H. L. Cabrera[1], B. Zengin[2]

1. Laboratory for Solid State Physics, ETH Zürich, 8003 Zürich, Switzerland
2. Department of Physics, Istanbul Technical University, Maslak 34469 Istanbul, Turkey

Collecting Photons From An Scanning Tunneling Microscope (pSTM)

Department of Physics

Presentation Overview

- Introduction
- Photon-Scanning Tunneling Microscope (pSTM)
- A Geometrical Challenge
- Computational Methods
- Results

Introduction

Setup of a STM with Photon Detection Using an Optical Fiber

A modified Scanning Tunneling Microscope (STM) is used for the analysis of local production of light during the imaging process in photon-STM modus (pSTM).

Shim, Hyungjoon & Woo, Jeongseok & Lee, Geunseop & Koo, Ja-yong, Setup of a STM with Photon Detection Using an Optical Fiber, Journal of The Korean Physical Society - J KOREAN PHYS SOC. 51 (2007).

Watkins, Neil & P Long, James & Kafafi, Zakya & J Mäkinen, Antti, Fiber optic light collection system for scanning-tunneling-microscope-induced light emission. The Review of scientific instruments. 78. 053707. 10.1063/1.2740479 (2007).

Sivel, V. and Coratger, R. and Ajustron, F. and Beauvillain, J., Photon emission stimulated by scanning tunneling microscopy in air, Phys. Rev. B, 45, 8634--8637 (1992).

Department of Physics
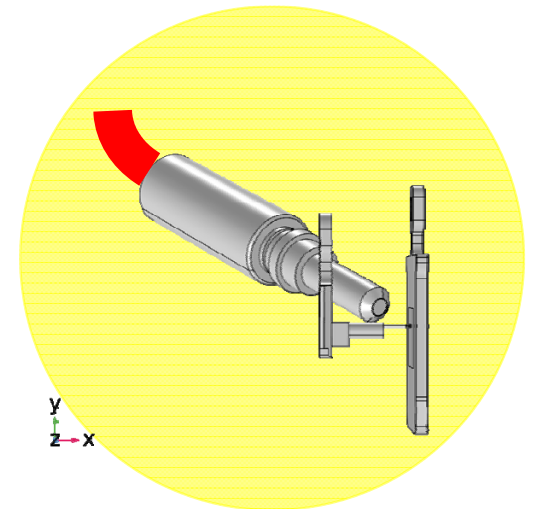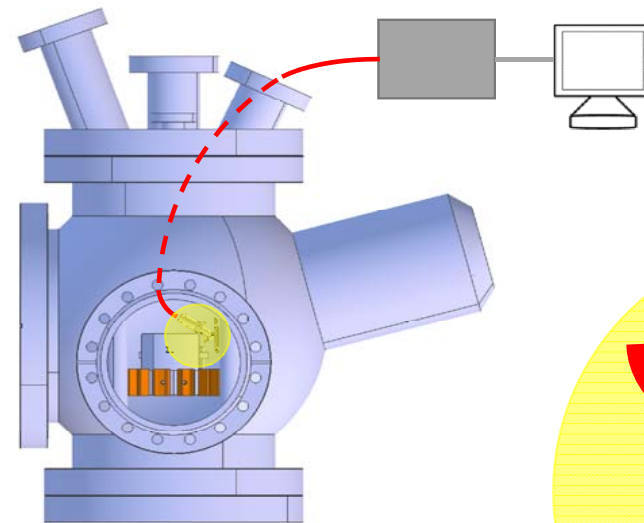
Photon-Scanning Tunneling Microscope (pSTM)
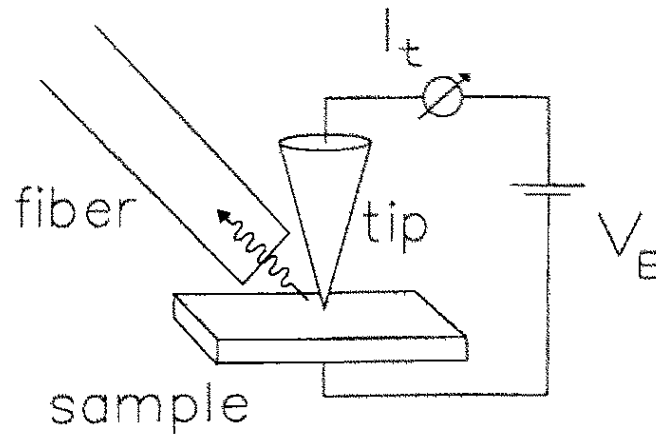## Imaging With Current and Light

Fig. 1. Diagram of the STM tunnel junction with the large core (1 mm) optical fiber positioned to collect photon emission. The fiber has a numerical aperture of 0.5 and is directed at an angle of 40° with respect to the sample plane.

Department of Physics

Photon-Scanning Tunneling Microscope (pSTM)

Characteristics of the Production of Photons
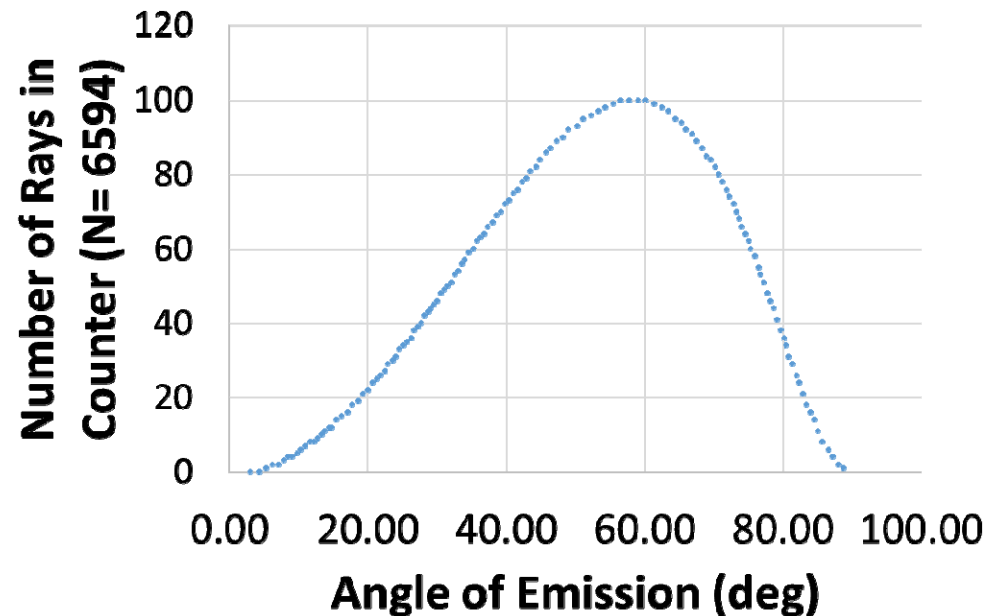
Experimental angular distribution of the produced light.

Uehara Y., Kimura Y., Ushioda S. and Takeuchi KI., Theory of visible light emission from scanning tunneling microscope, Jpn. J. Appl. Phys. 31 pp.2465-2169 (1992).

Department of Physics

# A Geometrical Challenge
Basic Ideas

- In the STM the tip is placed perpendicular to the sample.

- The optical sensor muss take a position close to the electrostatic junction.

- The alignment process of the photonics setup has to follow the results of the simulations.

- COMSOL Multiphysics® simulations based on information from experiments and theory.

A Geometrical Challenge
The Photonics Setup in a Limited Space

- Angle of emission of photons has a well-defined maximum.

- The space around the electrostatic junction is very limited.

- The photonics assembly must allow the exchange of tip and sample.

- The alignment has to be done from the outside of the UHV chamber.

- Look for the position that optimizes the capture of photons.
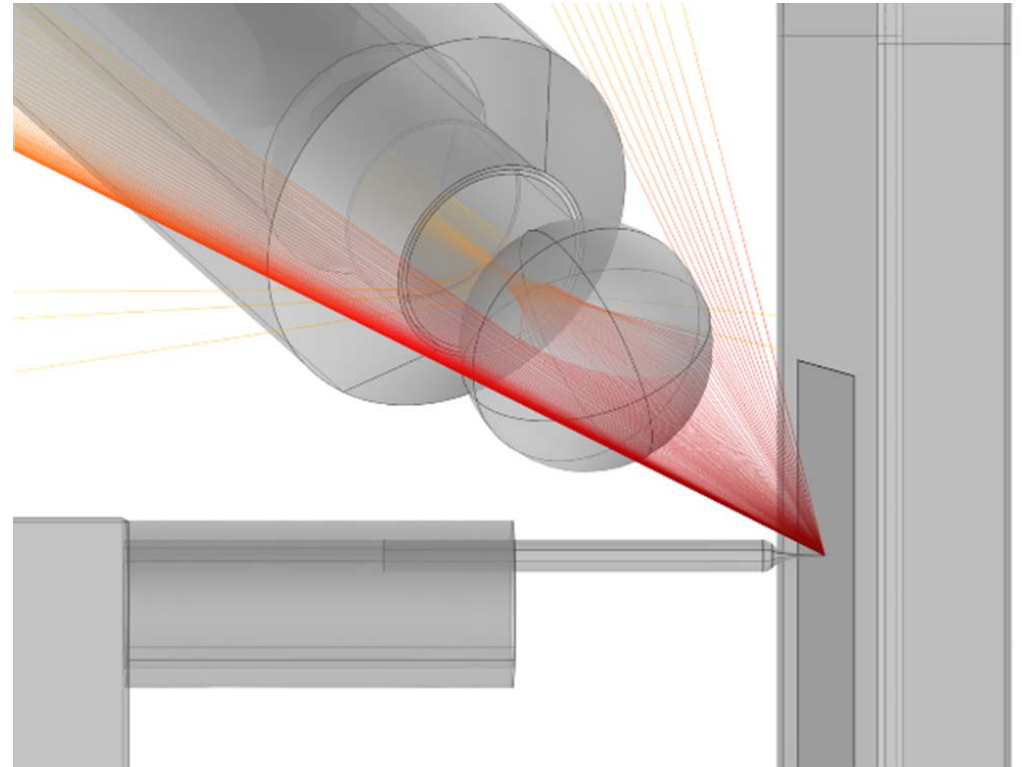

Department of Physics
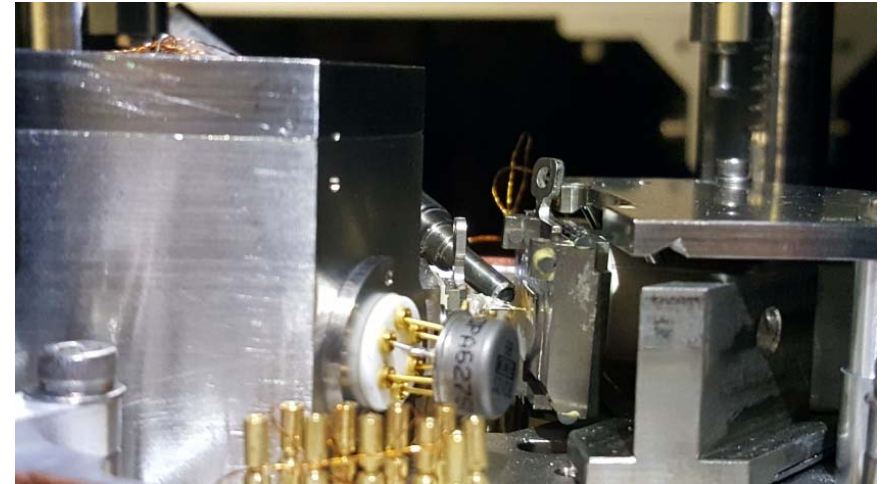
Computational Methods
Modeling With the Ray Optics Module of COMSOL Multiphysics®

- The best model simulates the propagation of light generated in the electrostatic junction of the STM microscope and focused towards an optical fiber by a ball lens.

- The rays are released from a point source on the sample surface with a defined angular distribution.
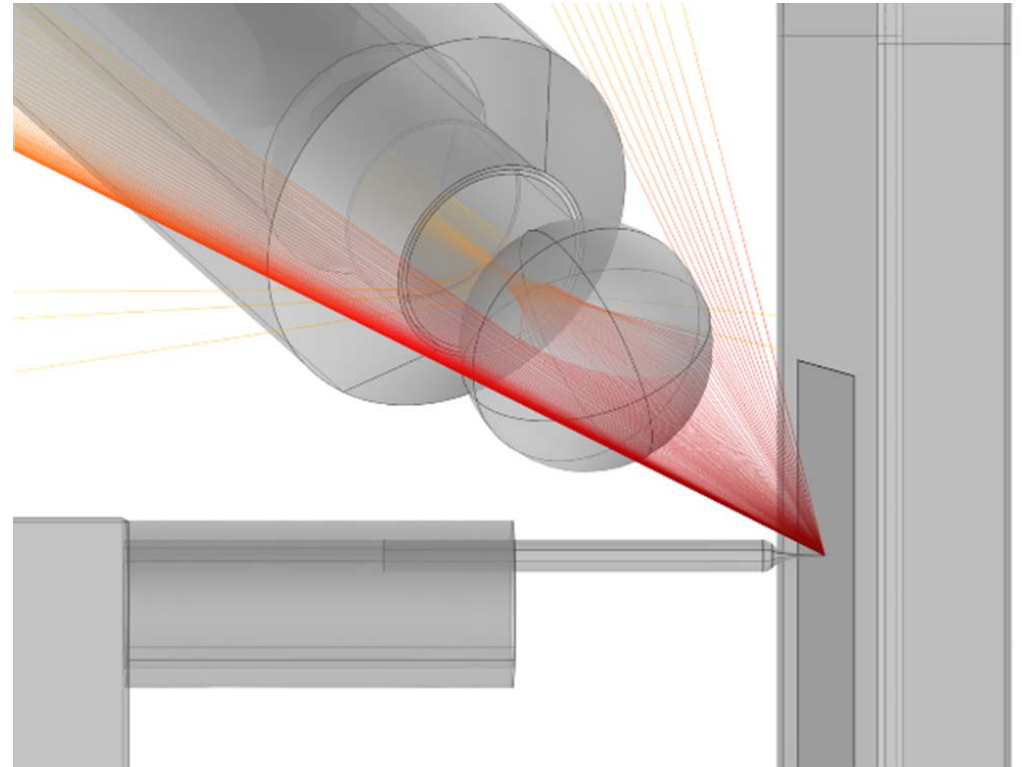
Computational Methods
Modeling With the Ray Optics Module of COMSOL Multiphysics®

- Emission and capture process using the **Release from Data File**, **Release from Point** and **Ray Detector** features of the **Physics interface Geometrical Optics**.

- The **Geometry** of the model is completed by using the **ECAD Import Module**.

Hugo Cabrera

Computational Methods
Modeling With the Ray Optics Module of COMSOL Multiphysics®

The **Ray Optics Module** provides the framework to consider the refractive index n_2 and the focal length of the ball lens f in the equation

$$f = \frac{rn_2}{2(n_2 - n_1)},$$
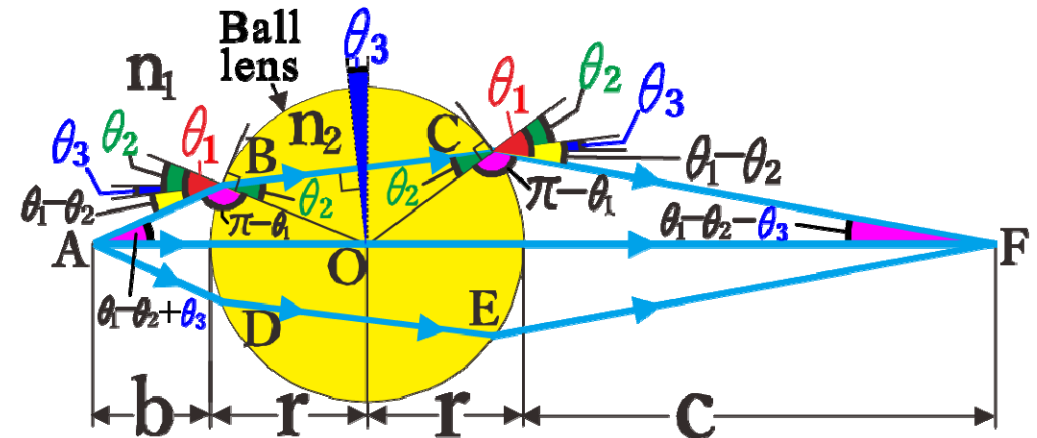
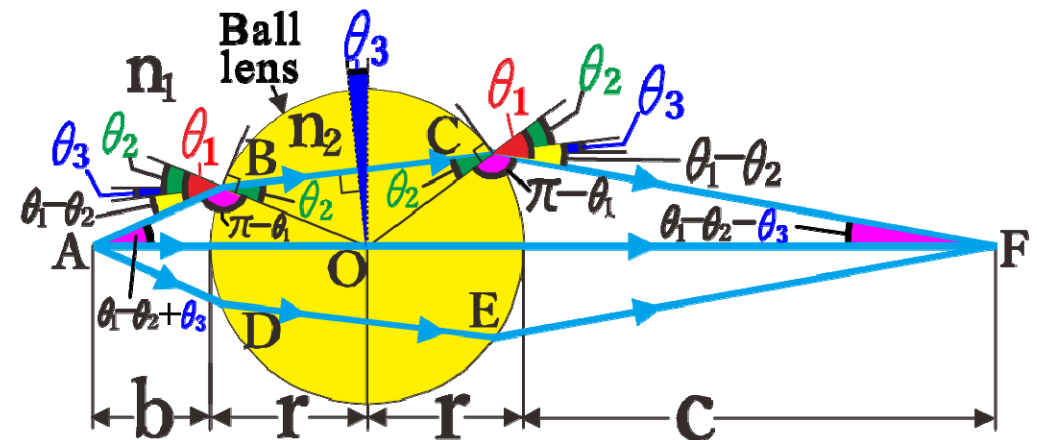where r is the radius of the lens and $n_1 = 1$.

Fig. 19. An optical paths analysis of magnified spatially imaged iris method.

T. Kawakami, M. Date, M. Sasai, and H. Takada, 360-degree screen-free floating 3D image in a crystal ball using a spatially imaged iris and rotational multiview DFD technologies, Appl. Opt. 56, 6156-6167 (2017).

Computational Methods
Modeling With the Ray Optics Module of COMSOL Multiphysics®

The goal is to optimize the position of the photon detector assembly, in particular the distance from the ball lens to the entrance of the optical fiber b and the distance between the junction and the ball lens c and, related by

$$\frac{1}{b+r} + \frac{1}{c+r} = \frac{1}{f}.$$

Fig. 19.   An optical paths analysis of magnified spatially imaged iris method.

Department of Physics

Computational Methods
## Use of the Parametrization Features

The model is appropriate for the study of the effects of changing the values of the geometrical parameters, optical materials and wavelength of the photons using the **Parametric Sweep** feature by means of a **Cluster Computing**.
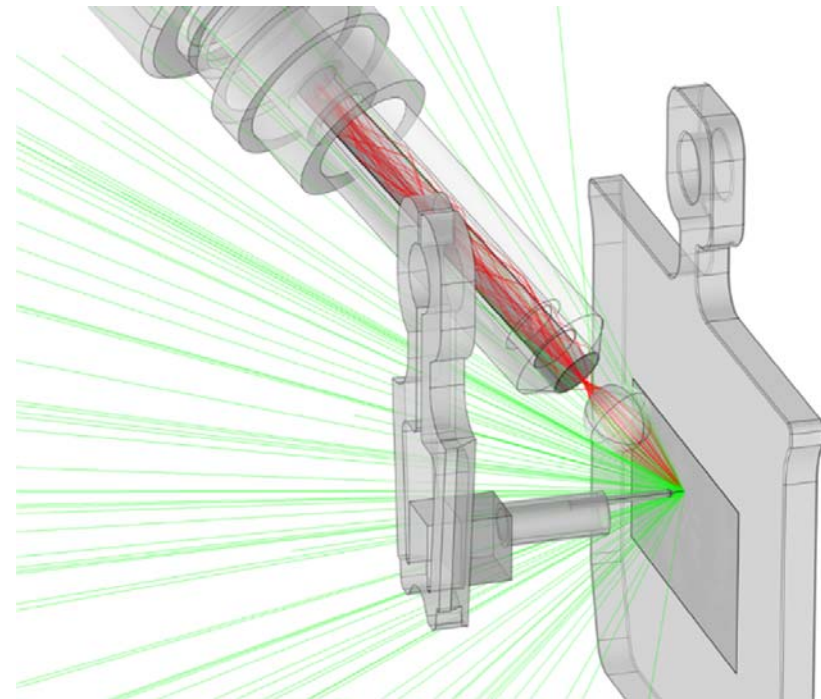
Computational Methods

The Best Solution

An optimal configuration for the photonics read out consists of a ball lens ($r = 1$ mm) in front of an 1.5 mm optical fiber at a distance of 3 mm from the emission point.
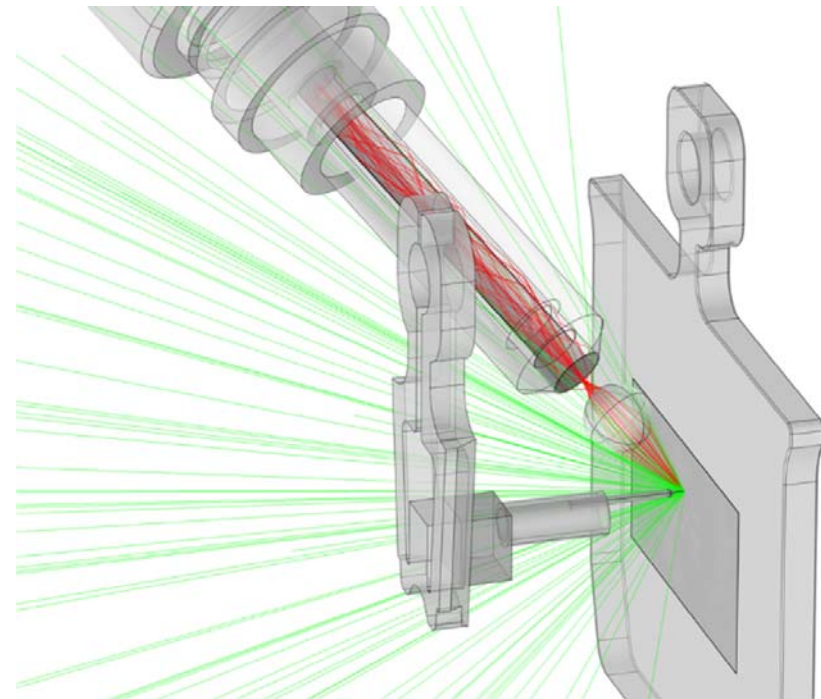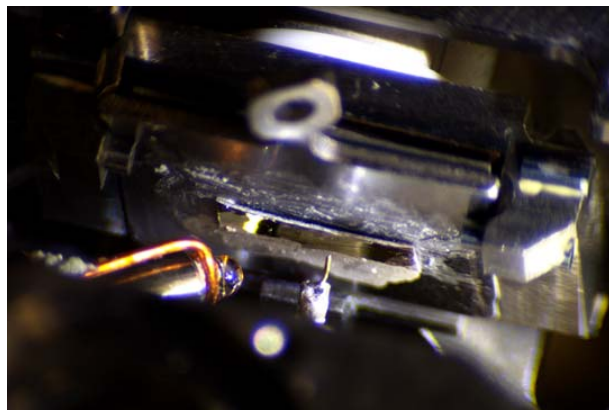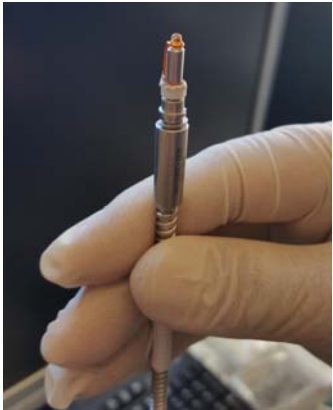
Results
Counting Photons and Already Thinking About Electrons

The display tools are fundamental to consider the following experimental possibilities and the design of the new instruments.
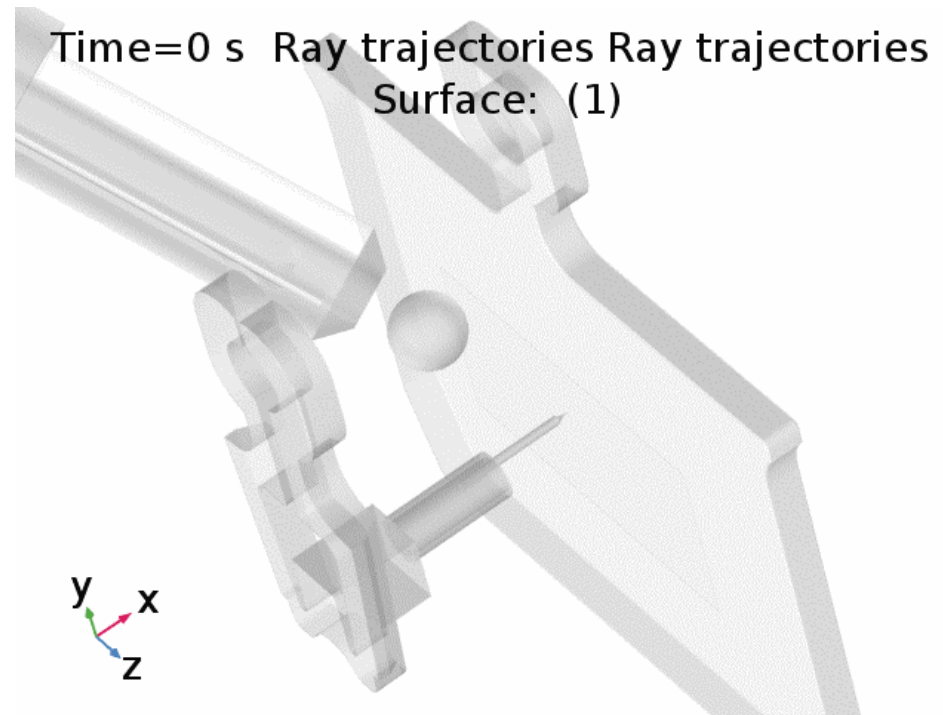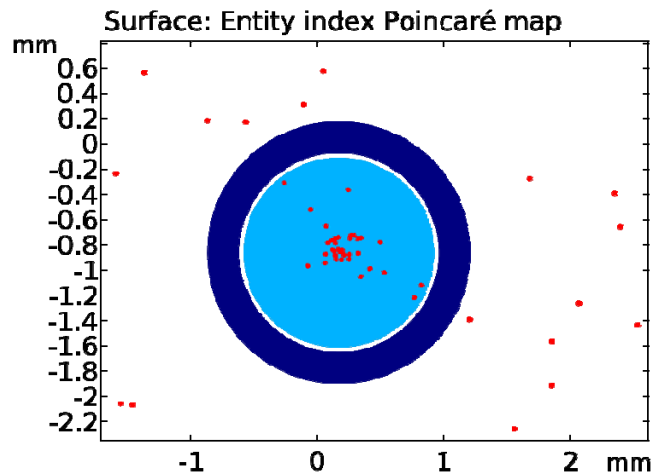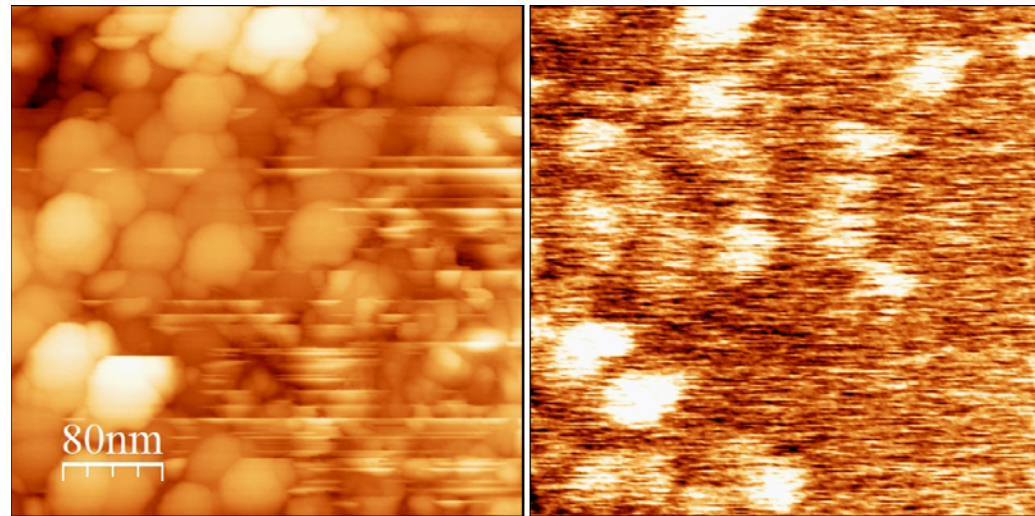
Results
pSTM at Work After the Simulations

The simulations allowed to establish the best model for the light collection system. The experiment has been carried out following these results and it has been possible to capture the photons effectively.

80nm

Proof of principle of the pSTM: Raw data of an 400×400 STM image of a sample [Au(10nm)Titan(100nm) on Mica] obtained with a Ag/Au tip (left). The same region imaged with the optical channel (right). Bias voltage V = 2.3 V, I_t = 20 nA, speed = 1600 nm/s.

Contact information

ETH Zurich

Laboratory for Solid State Physics

HPT C 2.1, Auguste-Piccard-Hof 1

8093 Zurich

http://www.microstructure.ethz.ch/

Thank you very much for your attention!