Trends, Wishes and Dreams (TWD) Symposium on Detection and Imaging Technologies

Barcelona, 30th June and 1st July 2016

Imaging in TPC detectors equipped with high granularity charge readout: transferring technology from rare event searches

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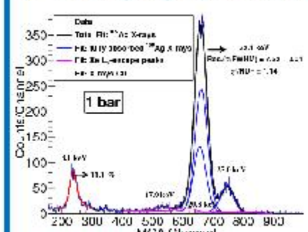
Introduction

- Imaging techniques are essential for medical diagnosis. The traditional scintillation detectors have limited efficiency and resolution, while new semiconductor detectors are expensive.
- What do we need for imaging?
  - A large active volume to reduce exposure time and doses
  - A high fraction of "good" events
    - Good energy resolution
    - Excellent spatial resolution
    - A powerful signal reconstruction software
  - Easy to mount and low cost

The Idea/Concept

- Gas chamber detectors equipped with high granularity charge readout working with Xenon at high pressure
  - good energy resolution and excellent spatial resolution,
  - competitive efficiency, uniformity and no dead areas
  - easy to build, long term stability, low cost and the ability to scan large areas
- These novel detectors in the frontier of technology development are more and more used in particle physics due to their high performance→ ready be transferred to medical imaging.
- RESTSoft (Software for Rare Event Searches with TPCs)→A software package optimized for simulation, data acquisition, event reconstruction and analysis
- The Zaragoza group offers its expertise, know-how and a lab to work on this concept.



Cd109 X-Ray spectra in a TPC detector (Xe+1.7%TMA)

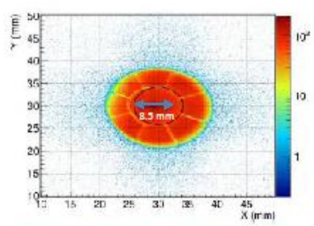
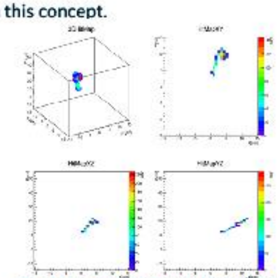


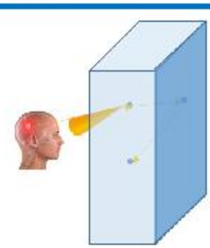
Image of the spider-web shape of the window strongback - CAST experiment



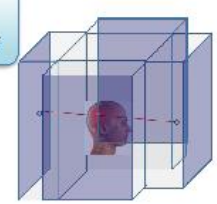
Na source- 511keV events (8mm/pixel) - TREX-BB detector

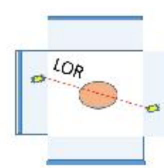
Potential Impact

A qualitative leap in terms of imagen quality and cost thereof



Compton Camera





PET system

"4H" X-ray Camera

Zhehui Wang[1], L. Claus[2], J. Goett, III[1], J. Porter[2],
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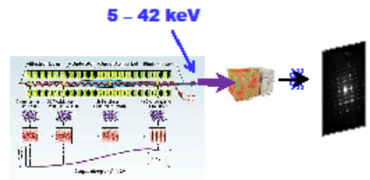
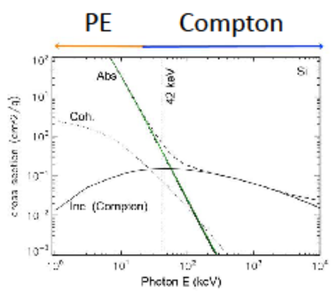
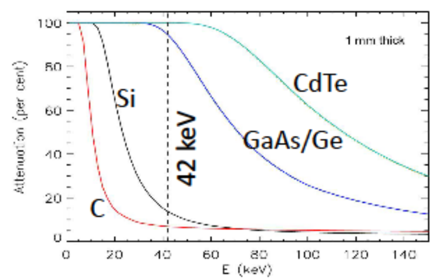
Introduction



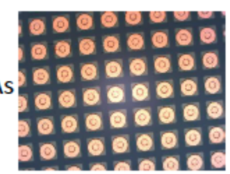
- Picosecond sensor for high-energy photons
- GHz frame rate
- Large data capability

The Idea/Concept

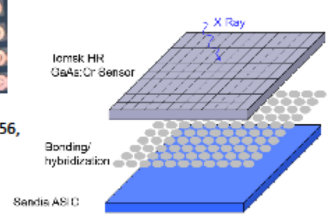


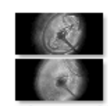


GaAs



Pixel: 45 X 45 um², FORMAT: 256X256, 768X512 (55 um pitch)





10ns Blast Wave Visible Images

FURI

1.5ns, 2 Frames, 448x1024 pixels
350nm Sandia Process

Potential Impact

Accelerator driven light sources: Synchrotron/XFEL, Fusion, Dynamic material research

Silicon-based micro-dosimetry system for advanced radiation therapies

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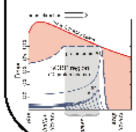
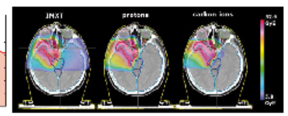
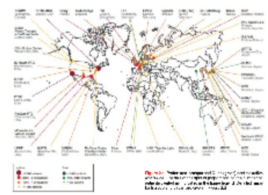
[2] Departamento de Física de Partículas, Universidad de Santiago, Santiago de Compostela, Spain
[3] Laboratoire d Imagerie et Modélisation en Neurobiologie et Cancérologie (IMNC-CNRS), Paris, France

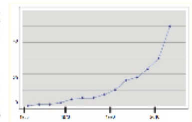
Introduction

- 1 out of 2 persons born today will be diagnosed with cancer in their lifetime (*SEER Cancer Statistics Review 1975-2013*)
- > 50% of all cancer patiens will receive radiotherapy for curative or palliative aims
- **Hadrontherapy** is a fast-growing modality of radiation therapy









Proton therapy centers 1950-2015

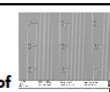
There are 61 hadrontherapy centers in the world with 32 others under construction (19 and 10 in Europe, respectively). (*Nuclear Physics European Collaboration Committee)*

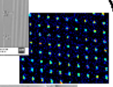
The Need

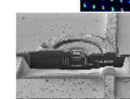
- Treatment planning systems are used to determine the dose distribution obtained for a certain beam arrangement to be applied to a tumor volume.
- **No adequate bio-dosimeters are currently available** for the routine verification of biological dose in hadrontherapy

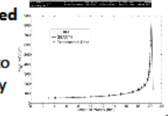
The Expertise

- ✓ The Spanish National Center of Microelectronics (IMB-CNM) **has more than 15 years' experience of producing advanced silicon detectors for nuclear and high energy physics experiments**
- ✓ Together with experts in dosimetry (USC) and radiobiology (IMNC), CNM has developed a silicon microsensor technology that can provide **cell-like silicon sensitive volumes to allow for unprecedented spatial and dose resolution.**
- ✓ **Proof-of-concept devices have already been used** to characterize with high accuracy the radiation quality parameters of carbon and proton beams.









The Idea

Our objective is the **realization of a complete microdosimetry system** for the verification of the biological efectiveness of hadron treatment plans based on this novel silicon technology.

We propose to address this challenge with a **well-balanced, multidisciplinary team with a strong combination of expertise** including: microelectronics technology, electronics, system integration, data processing, Monte-Carlo simulation, radiation therapy and radiobiology.

Potential Impact

The successful development of a new type of silicon-based microdosimetry system will improve the cancer treatment planning in the growing modality of radiation therapy with hadrons. **Millions of cancer patients worlwide** could be benefited.

The system could also address the **radiation protection requirements in avionics and space** radiation environments, helping to understand and thus minimize the cancer risk for aircrew personnel and astronauts.

The use of energetic heavy ions to produce nanometre resolution molecular images in ambient conditions

Brian Jones, Vladimir Palitsin, Geoff Grime and Roger Webb

University of Surrey, United Kingdom

Introduction

Ambient mass spectrometry techniques relying on differentially-pumped mass spectrometers and various ionisation methods that can be applied in air (e.g. lasers, charged droplets, plasmas, etc.) have been put to routine analytical use over the past decade. All ambient ionisation methods have poorer imaging capabilities than secondary ion mass spectrometry (SIMS), which uses keV/u atomic and cluster ions in a vacuum to sputter material from a sample's surface. MeV/u primary ions induce electronic sputtering and can be extracted from a vacuum system to offer a comparable imaging performance to traditional SIMS. Our group has developed ambient MeV-SIMS to provide simultaneous X-ray and molecular analysis [1-4] (see Fig. 2) with submicron lateral resolution, thus providing a completely new working regime for SIMS. It has become evident that significant improvements can still be made to MeV-SIMS by increasing the mass of the primary ion to achieve nanometre lateral resolution of massive (>45 kDa) intact molecular species with ambient MeV-SIMS. The proposed method is outlined below.

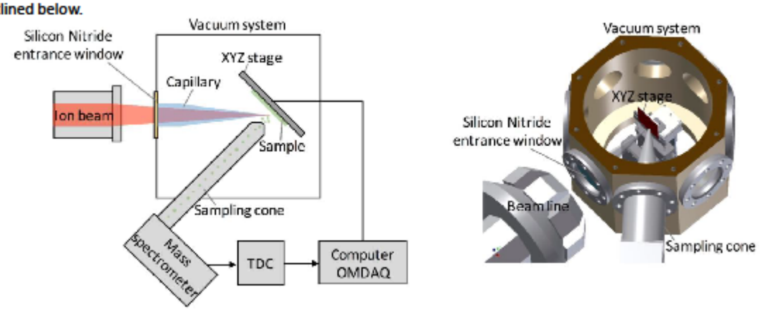


Figure 1. The proposed system

The Idea/Concept

The ideal heavy ion beam for ambient MeV-SIMS analysis can be provided by a linear accelerator or a superconducting cyclotron, such as the one found at KVI-CART of the University of Groningen, Netherlands; specifically, the use of Pb ions or heavier at 1 to 3 MeV/u gives the best possible useful lateral resolution for desorbing intact molecular species as massive as proteins. To achieve the required spot size, a tapered glass capillary forms a nanoprobe to bombard the target with a low current of the heavy ions. A vacuum compatible XYZ positioning system providing nanometre precision will be used to scan the samples to produce an image. A differentially-pumped orthogonally-pulsed mass spectrometer will collect and analyse the molecular signal generated. The entire system will be transportable for use at different facilities. Various ionisation sources can be attached when accelerator beam time is not available. To make vacuum analysis possible with this system, a thin silicon nitride entrance window (see Fig. 1), which maintains a vacuum for the sample and the mass spectrometer while allowing the primary ion beam to pass, can be attached.

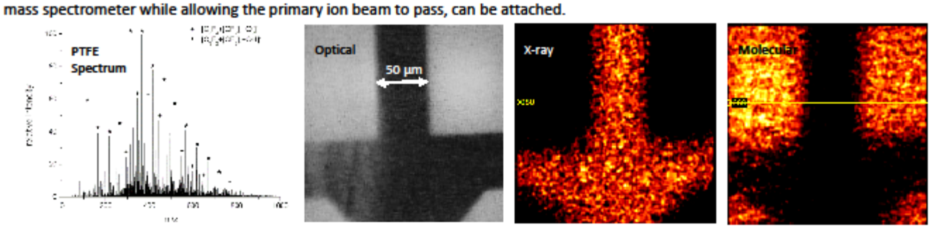


Figure 2. Preliminary data of Cu grid on PTFE polymer acquired using a focussed beam of 0.2 MeV/u oxygen in air

Potential Impact

The major impact of ambient MeV-SIMS is that it provides analysts with the only nanometre lateral resolution ambient imaging mass spectrometry technique that also allows for simultaneous X-ray analysis. This offers a completely unique approach for chemical and elemental analysis of samples in biology, materials science, art, archaeometry, forensics and cultural heritage.

References

[1] Wakamatsu Y, Yamada H, Ninomiya S, Jones BN, Seki T, Aoki T, Webb R, Matsuo J. Highly sensitive molecular detection with swift heavy ions. Nucl Instr Meth Phys Res B 2011;269(20):2251-253.
[2] Jones BN, Matsuo J, Nakata Y, Yamada H, Watts J, Hinder S, Palitsin V, Webb R. Comparison of MeV monomer ion and keV cluster ToF-SIMS. Surf Interface Anal 2011; 43(1-2):249-52.
[3] Wakamatsu Y, Yamada H, Ninomiya S, Jones BN, Seki T, Aoki T, Webb R, Matsuo J. Biomolecular emission by swift heavy ion bombardment. AIP Conf Proc 2010; 1321(1):233-36.
[4] Jones BN, Palitsin V, Webb R. Surface analysis with high energy time-of-flight secondary ion mass spectrometry measured in parallel with PIXE and RBS. Nucl Instr Meth Phys Res B 2010;268(11-12):1714.

Acknowledgements

We greatly appreciate the generous support of the IAEA for CRP F11019: Development of Molecular Concentration Mapping Techniques Using MeV Focussed Ion Beams.

Electron and Photon beam monitors

Simone Dal Zilio, Angelo Giglia and Marco Lazzarino

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Marco Veronese and Mario Ferianis

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Introduction

Ultra high brightness electron beams are used in advanced accelerator facilities, FELs and colliders, with micron level beam sizes. The control of machine optics and transport requires transverse profile measurements of such small beams. In many FEL facilities such as LCLS and FERMI, optical transition radiation screens have shown severe performance degradation due to coherent emission from micro-modulations in the bunch and can no longer being used. For such reasons wire scanners have regained strong interest: they employ free standing very thin wires but with limited choice for materials an thicknesses. By a multidisciplinary approach to the problem, we have adapted the nanofabrication technique to electron beam diagnostics: the result is a new device allowing for much greater flexibility in the choice of design parameters materials, thickness and width of the wires.

The Idea/Concept

A new wire scanner for application in FELs or Synchrotron beam lines for beam characterization

Present technology:

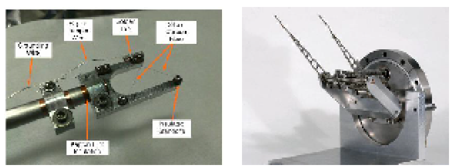


Fig.1 A carbon (left[1]) and metal (right[2]) based wire scanner at the present employed in the FEL, collimators and synchrotrons beam lines

The short term goal: to produce a device capable of overcoming the present wire-scanner technological limitation offering:

- Higher resolution,
- Higher mechanical stability and reliability
- higher flexibility in terms of design parameters such as wire width, thickness and material
- lower impact on the electron/photon beams

The long term goals:

- To reach an non perturbing operation leading to an online diagnostics suitable for slow feedbacks
- Application to both electrons and soft X-ray beams

NanoFabrication approach device:

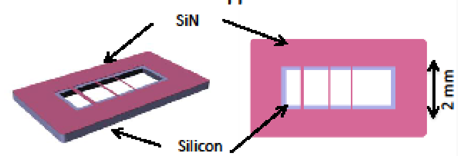


Fig.2 Scheme of the proposed device

The proposed device: a SiN thin membrane (100-2000 nm) is patterned to produce suspended the micro "bridges", 1-2 mm long and 1 to 50 µm wide

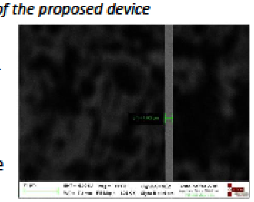
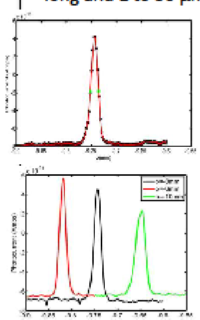


Fig.3 SEM image of a detail of a produced SiN "bridge" device



First results: extension of application of this novel device to:

-monitor high brilliance photon source such as synchrotron radiation facilities (test on BEAR beamline at Elettra).

-characterization in FEL beamlines where micron-level FEL beam spots are produced (in progress).

Fig.4 (Up) Beam vertical scan obtained at 1000 eV. (Down) Out of focus scans (focus position is at x=-7mm).

Potential Impact

The enhanced range of design parameters offered by nanofabrication can lead to devices which are much more adaptable to different beam parameters, more flexible and applicable also to photon beams. Potentially designable to be almost not invasive, allowing for online optics measurements and use in feedbacks. This would lead to a real breakthrough in the management of electron optical functions in FELs which define the stability of transverse electron distribution and thus photon density in FELs. The long term goal is to demonstrate devices capable of sub micron transverse beam size measurements reaching the demanding resolutions of colliders such as ILC and CLIC.

(1) Scanning wire beam position monitor for alignment of a high brightness inverse-Compton x-ray source, Michael R. Hadmack, Eric B. Szarmes, Proceedings of IBIC2013, Oxford, UK (WEPF21) ; 2) http://sl-div-bi-pb.web.cern.ch/sl-div-bi-pb/WelcomeBWS.html

Two Photon Absorption Transient Current Technique for electric field mapping in solid state particle detectors

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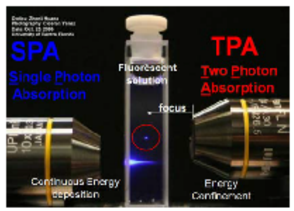
Introduction

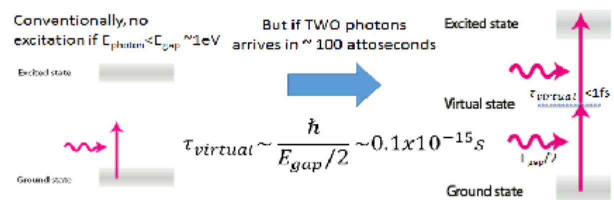
We evaluate solid state particle detectors by localized volume generation (voxels) of electron-holes pairs with femtosecond infrared lasers. The localized charges allow calculation of the built-in electric field applying the Ramo theorem directly. Classical Transient Current Technique (TCT) uses ps-long pulsed visible lasers (short penetration, reduced spot area) or very near infrared ps-pulsed lasers (up to 1064 nm, full detector penetration, no spatial resolution along the beam) . Ultrashort Pulsed Lasers, with a photon energy shorter than the detector bandgap, can excite carriers by Two Photon Absorption (opposed to linear phovoltaic effect) giving both localized eh pairs generation and full device length penetration. TPA Transient Current Technique (TPA-TCT) can be applied both to irradiated and non-irradiated semiconductor detectors.

The Concept

Two Photon Absorption in semiconductors operates at photon energies below the bandgap. Conventional photoelectric effect is strongly suppressed so the device is basically transparent. Only in the focal volume the light intensity is strong enough to generate current carriers by means of electron virtual state assisted absorption. We use femtosecond pulsed lasers because, for the same average power, the two photon absorption probability increases with shorter light pulses. Transient Current laser excitation in the TPA regime opens the possibility to generate charge voxels at any depth in the device. Collected charge correlated with focus position resolves position and size of charge collection junctions. Analyzing the current transients we can estimate the built in detector electric field limits and its modification due to radiation damage.



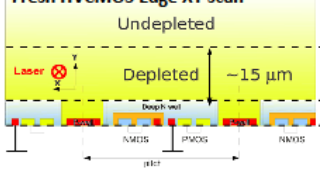
Visual Example of TPA in fluorescent liquids

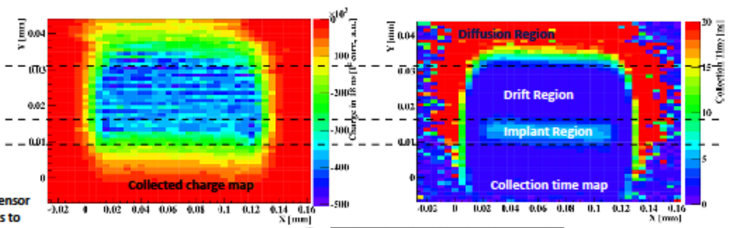


Potential Impact

Transient Current TPA shows in real time the detector signal response at different voxels. With that information we can determine the geometry of the electric field in the detector. For a fresh (non-irradiated) detector, is a test method to know if the (by doping) electric field design is correct. For irradiated detectors, TPA-TCT enables a higher resolution on the electric field measurement, compared with other classical TCT. Drawing the electric field geometry, we can evaluate the detector design efficiency and also determine the radiation effects, both very useful data to improve detector design for radiation hardness.

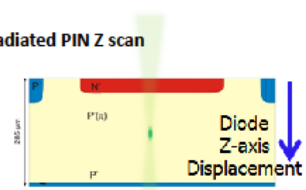
Fresh HVCMOS Edge XY scan

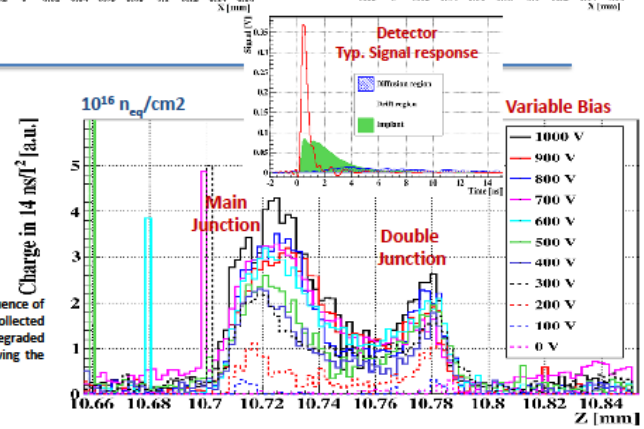




Laser at 1300 nm, 240 fs, pJ pulse energy, XY scan of sensor edge (Δx=5 µm, Δy=1 µm).Voxel pair generation allows to pinpoint the built in electric field by means of collected charge and collection time maps

Irradiated PIN Z scan





Right: We make a TPA Z-scan on an irradiated PiN detector (fluence of 10^{16} n_{eq}/cm ^{2}), for different voltage bias. The plot shows the collected charge in 14 ns of detector signal. The main electric field is degraded and a parasitic electric field appears at the device end, showing the well known double junction effect for heavy detector damage.

Automated Multimodal Correlative Microscopy for high resolution *in vivo* imaging.

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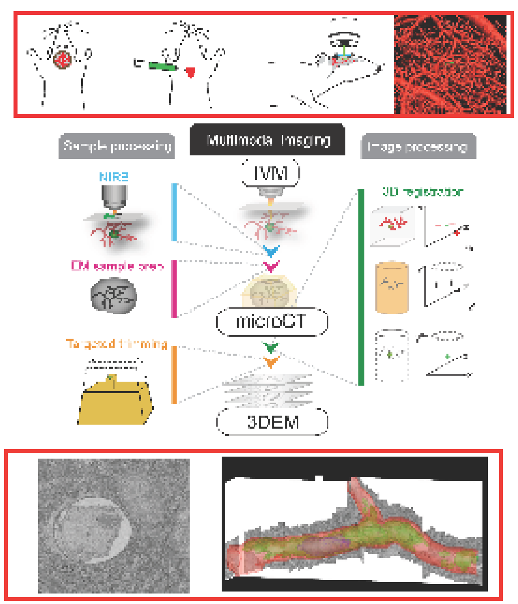
[2] FEI, Life Sciences

Introduction

Modern research in Life Sciences is integrating multiple and diverse data from complex biological models, to understand at the molecular level, the mechanisms underlying the development, the function and dysfunction of living organisms. For this, imaging technologies are playing a crucial role. One big challenge is to record the living state (functional and dynamic) at the highest resolution possible (ultrastructural level). One of the most efficient solution is to combine and correlate on the same specimen, various imaging technologies, such as light microscopy (LM) and electron microscopy (EM). Correlative Light and Electron Microscopy (CLEM) is now an imaging field per se that covers a large spectrum of applications on multiple biological domains and models. The challenge, when it comes to correlate intravital imaging (by LM) to subcellular recordings (by EM), is to improve the targeting precision in 3D but also to enhance the speed and the resolution of the imaging. In doing so, the enhanced recording throughput is expected to enable quantitative analysis of biological phenomena.

We have recently demonstrated the power of multimodal correlative microscopy that **combines intravital imaging** of single metastatic cells to **large volume electron microscopy** (1). With this technology, it is now feasible to study the cellular mechanisms, for example of cancer spreading, in relevant models in vivo. Working closely with numerous laboratories in the Life Sciences, we are now establishing workflows for various applications in the fields of cell biology, development biology, neurobiology and physiology.

The Idea/Concept



Potential Impact

We aim to dramatically improve the Multimodal CLEM processes to allow even faster correlation and more importantly, to make it more accessible to non specialized laboratories. In doing so, we will answer to the needs of a growing and eager community with a unique, versatile and powerful tool to link function to structure in biologically relevant multicellular models. Achieving this goal will only be possible with key technological development to offer new instrumentation and automation in the areas of image processing (software), of sample preparation (mechanics) and of the large volume imaging (microCT, EM).

(1) M A Karreman et al., "Fast and Precise Targeting of Single Tumor Cells In Vivo by Multimodal Correlative Microscopy," Journal of Cell Science 129, no. 2 (January 15, 2016): 444–56, doi:10.1242/jcs.181842.

Lighting up a photonic network inside a living body

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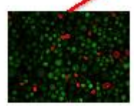
Dipartimento di Fisica, Università di Roma La Sapienza, Italy

There is a need for real-time imaging of the inside of a living body. For example, the exact position of bones in space to fix fractures and disfunctions. Light cannot penetrate inside living tissue because it is absorbed and scattered.

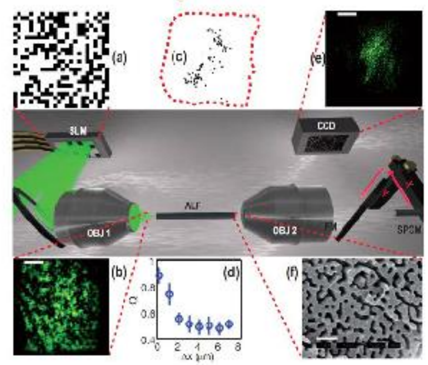
Guiding light into the body

Imaging viscoelastic tissues and organs



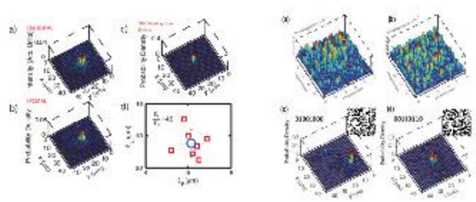
Fluorescence tagging

Gold nanoparticle tagging



The idea is to couple light into the body using adaptive optics and the body itself as a photonic infrastructure to achieve fluorescence and reflection infrared imaging at high resolution from the inside.

Experiments on Anderson localization in disordered PMMA fibers



Adaptive optics and localized transmission in disordered fibers

Potential impact is in the field of surgery, diagnostics, and in the understanding of the human body. A surgeon could evaluate the shape and deformations of an organ surface without having to operate.

ATTRACT

Trends, Wishes and Dreams (TWD) Symposium on Detection and Imaging Technologies

Barcelona, 30th June and 1st July 2016