Collecting Photons from a Scanning Tunneling Microscope (STM)

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INTRODUCTION: 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) [1].

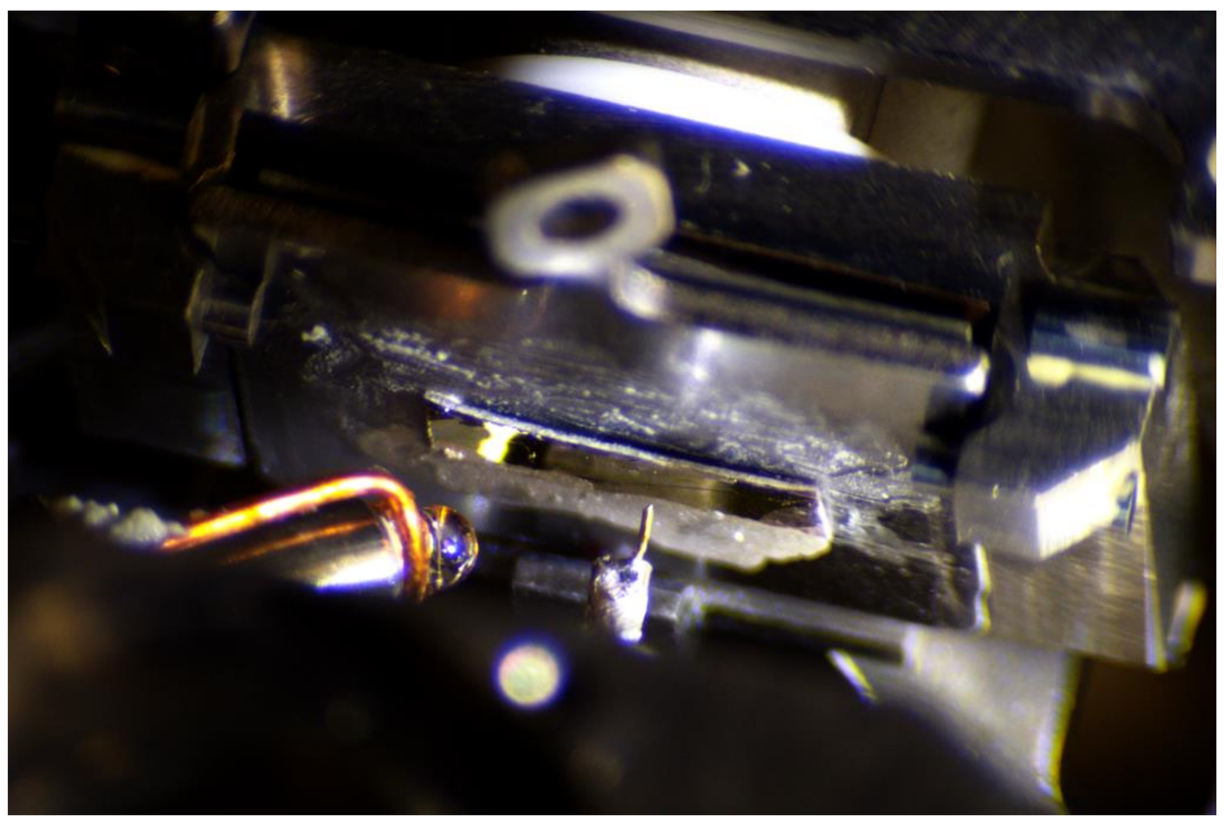

Figure 1. Optical sensor in position close to the electrostatic junction. The tip is placed perpendicular to the sample, the alignment process of the photonics follows the results of the simulations.

COMPUTATIONAL METHODS: The 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. The Ray Optics Module of COMSOL Multiphysics® 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 $n_1 = 1$. Several sweeps over geometrical parameters allow to optimize the position of the photon detector assembly, in particular the distance between the junction and the ball lens b and the distance from the ball lens to the entrance of the optical fiber c, related by

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

The main goal of the simulations is to determine the composition and best position for the photo sensor system considering the reduced space in the setup and the nature of the photon emission [2].

RESULTS: 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.

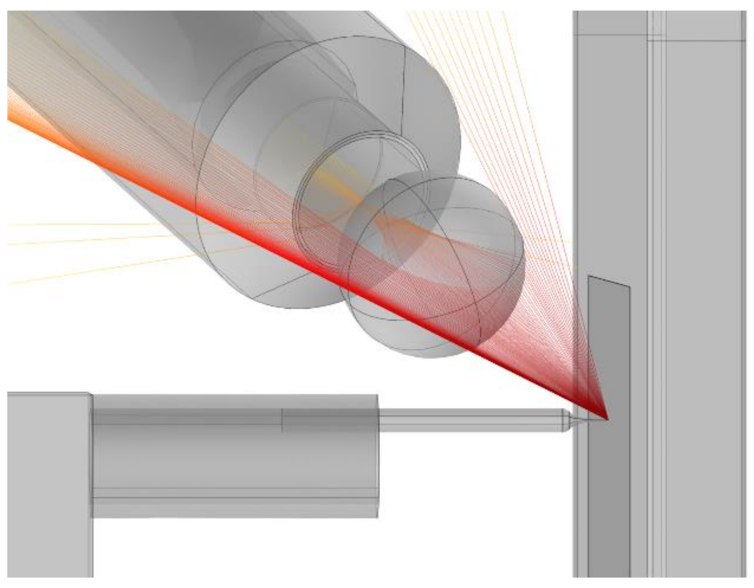

Figure 2. Emission and capture process using the Release from Data File feature.

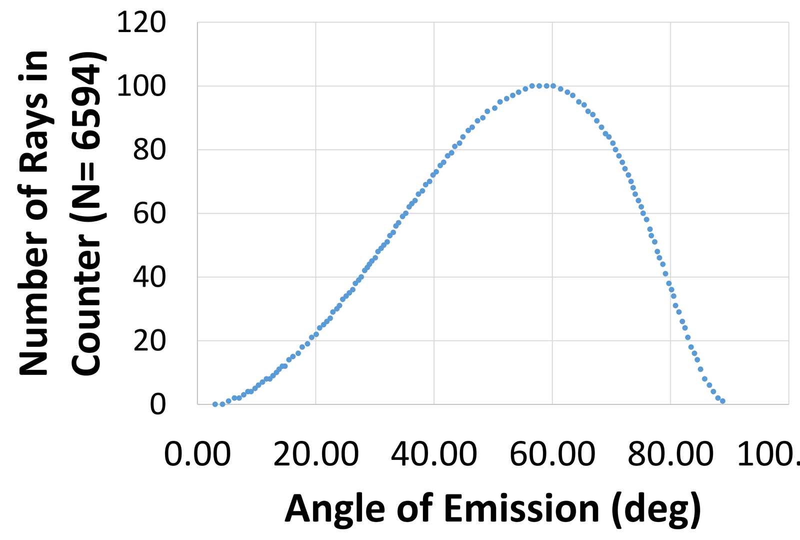

Figure 3. Experimental angular distribution of the produced light [3].

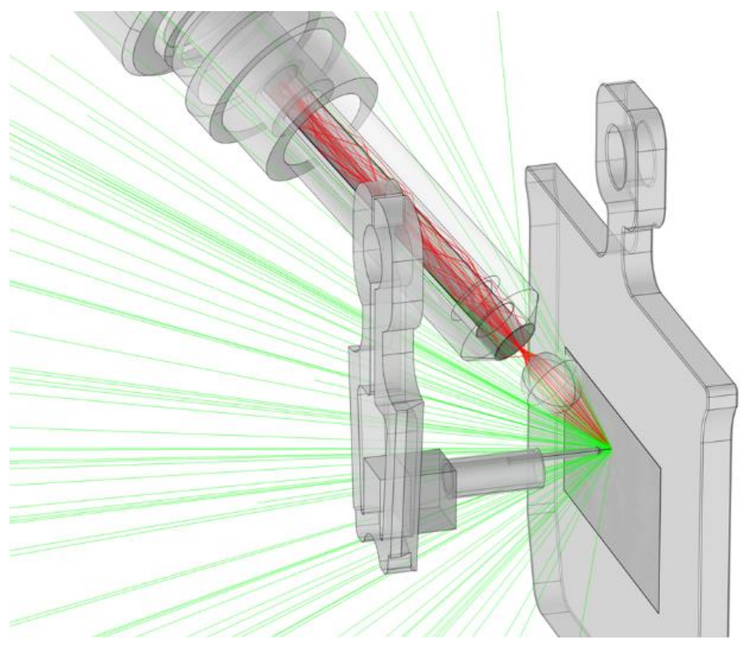

Figure 4. Electrostatic junction and optical sensor drawn with the Import CAD Module. The initial ray direction vectors are Lambertian distributed.

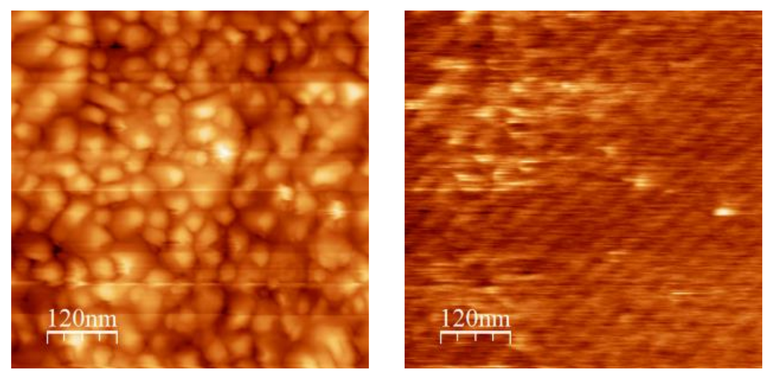

Figure 5. Proof of principle of the pSTM: Raw data of an 600×600 STM image of a Au(10nm)Titan(100nm) on Mica sample obtained with a Ag/Au tip (left) and the same region imaged with the optical channel (right) [4,5].

CONCLUSIONS: 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.

REFERENCES:

1. 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).
2. 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).
3. 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).
4. 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).
5. 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).

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