ΕΡΕΥΝΗΤΙΚΕΣ ΔΡΑΣΤΗΡΙΟΤΗΤΕΣ

ΕΡΓΑΣΤΗΡΙΟΥ ΟΠΤΟΗΛΕΚΤΡΟΝΙΚΗΣ, LASERS & ΕΦΑΡΜΟΓΩΝ ΤΟΥΣ

ΔΙΕΥΘΥΝΤΗΣ: Α.Α. ΣΕΡΑΦΕΤΙΝΙΔΗΣ (ΚΑΘ.)

ΜΕΛΗ:

ΖΕΡΓΙΩΤΗ Ι. (ΑΝΑΠ. ΚΑΘ.)
ΜΑΚΡΟΠΟΥΛΟΥ Μ. (ΚΑΘ.)
ΠΑΠΑΓΙΑΝΝΗΣ Α. (ΚΑΘ.)
ΤΣΙΓΑΡΙΔΑΣ (ΕΠΙΚ. ΚΑΘ.)

Outline of the presentation

Part 1. The research activities of the National Technical University of Athens “Laboratory of Optoelectronics, Lasers and their Applications” LOLA”

1. Development of gas, chemical, excimer and solid-state lasers (UV, VIS and IR),
2. Various laser applications
3. Laser applications in biophysics and medicine
4. Laser remote sensing and LIDARs
5. Laser materials micro-nano processing
6. Lasers in cultural heritage
7. Theoretical studies of optical fibers

Part 2. Selected research activities of NTUA-LOLA

a. Laser remote sensing of the atmosphere

b. Lasers in cultural heritage

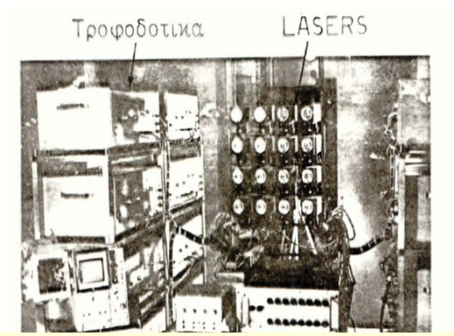
c. Plasmon assisted in optical trapping

d. Study of composite optical fibers

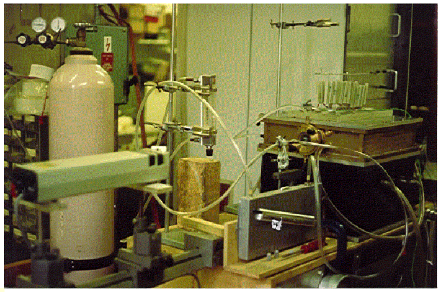
Part 1. Research activities of NTUA-LOLA (I)

A. Development of Gas, Chemical, Excimer and Solid-State Lasers (UV, VIS and IR) (since 1980-today)

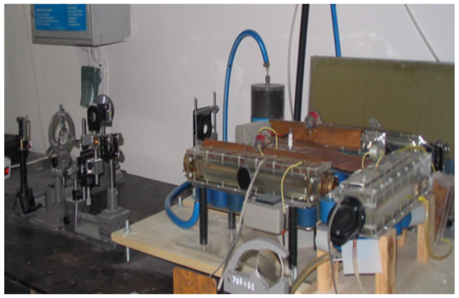
1. Development of gas lasers (CO_2, CO, Ar, Kr, F, H_2O vapour, etc.),
2. Development of flash-pumped solid state lasers (Ruby, Nd:YAG, Ho:YAG/YLF, Er:YAG, Yb:YAG, etc.)
3. Development of Q-Switched mid-IR solid-state lasers (Er:YAG),
4. Development of chemical vibrational-rotational lasers (HF),
5. Development of Blumlein self-terminating lasers (N_2),
6. Double beam laser systems (HF/N_2 and CO_2/N_2 lasers),
7. Development of various preionisation techniques (corona, semiconductors, sparks,),
8. Semiconductively preionised excimer lasers (ArF, KrF, etc.),
9. Ps, fs laser systems development,
10. High power lasers (EUREKA, ELI and HIPER European Projects participation),
11. Stimulated Raman Scattering (SRS) in single-pass high-pressure cells (H_2, H_2+D_2, D_2) using the Nd:YAG laser as excitation source,
12. Laser rangefinders development, laser LIDARS development,
13. Space-borne diode-pumped Nd:YAG laser sources for the European Space Agency (ESA).



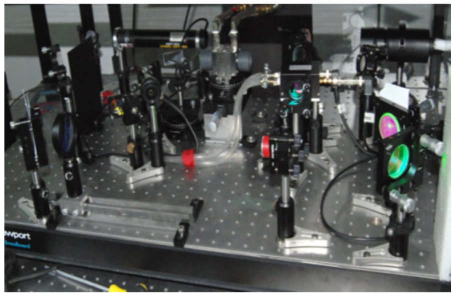
16 Ruby lasers, high speed camera, first laser development in NTUA, (1980-1982).



CO_2 laser development for industrial applications (1980-2000).



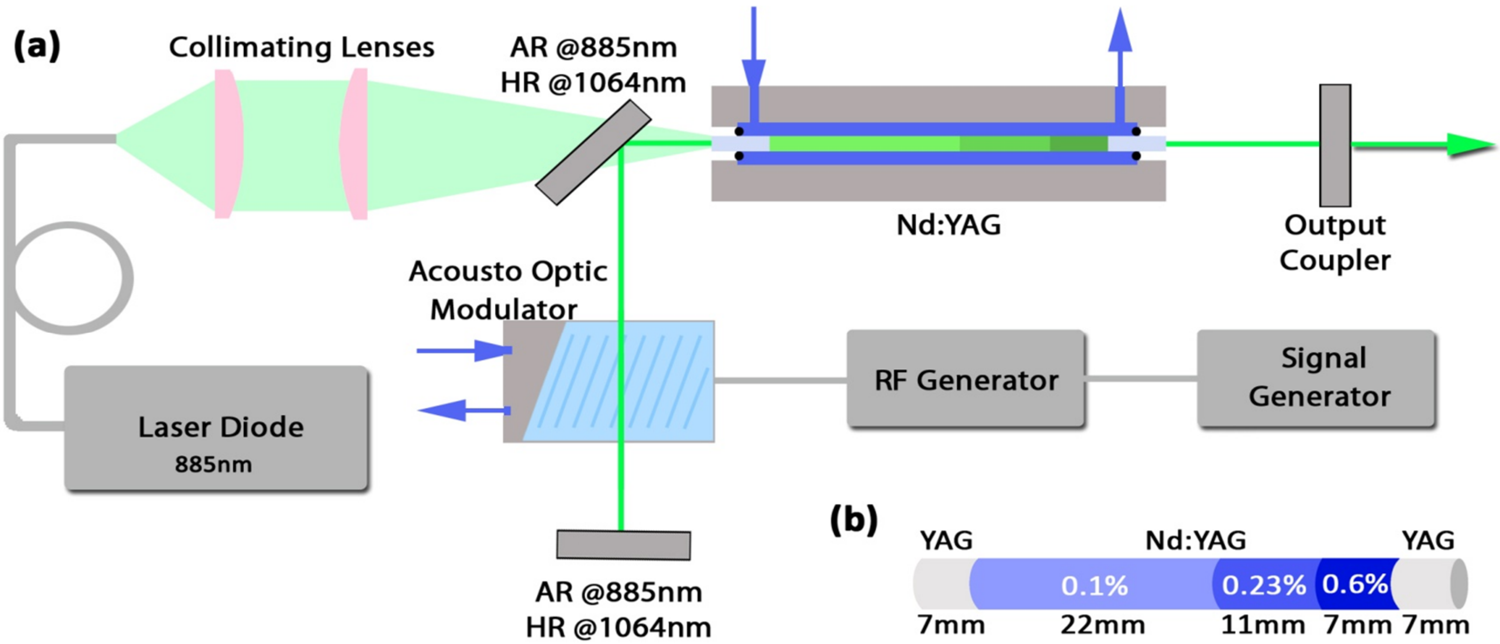
HF laser development for medical applications (1980-2005).



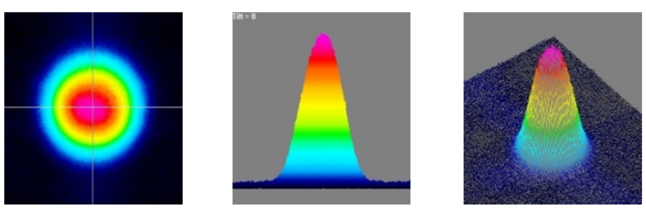
Development of space-borne laser sources for the European Space Agency (2005-today).

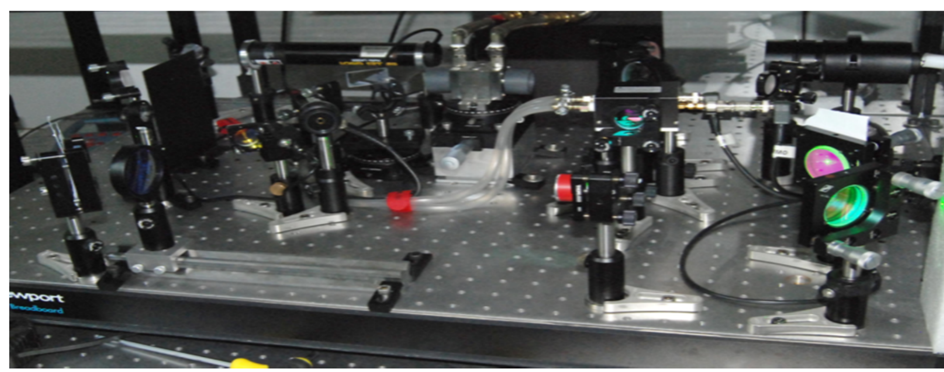
The research activities of NTUA-LOLA (II)

Development of space-borne laser LIDAR sources for the European Space Agency (2010-today) under Clean Room conditions



QOMA I: TEM_{00}, 2.6mJ/pulse, 1kHz



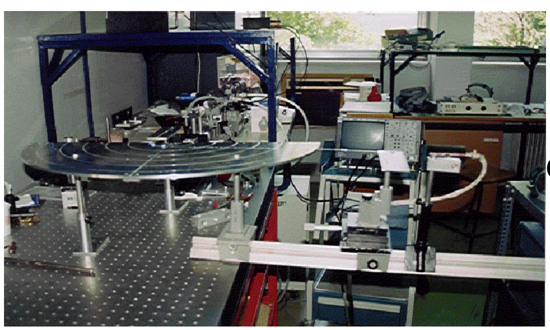


Current project: 10mJ/pulse, 100Hz

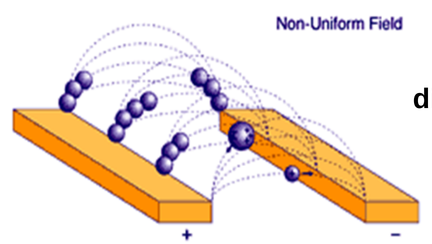
The research activities of NTUA-LOLA (III)

B. Laser Applications (since 1980)

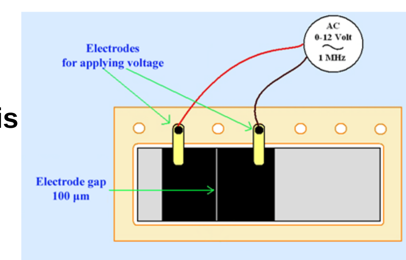
1. Short (ns, ps, fs) laser pulses interaction with novel technological materials,
2. Study of electro-optical and optically active materials (KD*P, LiNbO3 BGO, BSO),
3. Ablation of biopolymer materials using pulsed CO_2, HF, Nd:YAG, Excimer and Er:YAG lasers,
4. Radiation pressure effects, optical trapping – calibration techniques,
5. Dielectrophoresis techniques, laser detectors, photon drag effect,
6. Optical fibers and waveguides,
7. Industrial applications of lasers (cutting, marking, welding),
8. Laser interaction with matter: applications to surface processing and microstructuring,
9. Laser robots/laser welding,
10. Evaluation of laser beam and materials interactions using SEM, XRF, XRD, RBS, LIBS and AFM techniques,
11. Theoretical extensions and experimental improvements of the Z-scan technique for measuring nonlinear optical properties of new materials,
12. Theoretical and numerical study of soliton propagation in optical fibers under perturbations,
13. Study of the photo-bleaching effect and its applications to the development of three-dimensional optical memories,
14. Theoretical and experimental study of optical trapping on micro-structured surfaces.



CO_2/HF/Er:YAG laser optical fibers testing set-up (1990-2010).



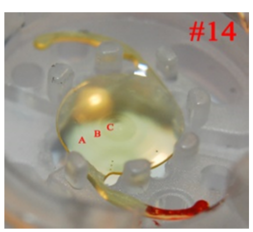
Using dielectrophoresis for measuring optical forces (1995-2005).

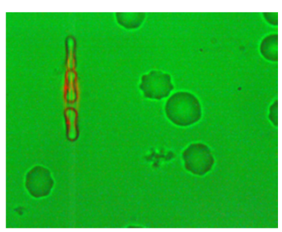
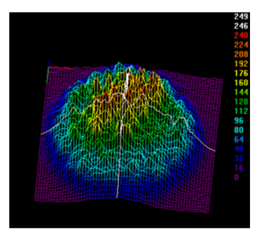
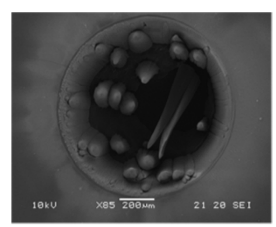
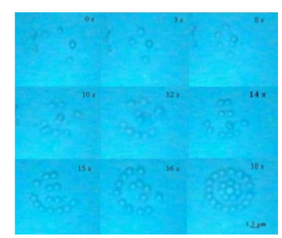


The research activities of the NTUA-LOLA (IV)

C. Laser applications in Biophysics and Medicine (since 1990)

1. **Ablation of biological tissues (*ex vivo*) and tissue simulators using UV-VIS-IR lasers,**
2. **Optical trapping – optical tweezers and their calibration techniques (mostly dielectrophoresis techniques),**
3. **Lasers in semi-invasive biomedicine (cardiovascular, dental, derma and eye microsurgery),**
4. **Lasers in diagnostic biomedicine (Laser Induced Florescence-LIF, Optical Coherence Tomography-OCT),**
5. **Evaluation of laser beam and biomaterials interactions using SEM, LIBS and AFM techniques,**
6. **Manipulation and biomechanical characterization of cells and drug delivery nanosystems,**
7. **Optical tweezers and microsurgery (multiple laser beams),**
8. **Laser ablation and high precision patterning of biomaterials and intraocular lenses, custom lenses and custom ablation, apodization, ablation modified IOLs.**

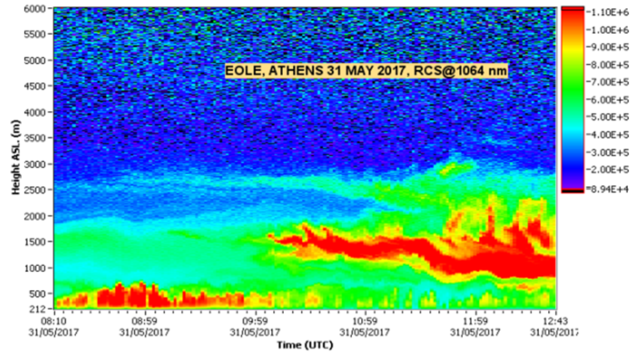


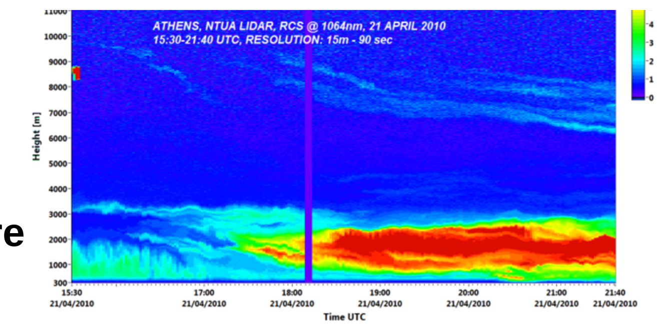





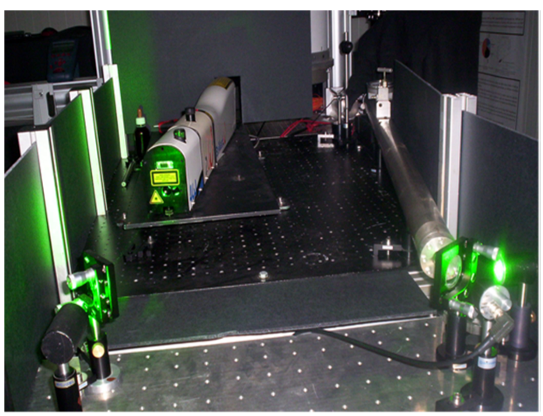
The research activities of NTUA-LOLA (V)

D. Laser Remote Sensing of the Atmosphere (since 1995)

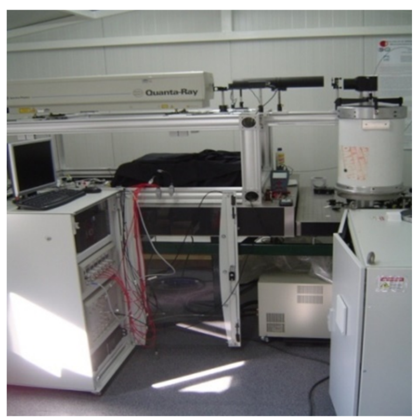
1.Laser **remote sensing** of the atmosphere (LIDAR technique)
2. Atmospheric Physics and Environmental Physics
3. Air **pollution** monitoring
4. Laser **spectroscopy** (detection of environmental pollution)
5. **Real-time measurements** : optical-microphysical-chemical aerosol properties & aerosol-cloud interactions (0.5-15 km)
6. Long-range **transport** of aerosols and ash particles
7. **Real-time measurements**: temperature-water vapor (<8 km)
8. Measurements of **atmospheric structure** (0.5-20 km)
9. Measurements/studies of **industrial emissions** of aerosols using lidars
10. DIAL system for **ozone monitoring** in the lower troposphere (0.5-6 km)







Ozone DIAL



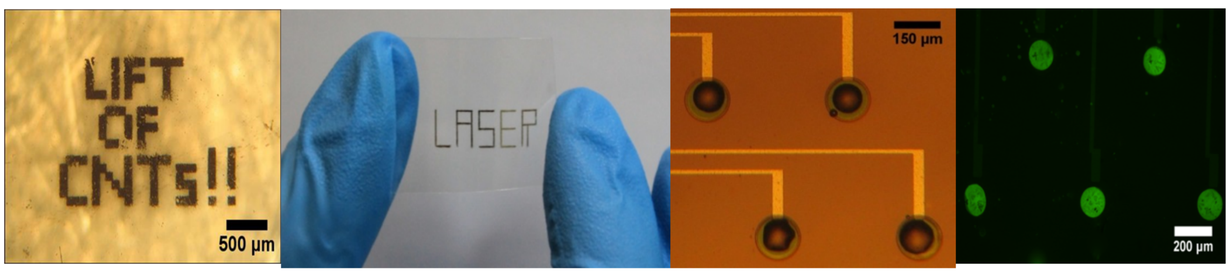
6-λ Raman lidar

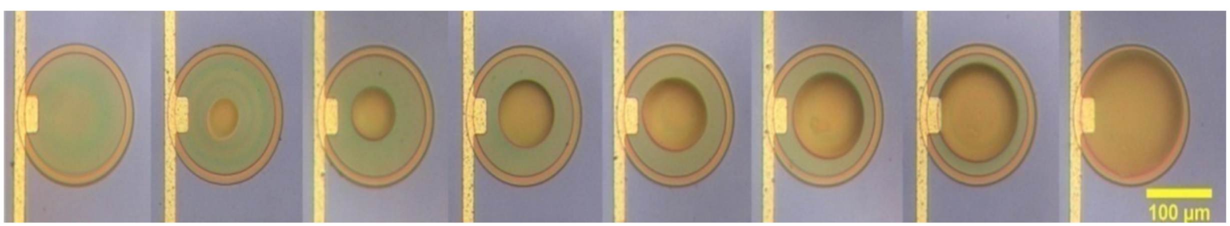
Mobile depol-lidar

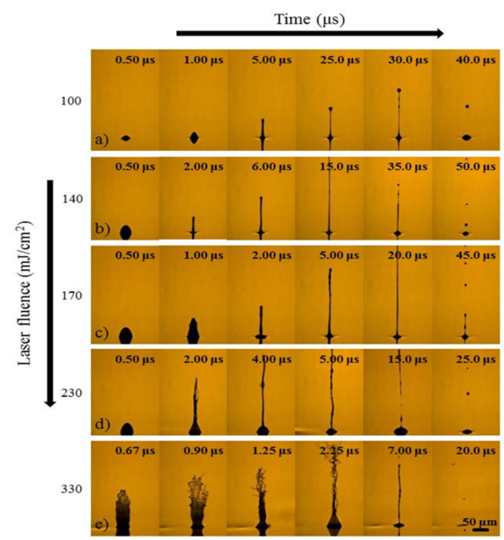
The research activities of NTUA-LOLA (VI)

E. Laser materials micro-nano processing (since 2003)

1. Laser development of **biosensors**, laser printing of biomolecules,
2. **Laser Induced Forward Transfer** of polymers and carbon based nanomaterials,
3. Laser Induced Forward Transfer for **organic electronics**,
4. Time resolved **imaging** for the dynamics of the laser induced jet formation,
5. Laser **surface modification**, laser induced tuning of the surface wetting,
6. Pulsed laser printing of **carbon nanotubes** (CNTs),
7. Pulsed laser printing of biomolecules for **capacitive sensors**.







The research activities of NTUA-LOLA (VII)

F. Lasers in Cultural Heritage (coins, statues, paintings, paper, books - since 2000)

Optical technologies for the preservation and revelation of cultural heritage:

1. **Analytical and diagnostic applications,**
2. **Laser spectroscopic techniques for chemical analysis,**
3. **Laser interferometric techniques for structural diagnostics,**
4. **Laser cleaning applications (books, papers, etc.),**
5. **Laser cleaning of stonework, metals, etc.,**
6. **Laser cleaning of painted artworks, polychromes etc.**

In categorizing the use of lasers for the preservation, one may distinguish three major types of applications.

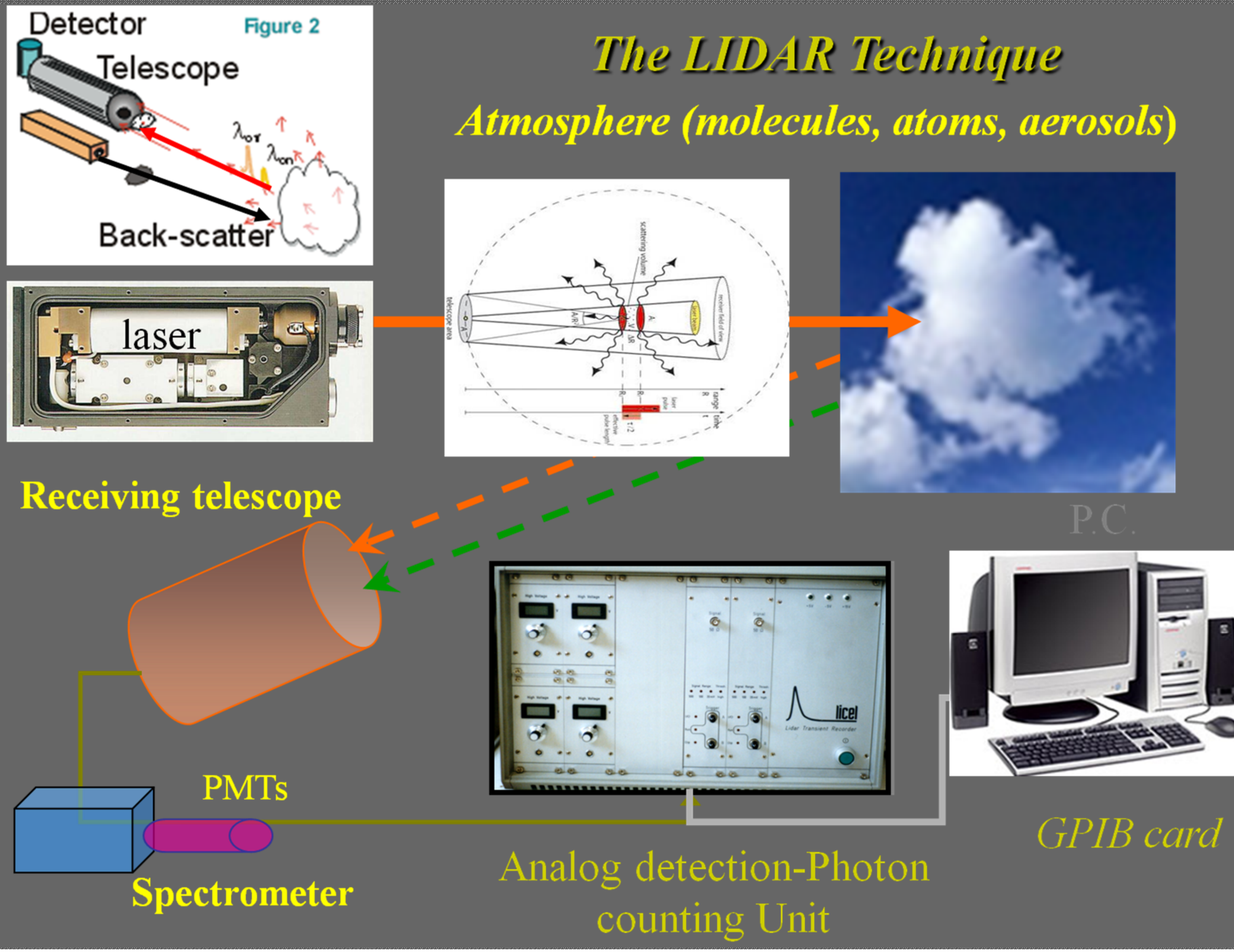
- ***Analytical*, for the determination of elemental or molecular compositions of materials. These rely on laser spectroscopic techniques such as laser induced breakdown spectroscopy (LIBS), laser-induced fluorescence (LIF), laser Raman spectroscopy, and laser mass spectroscopy (LMS).**

- ***Structural diagnostics*, for the detection and mapping of defects (e.g., cracks, detachments, stress concentrations) in the bulk of an artifact, which may not be visible or may induce invisible effects. These rely on laser interferometric techniques based on optical and digital holographic interferometry, including the techniques of speckle pattern interferometry and, more recently, laser shearography. Laser Doppler vibrometry also serves this purpose.**

- ***Restoration*, including primarily laser cleaning. Lasers are effective tools for the removal of unwanted surface materials, such as black encrustations, pollutants, chemically altered surface layers (for example, oxidized and polymerized varnishes), unwanted overpaints, and so forth.**

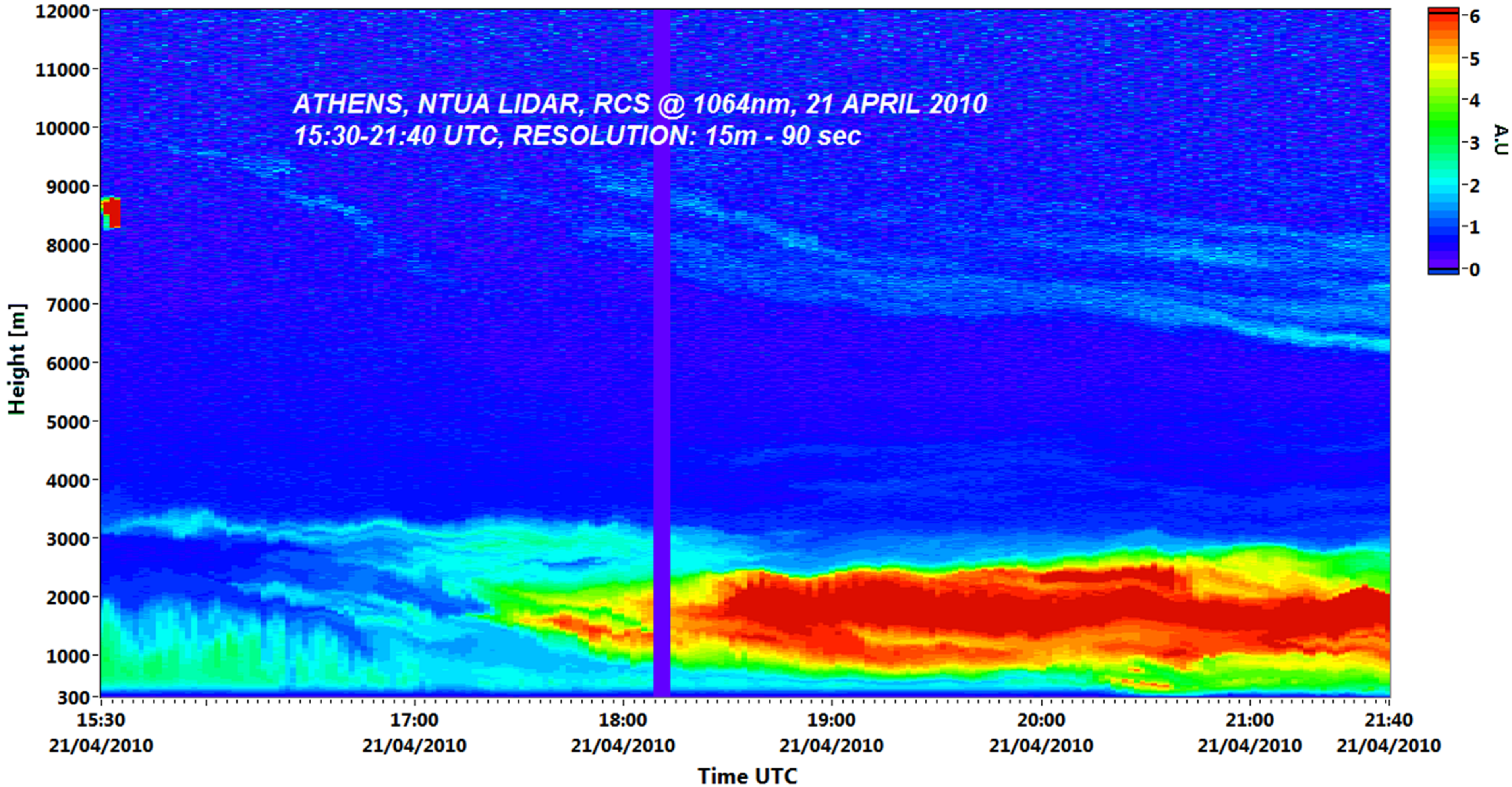
Part 2. Selected research activities of NTUA-LOLA

a. Laser Remote Sensing of the Atmosphere (I)



Laser Remote Sensing of the Atmosphere (III)

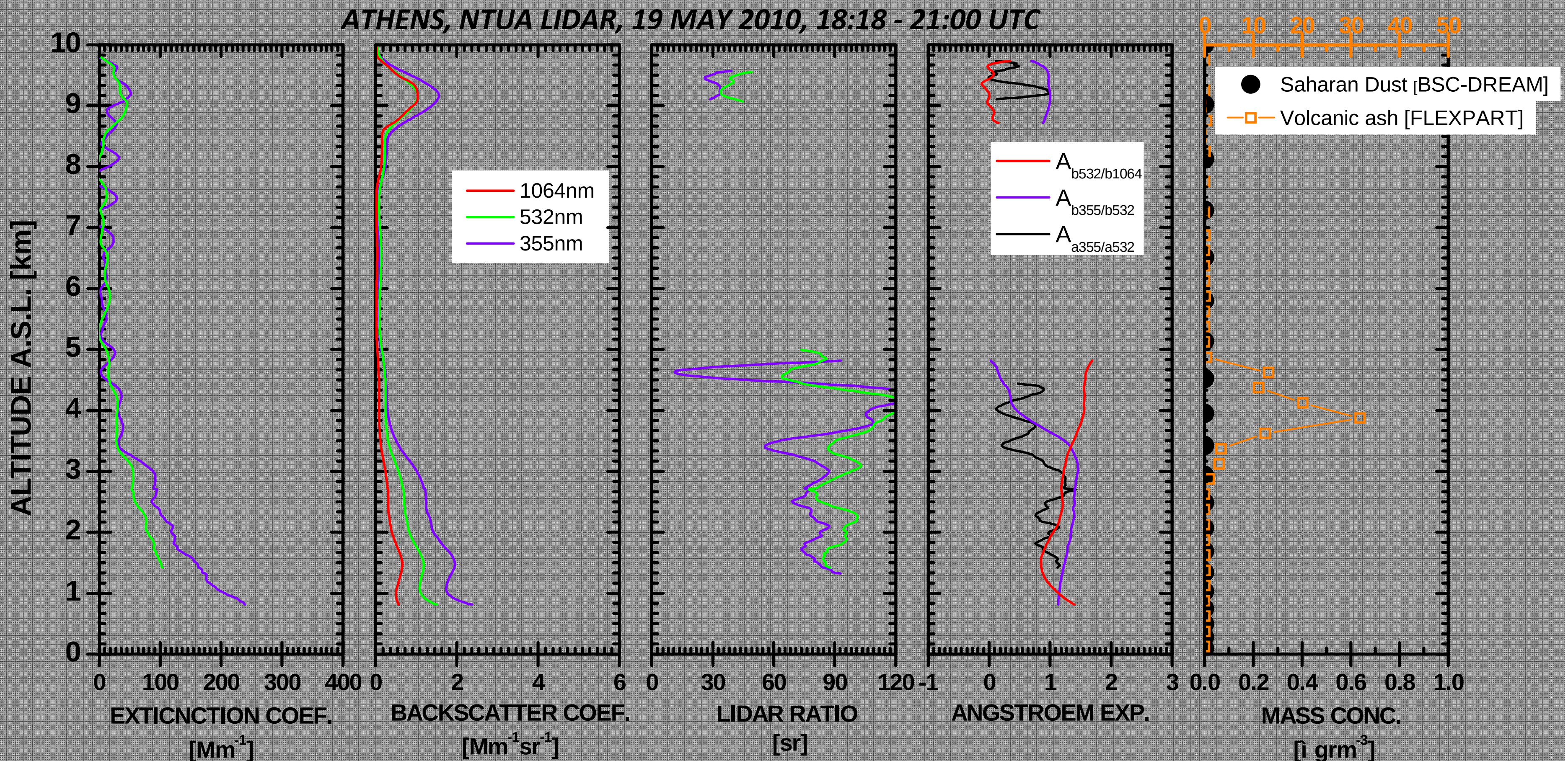
Volcanic Eruption April-May 2010



Volcano dust in the atmosphere, over Europe (21-April-2010).

Laser Remote Sensing of the Atmosphere (IV)

Volcanic Eruption April-May 2010



Papayannis et al., *Atmos. Environ.*, **48**, 56-65, 2012

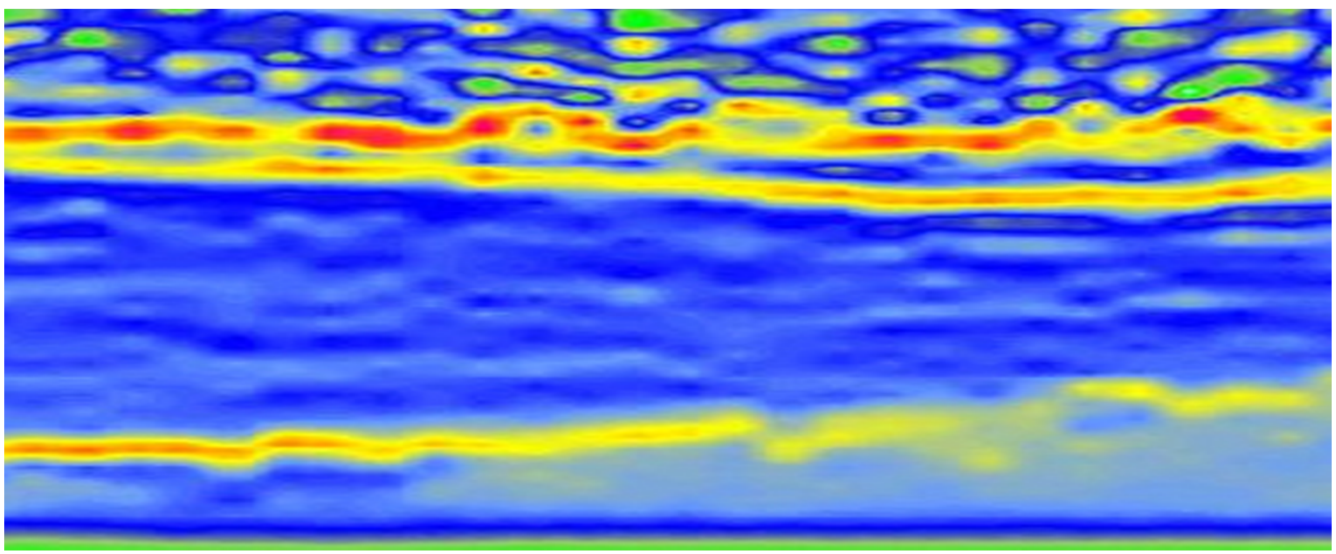
Laser Remote Sensing of the Atmosphere (V)

Volcanic Eruption Etna 2001-2002

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Atmospheric Environment 42 (2008) 893–905
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

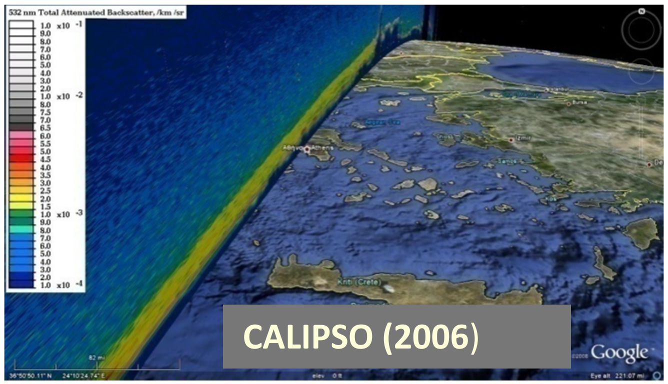
Volcanic dust characterization by EARLINET during Etna's eruptions in 2001–2002

X. Wang[a,b,*], A. Boselli[c], L. D'Avino[a], G. Pisani[a], N. Spinelli[a], A. Amodeo[c], A. Chaikovsky[d], M. Wiegner[e], S. Nickovic[f,1], A. Papayannis[g], M.R. Perrone[h], V. Rizi[i], L. Sauvage[j], A. Stohl[k]



NTUA Ongoing Long-term Activities

- **Calibrate Space-borne Platforms**



- **Airborne field campaigns (EUFAR)**

Summer 2012 (Aegean Sea)

Part 2. Two selected research activities of NTUA-LOLA
b: Lasers in cultural heritage

1. DIAGNOSTIC TECHNIQUES.

Laser-Induced Fluorescence (LIF): Analytical schemes have been proposed for performing LIF analyses of works of art which provide information on pigments, painting media and varnishes. Fluorescence spectral information has been used to identify pigments and mixtures of pigments to differentiate between various kinds of painting media and between fresh and aged varnish layers. LIF is a non-destructive technique applicable *in situ*, and is capable of detecting both organic and inorganic species which exhibit fluorescence, upon irradiation with UV or visible excitation.

Φασματική πληροφορία

Laser-induced-breakdown spectroscopy (LIBS) is an analytical technique that enables the determination of the elemental composition of materials on the basis of the characteristic atomic emission from a micro-plasma produced by focusing a high-power laser on or in a material. LIBS has been used in a wide variety of analytical applications for the qualitative, semi-quantitative and quantitative analysis of materials. LIBS enables multielemental identification and quantitative analysis requiring little or no sample preparation.

Στοιχειακή σύνθεση

2. INVASIVE-CLEANING TECHNIQUES.

Laser ablation is mostly used as cleaning technique.

Some specific cases: Cleaning of ancient coins (I)

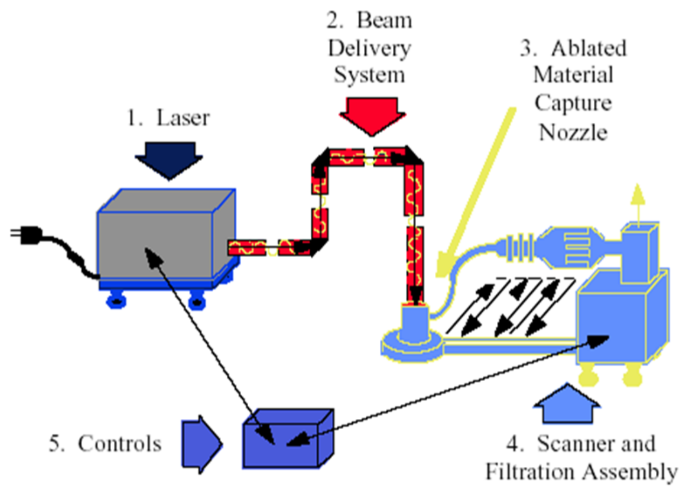
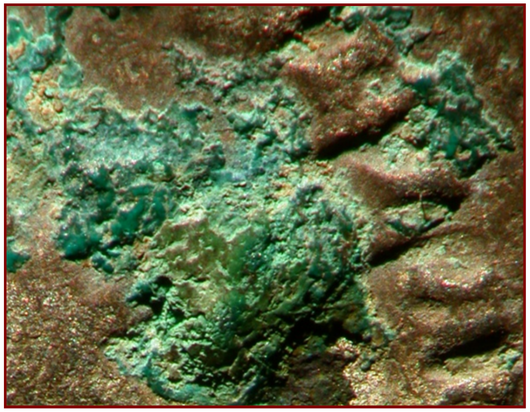


Figure 3
Laser-Based Coatings Removal Systems

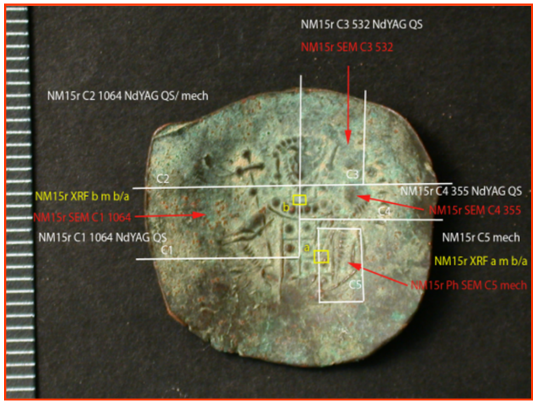
Upper left: portable laser cleaning system. Upper right, lower left and lower right: ancient silver Greek coin from Corinth, 4th century B.C., 8.444 g in weight, covered mostly with Fe deposits.

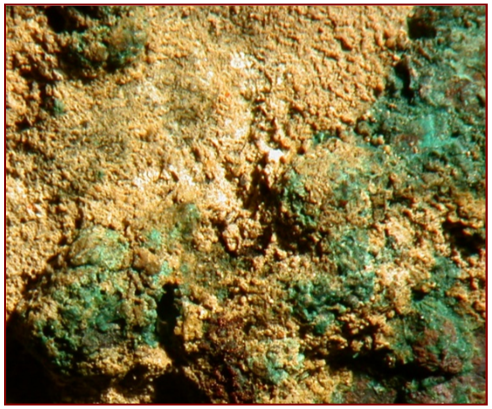
Some specific cases: Cleaning of ancient coins (II)





Silver-copper, ancient Roman coin, 238-244 A.C., 3.590 g in weight. It is mostly covered by silver and copper corrosion products



Follis, ancient Byzantine copper coin, 6th century A.C., 9.640 g in weight. It is mostly covered by copper corrosion products

Laser cleaning. One very important case (III)


a


b

Laser cleaned Roman coin with both Q-switched 2ω-Nd:YAG laser (*right side*) and a TEA CO_2 laser (*left side*).


a

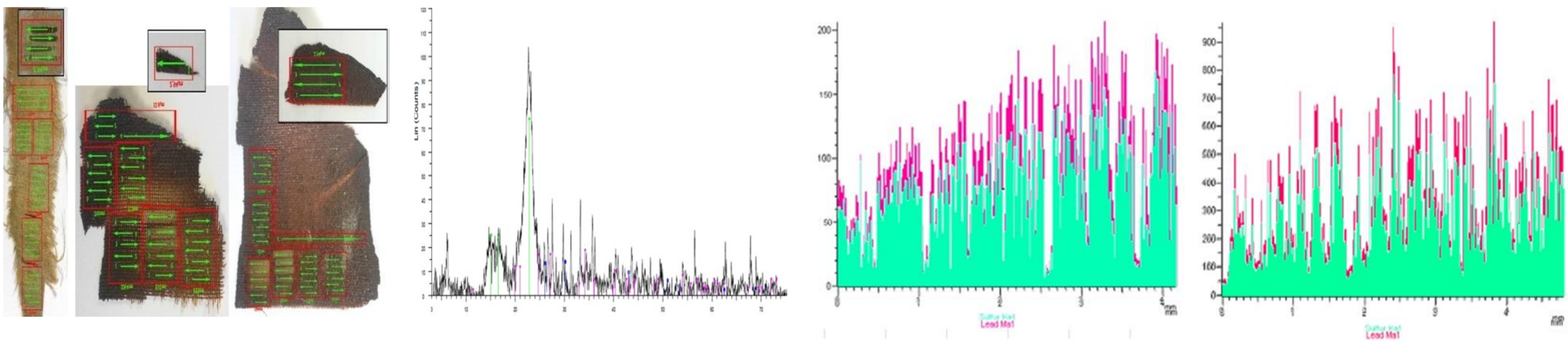

b

Laser cleaned Roman coin with both Q-switched 2ω-Nd:YAG laser (*right side*) and a TEA CO_2 laser (*left side*).

Laser cleaning

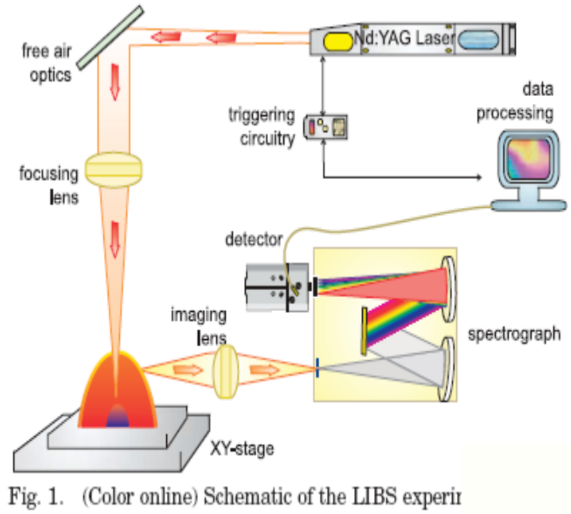
Characterization of burnt paintings after laser cleaning treatment

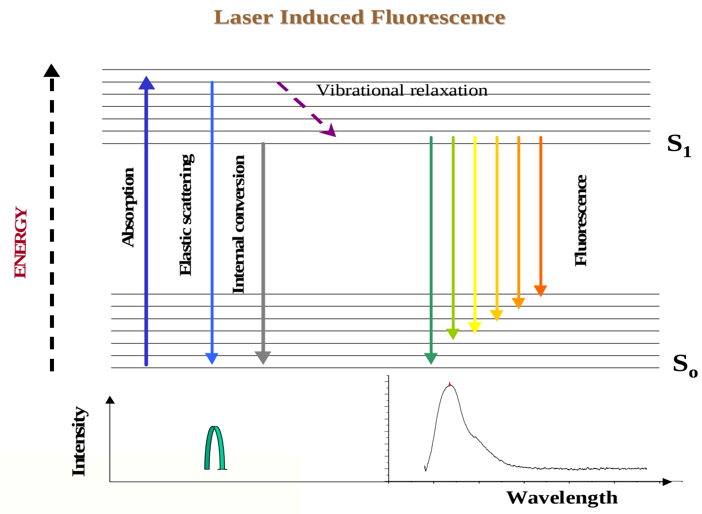
A. Gousetis[1], A.A. Serafetinides[1], M. Makropoulou[1], I.Tsilikas[1] N. Antonopoulou-Athera[2], E. Chatzitheodoridis[2]
M. Doulgerides[3], A. Terlixi[3]



The study is based on experiments of burnt paintings that belongs to the collection of National Gallery of Athens and were made by the great Greek artist Konstantinos Parthenis (1878-1967).

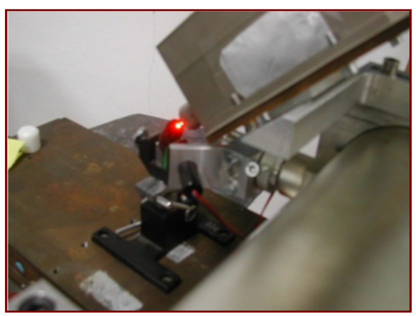
Laser Diagnostic Techniques (LIF, LIBS, etc.)

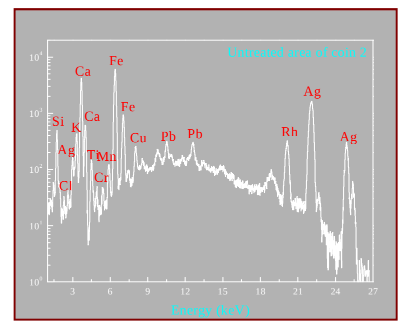




LIBS experimental layout/principle

LIF principle

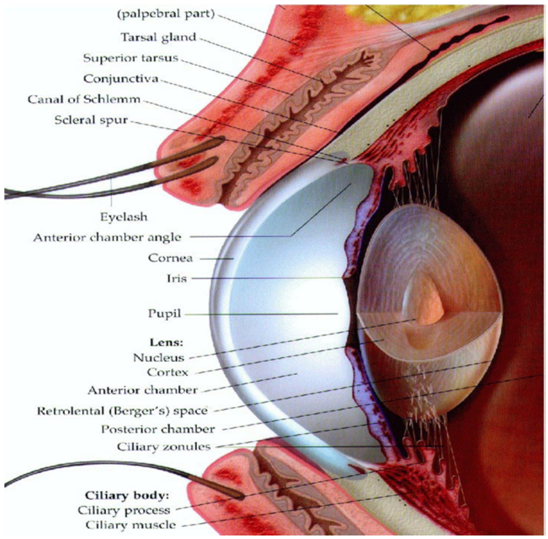




XRF analysis of silver coins

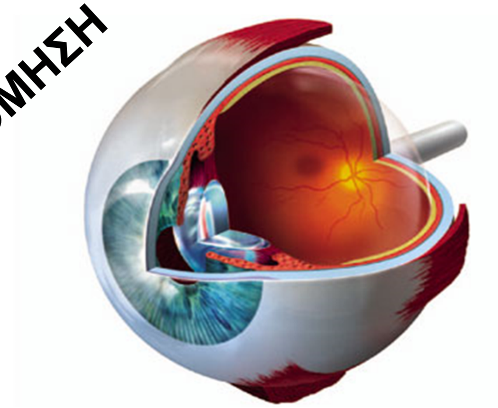
Part 2. Selected research activities of NTUA-LOLA

c: Laser applications in medicine : High precision patterning of intraocular lenses, custom lenses and ablation modified intraocular lenses

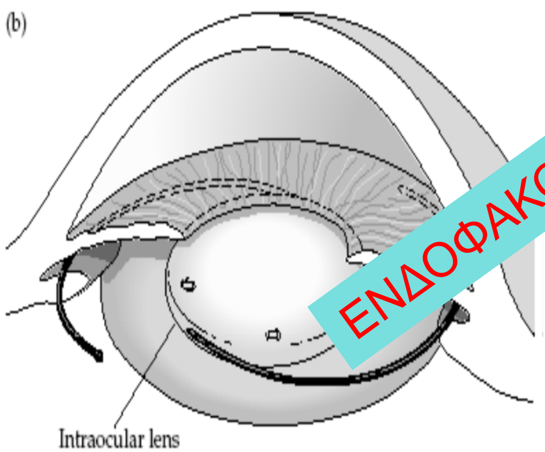


The total optical power of the emmetropic eye is approximately 60 D, of which the corneal power comprises approximately two-thirds of the power. The crystalline lenses, therefore, must provide the balance of power to achieve sharp imaging on the retina.

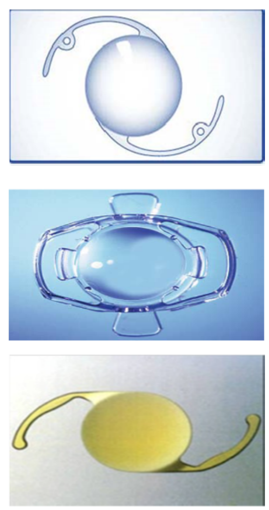
ΑΠΟΔΟΜΗΣΗ



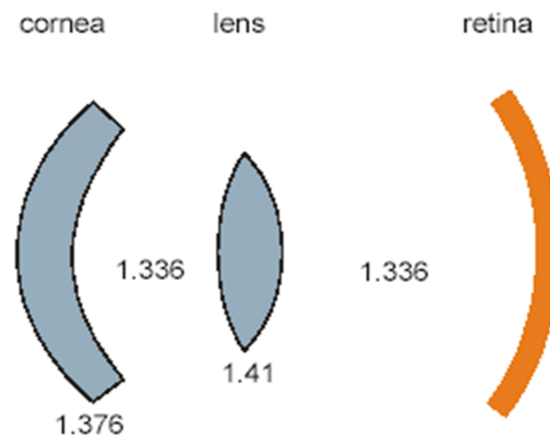
The main optical components of the eye are: cornea, lens and retina (screen).



ΕΝΔΟΦΑΚΟΙ



Traditional IOLs with different haptics.



New trends in vision correction: Intraocular lenses (IOL's).

In ophthalmology, the use of synthetic, biocompatible intraocular lenses (IOL's) is the most promising method of restoring excellent vision in cataract surgery, while multifocal intraocular lenses for good distant and near vision are also investigated.

IOL's are permanent artificial lenses that are surgically implanted to aid or replace the human lens.

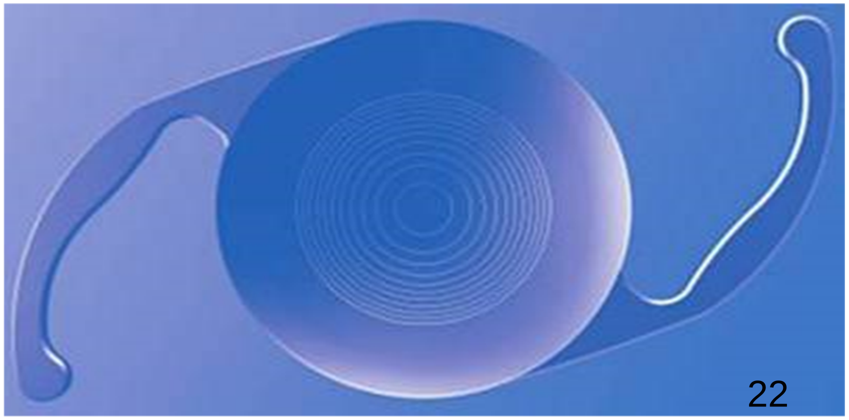
The lenses have different distributions of light on the pathway from the lens to the retina and can be divided into two groups:

Diffractive multifocals: separate the incoming light into two different focal points, one for near objects and one for distance objects,

Refractive IOL's: have a refracting surface with one or more focal points .

In modern IOLs fabrication, new diffractive-refractive multifocal lenses have been developed, providing good distant and near vision.

Example of multifocal refractive IOL design.



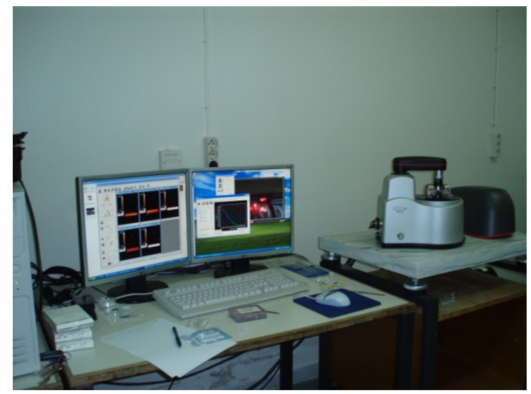
Sculpting Implants in situ: Light-Adjustable Intraocular Lens, Julie Kornfield et al, Caltech.

Materials and methods: ns laser ablation (II)

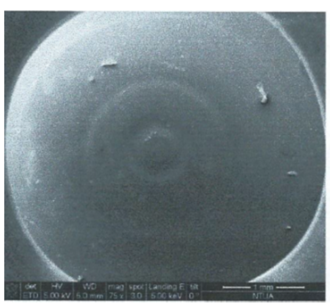
Etch depths corresponding to a particular laser energy fluence were measured at room temperature in open air, by counting the number of pulses required to perforate the sample.

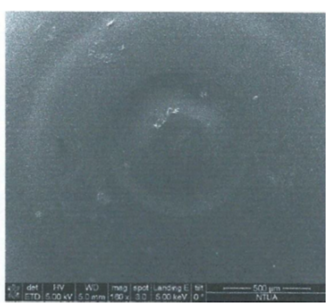
The fluence, Φ, at each setting was calculated as the ratio of the laser energy per laser spot area. For all experiments, fluence measurements are within an uncertainty of ±10%.

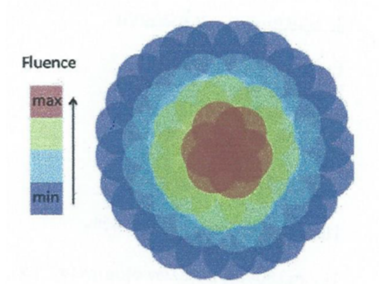
The surface morphology of the ablated areas was examined with SEM and AFM analysis.

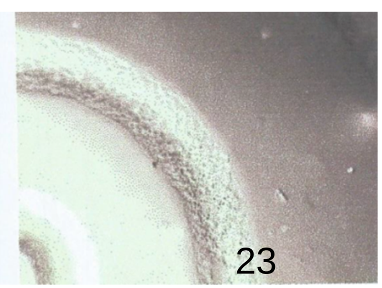


The photochemical, photomechanical and/or photothermal nature of the bond scission in polymer laser ablation processes was argued. It depends on the identity of polymers and experimental conditions such as laser fluence, wavelength, and pulse duration.





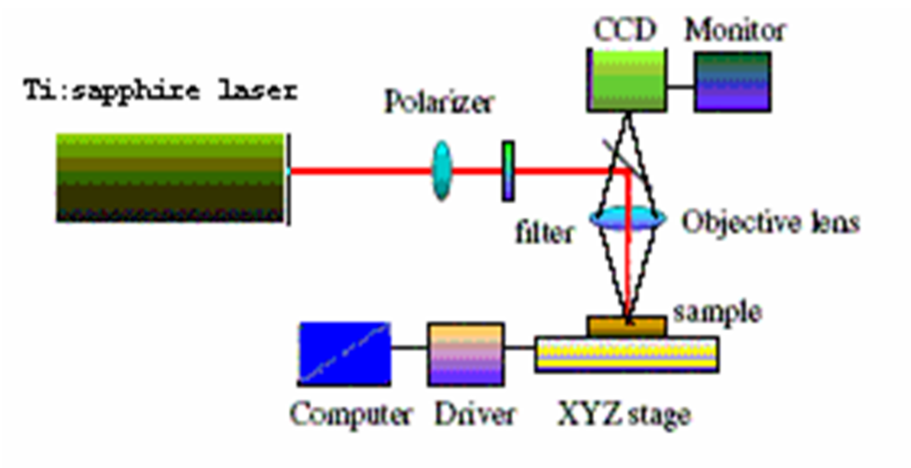




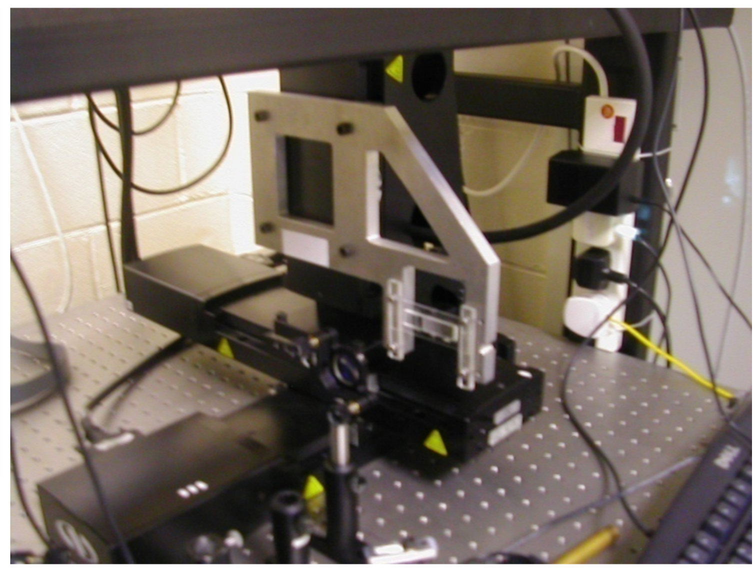
Materials methods and results: fs laser ablation

Ablation experiments of polymers (PMMA plates, intraocular lenses of PMMA, silicone and hydrophilic acrylic material) were performed by irradiating the polymers with a 100 fs laser source (λ = 800 nm, P_{peak} = 2.0 GW, PRF=5 kHz (Spectra Physics Hurricane Ti:Sapphire Regenerative Amplifier laser system).

We investigated the ablation efficiency and the phenomenology of the etched patterns (raster of grooves) by testing the ablation depth with a profilometer (DEKTAK 3000) and the surface modification with a high resolution optical microscope (the intraocular lenses) or an atomic force microscope - AFM (the PMMA samples).



The experimental set-up of Ti:sapphire fs laser is illustrated with a scanning unit of the sample holder (xyz-stage).

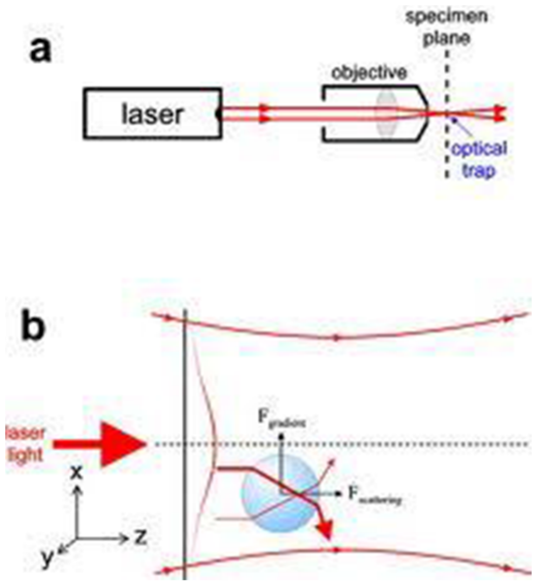


Part 2c. Plasmon assisted optical trapping: Fundamentals and biomedical applications

Basics of operation:

•A high-quality microscope objective lens is used to focus a laser beam to a very small spot (a).

•When an object is brought into the focal point of the laser light, the light pressure pulls the object to the focus (b). The particle is drawn towards the center of the beam and is held there.



$F_{opt} \sim E$ (laser)

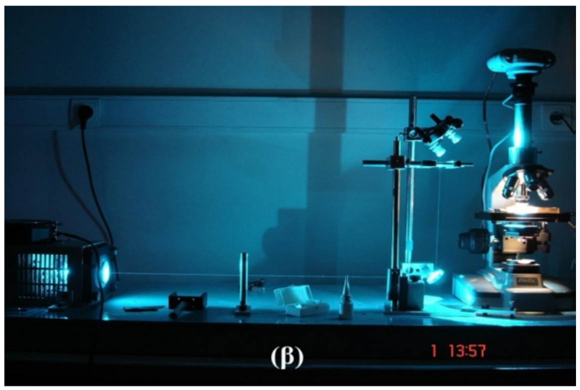
$$\vec{F}_{optic} = \frac{d\vec{P}_{tot}}{dt}$$

•Ένα διηλεκτρικό σωματίδιο κοντά στην εστία θα δεχθεί μια δύναμη F_{opt}., λόγω μεταφοράς ορμής από την σκέδαση των προσπιπτόντων φωτονίων

Quantitative aspects of the optical trapping forces

❖ The trapping forces depend on the **intensity of the laser beam**, the **shape of the laser focus**, the **size and shape of the trapped particles** and the **index of refraction** of the trapped particles relative to the surrounding medium.

❖ It is difficult to measure the trapping forces directly but there are several ways to calibrate the traps.

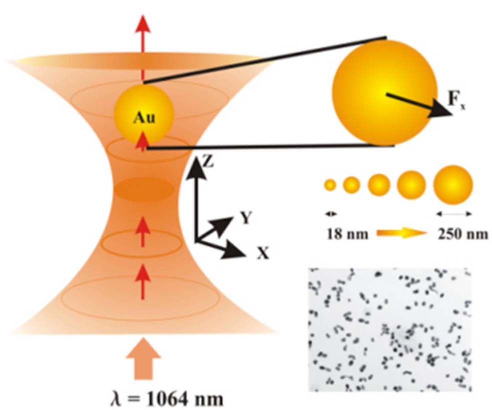


A standard tweezers configuration, based on a Ar^+ laser at 35 mW and a research grade microscope

•The escape force method: Stoke's law provides correlation between laser power and the escape force.

$$F_{esc} = K \cdot 6\pi r \eta \upsilon_{esc}$$

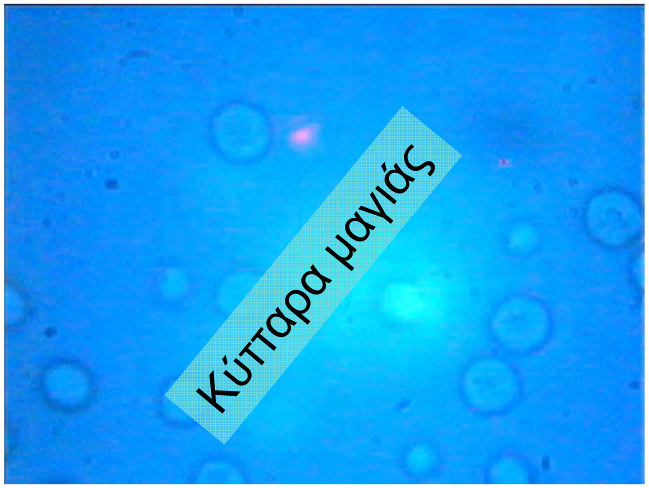
where η is the water viscosity, r the bead radius, v_{esc} the escape velocity of the bead and K (~1.33) a dimensionless correction coefficient.



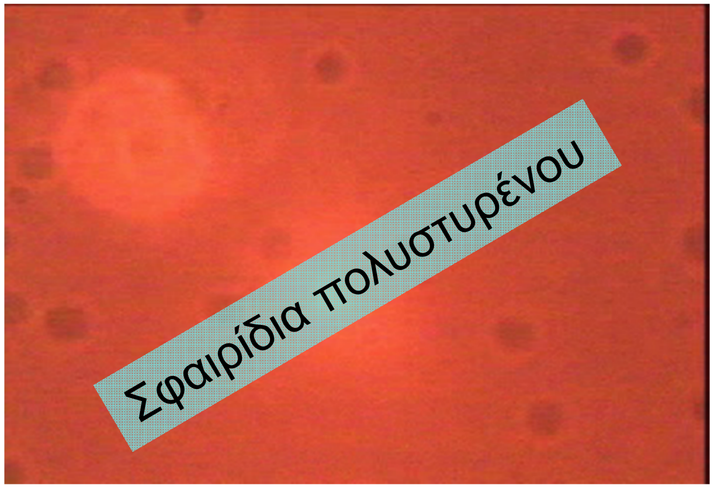
E. Papagiakoumou, D. Pietreanu, M.I. Makropoulou, E. Kovacs, A.A. Serafetinides, "Evaluation of trapping efficiency of optical tweezers by dielectrophoresis" J. Biomed. Opt., 11, 1 – 8 (2006).

Calibration* ⇒ *correlation between the laser power and the forces acting on the particle.

Examples of biomedical applications of optical tweezers and some limitations

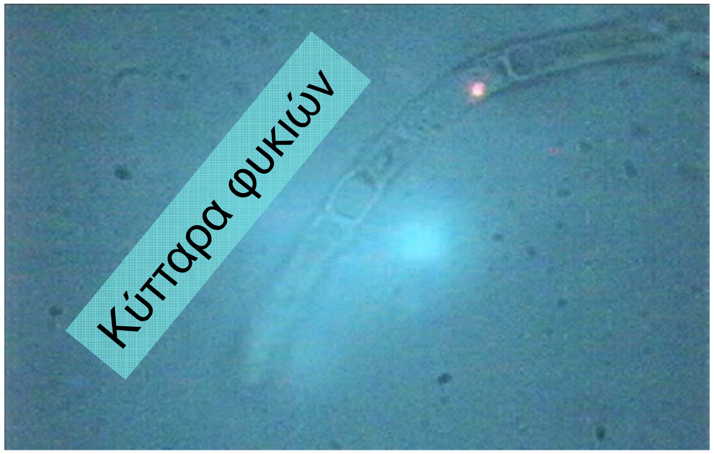


He-Ne laser optical tweezers (λ= 633 nm, 8 mW). He-Ne laser radiation is not absorbed by most biological tissues. Trapping of ***yeast cells***



Argon laser optical tweezers (λ= 514 nm) . Targets are yellow dyed polystyrene microspheres. Trapping and fluorescence.

Combination of He-Ne laser optical tweezers and Er:YAG laser microbeam operating on Klebsormidium algae. The microbeam creates alterations – cuts of the algae cell



Biomedical applications of optical tweezers and some limitations

What happens if the particle's dimensions are smaller than the laser trapping wavelength?

How can take advantage of properties of light resulting from interaction with structures smaller than the wavelength?

- The main disadvantage of the conventional optical trapping systems is the diffraction limit of the incident light (therefore the spatial resolution in trapping is ordinarily limited to more than several hundreds of nanometers).
- Increasing laser power can enhance the trapping force, but the threshold of optical breakdown poses a limitation on maximum trapping power that can be used, especially in the case of sensitive biological specimens.

One possible solution: ***Plasmon-assisted nanotrapping (suited for trapping sub-wavelength metallic or dielectric particles).***

Plasmonics:

The use of nanostructured gold substrates is now allowing optical tweezers to exploit plasmonics and confine nanoparticles to ever smaller dimensions.

Plasmonic-based optical nano-trapping: Introductory remarks

Plasmon: Quantized charge density wave in free electron gas.

❖**Surface plasmons (SPs) propagate along the interface of a metal and a dielectric material, and they include a combination of electromagnetic waves and surface charge density waves.**

❖**Localized Surface Plasmons (LSPs) are non-propagating excitations of the conduction electrons of a metallic nanostructure coupled to an EM field.**

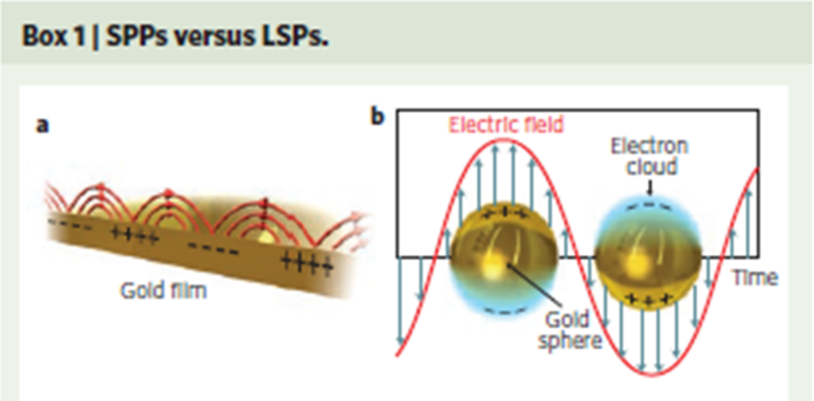


Illustration of SPPs and LSPs. a,b, Collective oscillation of electrons with the incident electromagnetic field at a flat gold–air interface (SPP; a) and in a gold nanoparticle (LSP; b).

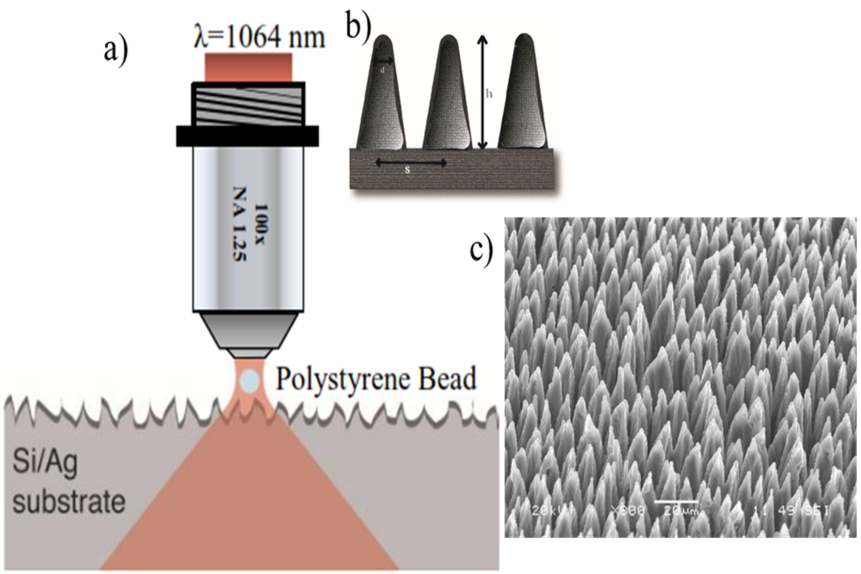
Plasmon nano-optical tweezers

Mathieu L. Juan[1], Maurizio Righini[1] and Romain Quidant[1,2]

NATURE PHOTONICS | VOL 5 | JUNE 2011 | www.nature.com/naturephotonics

Plasmonic-based optical nano-trapping

Initially, we studied an optical nano-trapping setup that exhibits enhanced efficiency, based on localized plasmonic fields around sharp metallic features. The substrates consisted of laser-structured silicon wafers with quasi-ordered microspikes on the surface, coated with a thin silver layer.



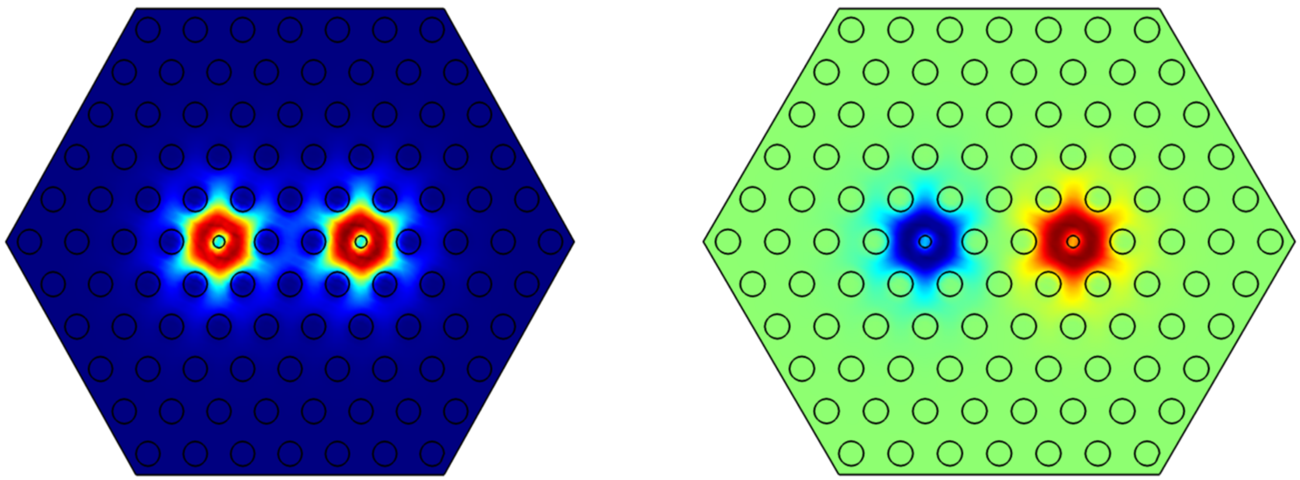
(a) Schematic diagram of the plasmonic optical trap setup based on microstructured silicon substrates.
(b) Schematic representations of the sample geometry. The spikes are conical, with tip diameter of 1-3 μm and height ~25 μm.
(c) SEM images (viewed at 45°) of laser microstructured silicon substrate.

Recently, we used localized fields of metallic structures for efficient trapping, with various patterns (dots, squares etc.).

Μελέτη αισθητήρων δείκτη διάθλασης και βιο-αισθητήρων με χρήση μικρο-δομημένων οπτικών ινών διπλού πυρήνα

Θεωρητική κατανομή του Ηλεκτρικού πεδίου σε δι-πύρηνες οπτικές ίνες

Συμμετρικές και αντι-συμμετρικές ίνες



- Αποδεικνύεται ότι η ευαισθησία του αισθητήρα είναι ανάλογη της διαφοράς των ενεργών δεικτών διάθλασης μεταξύ του άρτιου και περιττού τρόπου διάδοσης

- Μελέτη της λειτουργίας του συστήματος ως βιο-αισθητήρα θεωρώντας ένα λεπτό στρώμα βιο-υλικού το οποίο επικάθεται στα τοιχώματα των οπών.

- Συγκεκριμένα μελετάται η εξάρτηση της διαφοράς των ενεργών δεικτών διάθλασης από το πάχος και τον δείκτη διάθλασης του βιο-υλικού (Διπλωματική Εργασία) «**Μελέτη αισθητήρων δείκτη διάθλασης και βιο-αισθητήρων με χρήση μικρο-δομημένων οπτικών ινών**»

Tsigaridas, G. N., “A study on refractive index sensors based on optical micro-ring resonators”, *Photonic Sens.* (2017) 7: 217. doi:10.1007/s13320-017-0418-0

ΕΥΧΑΡΙΣΤΙΕΣ

1. Προπτυχιακοί – Μεταπτυχιακοί – Διδακτορικοί Φοιτητές (1981-σήμερα)
[>300 >50-60 >30]

2. Εθνικές Χρηματοδοτήσεις [> 3 Μ€]

3. Διεθνείς Χρηματοδοτήσεις [Ευρωπαϊκή Ένωση, ESA, ...] [> 8-10 Μ€]