 2007

Geneva is counting on Quantum Cryptography as it counts its Votes

The Swiss national elections on October 21 will mark a world first for Geneva as the canton employs quantum cryptography to protect the dedicated line used for counting its ballots. This unbreakable data code was conceived by the University of Geneva and developed industrially by its spin-off, *id Quantique*. With this

Standardization

An Industry Specification Group (ISG) of the European Telecommunications Standards Institute (ETSI) has been installed from October 2008 to address standardization issues in QKD, to support the commercialization of QKD devices on various levels and stages.

ISG should analyzes how trust in the security of QKD systems can be based on a standardization framework, which becomes indispensable once quantum cryptographic systems are transferred from the controlled environment of laboratories into a real-world environment.

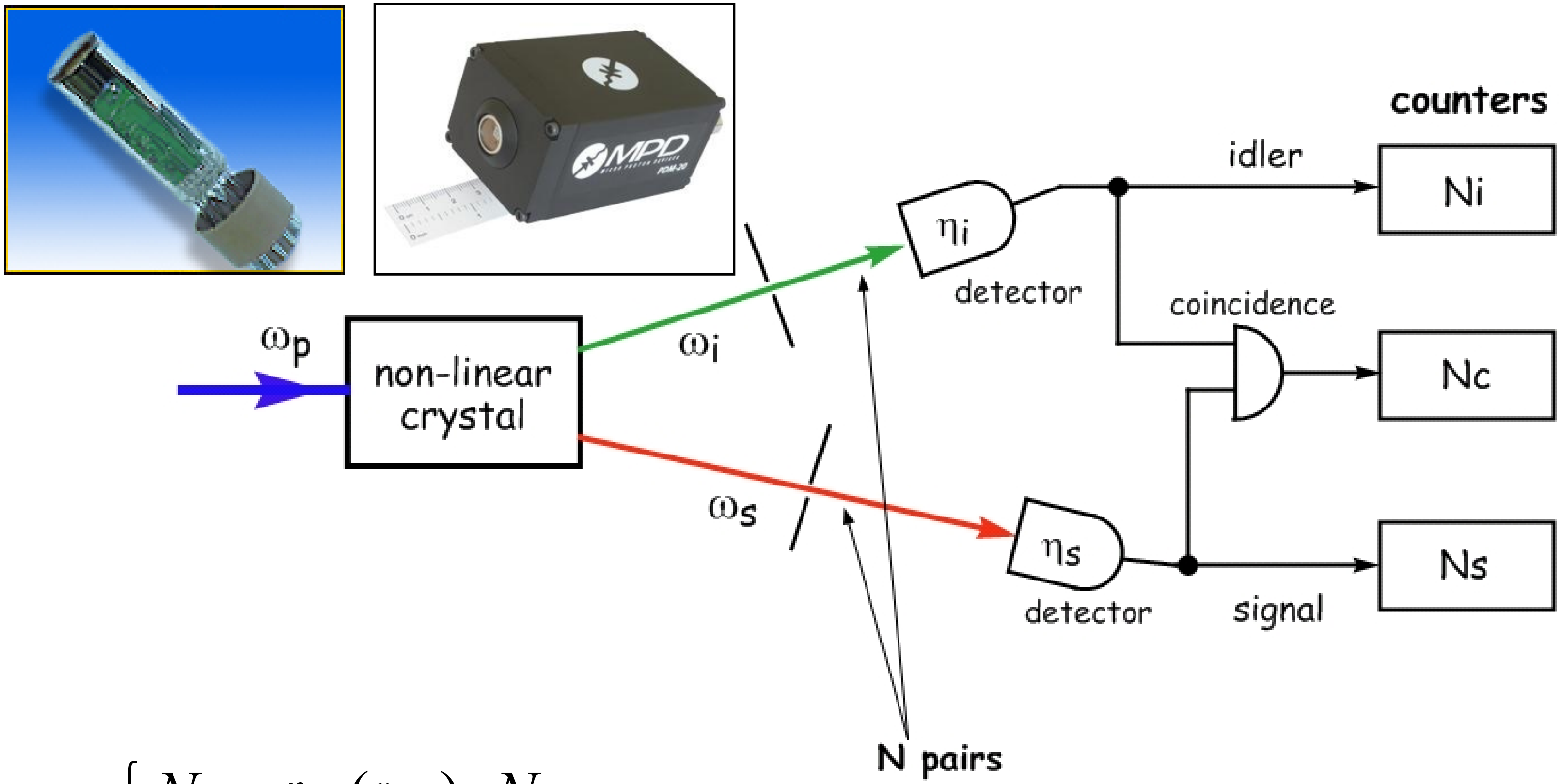
INRIM joined the ETSI ISG on QKD in October 2008

From several years in INRIM are present both experimental and theoretical research activities devoted to the investigation of entanglement in quantum mechanics and its application to quantum information processing and quantum metrology.

INRIM contributed to the success of the Qcrypt Project (2000-2003), co-sponsored by Italian Government and leaded by Elsag Datamat aiming the realization of a QKD system based on entangled photons.

Quantum Metrology/Absolute detector calibration

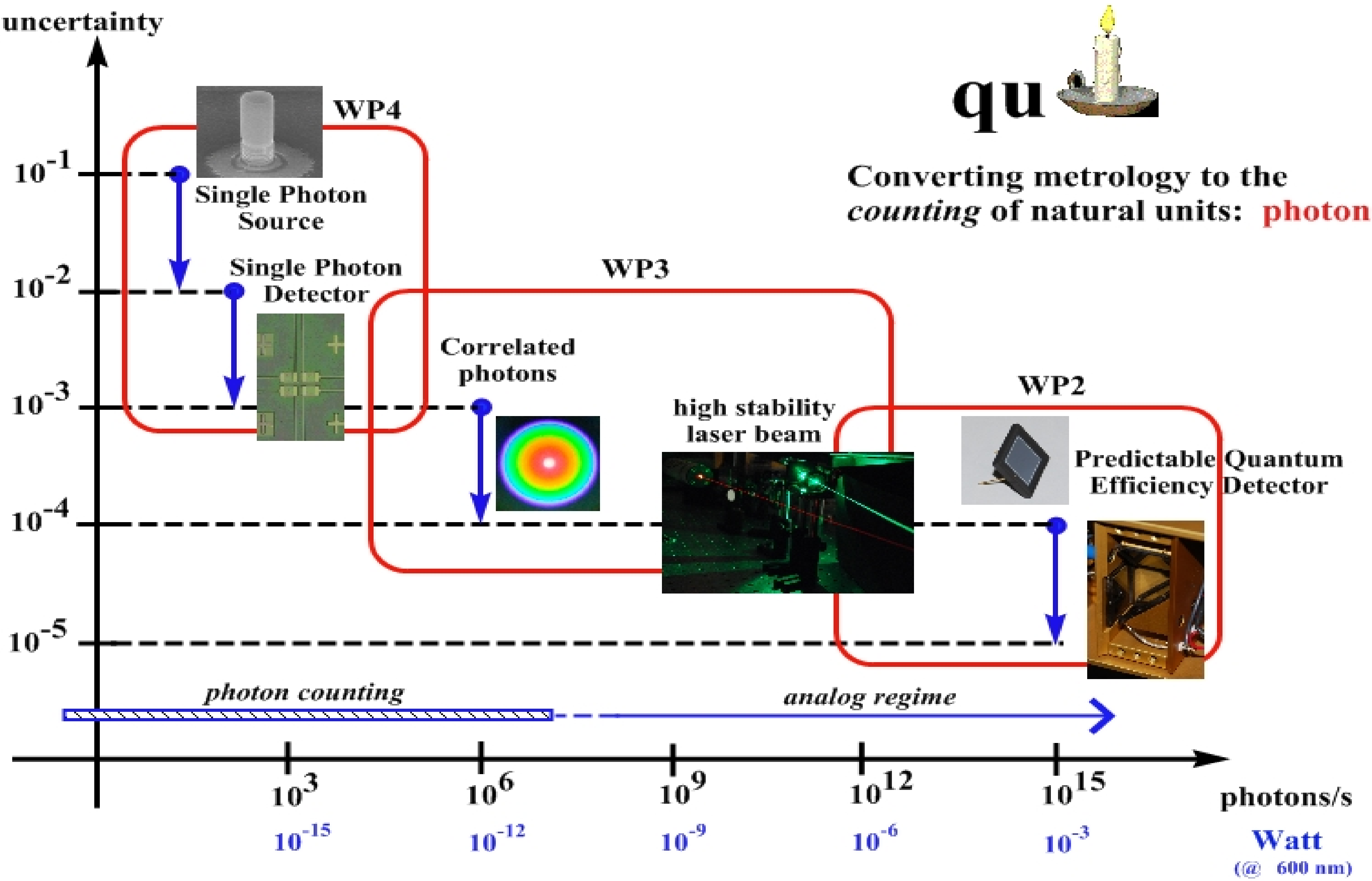
Calibration of photon counting detectors



$$\begin{cases} N_S = \eta_S(\omega_S) \cdot N \\ N_i = \eta_i(\omega_i) \cdot N \\ N_c = \eta_S(\omega_S) \cdot \eta_i(\omega_i) \cdot N \end{cases} \Rightarrow \begin{cases} \eta_S(\omega_S) = N_c / N_i \\ \eta_i(\omega_i) = N_c / N_s \end{cases}$$

N. Klyshko, Coherent photon decay in a non linear medium, Sov. Phys. JETP Lett.6,1967
S.E.Harris et al., Observation of tunable parametric fluorescence, Phys.Rev.Lett. 18, 1967
D.N. Klyshko, Sov. J. Quantum Electron. 10, 1112-1116,1988

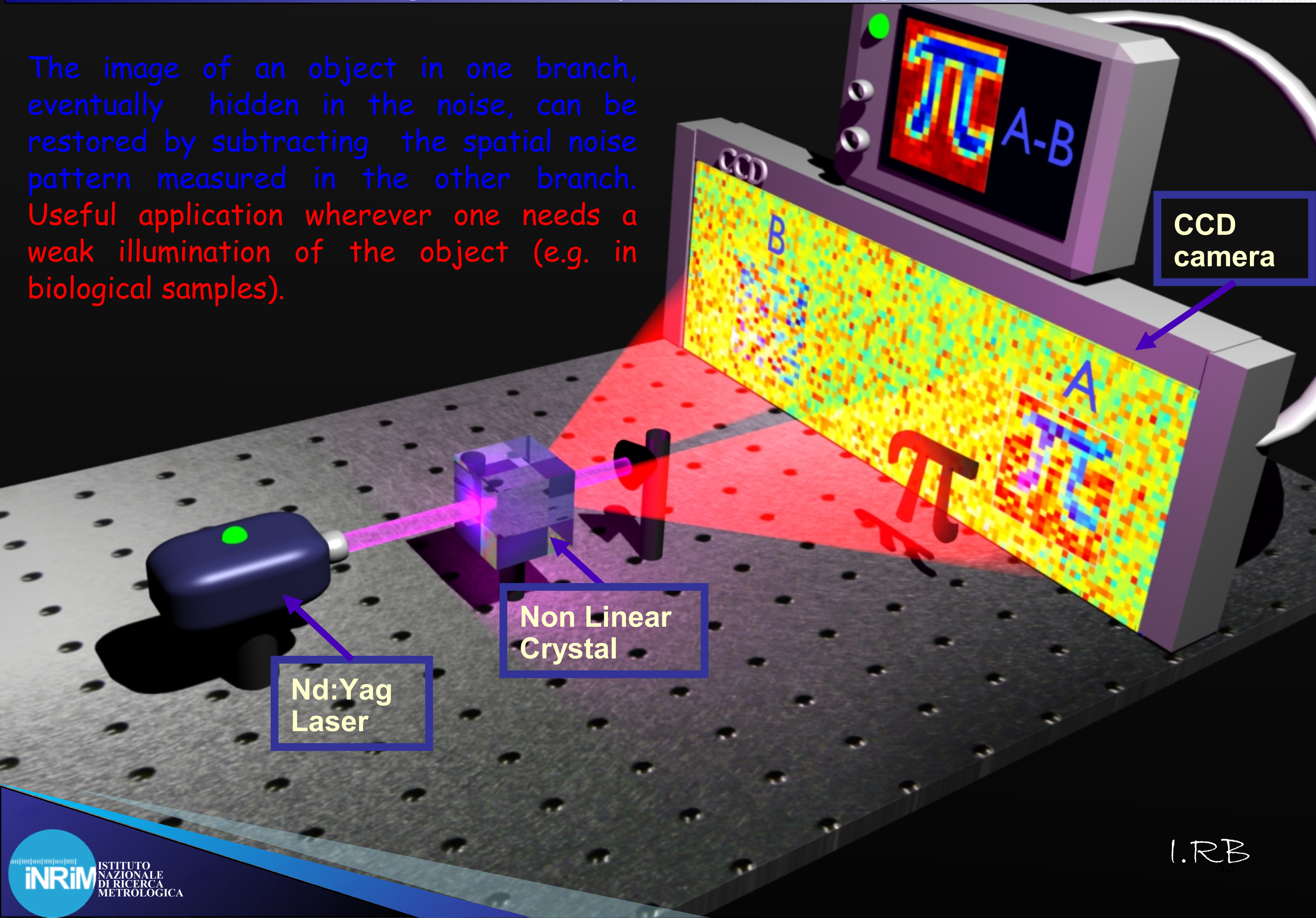
Quantum Metrology/Q-Candela Project



Converting metrology to the *counting* of natural units: photons

High sensitivity Quantum Imaging

The image of an object in one branch, eventually hidden in the noise, can be restored by subtracting the spatial noise pattern measured in the other branch. Useful application wherever one needs a weak illumination of the object (e.g. in biological samples).



CCD camera

Non Linear Crystal

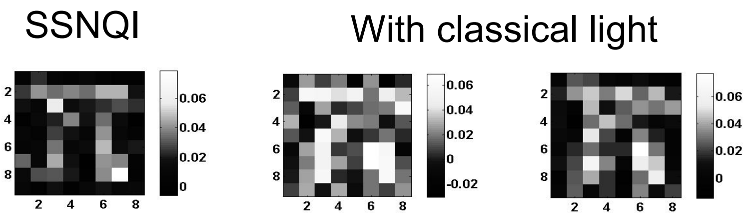
Nd:Yag Laser

I.RB

High sensitivity Quantum Imaging

We have realized a proof of principle of the method by exploiting spatial correlation in Parametric Down conversion and scientific low noise CCD cameras:

[G. Brida, M. Genovese, I. Ruo Berchera, *Nature Photonics* (2010), in press.]


SSNQI

With classical light

Engineering Quantum Imaging technique for applications in the field of biomedical imaging seems to be realizable without a big effort. It would requires:

Technical issues:
- enhanced resolution (shaping of the pump laser),
- increase Signal to Noise Ratio (reducing the optical losses up to 10-15% at all including CCD efficiency)

Budget issues:
- Different design of the set-up 5000€ ,
- probably two high sensitivity cameras 100 K€,
- a more refined laser 100K€,
- electronic and software for automatizing the procedures 15K€

Total 220K€.