

Scanning Near-field Optical Microscopy (SNOM)

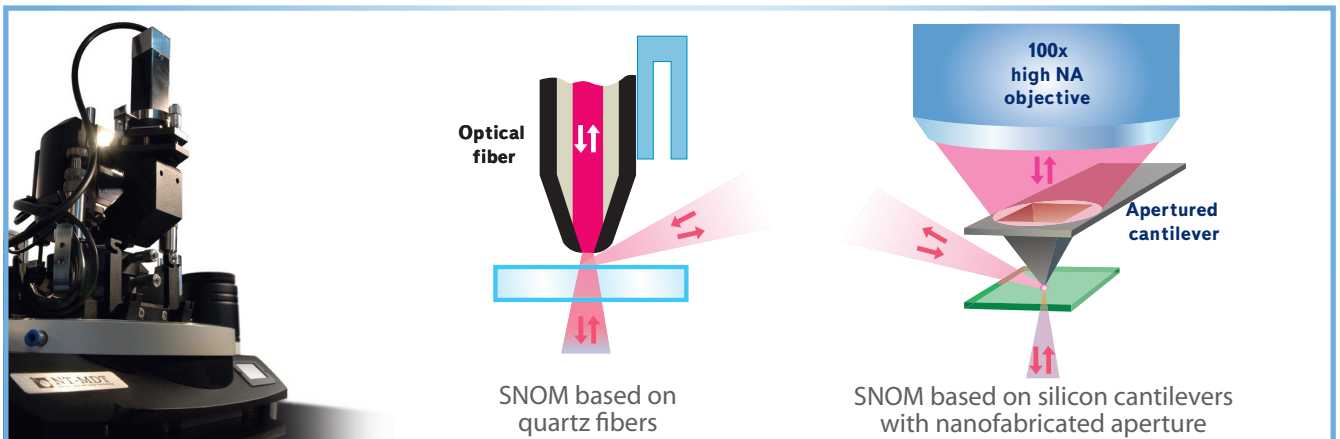
Optical Imaging and Spectroscopy on the Nanometer Scale

Scanning near-field optical microscopy (SNOM) enables studying sample optical properties (reflectivity, light emission/transmission/scattering, fluorescence etc.) with the spatial resolution of tens of nanometers. In contrast to a common optical microscope, where resolution is restricted by the diffraction limit (near 200 nm for the blue light in the confocal conditions), the resolution of SNOM is mainly determined by the size of the optical probe and can reach tens of nanometers.

In a “classical” aperture type SNOM, the optical probe is a subwavelength size aperture in the metal coating of the optical fiber tip or of the cantilever. It is used as the channel for transferring optical signal to/from the sample. The probe is scanned across the sample surface to study optical properties with high lateral resolution.

With the recent advances in scanning probe microscopy and its integration with optics, the new near-field techniques (not based on the aperture) for mapping sample optical properties on the nanometer scale became available. These are Apertureless SNOM, Scattering SNOM, Tip Enhanced Raman / Fluorescence, STM Light Emission and others.

SNOM techniques are widely used in nanophotonics (plasmonics, photonic crystals & waveguides etc.), laser technology, material science etc.



NT-MDT SNOM Features:

- **All major types of SNOM probes and measuring modes supported**

Apertured cantilevers, different types and shapes of apertured optical fibers and even sharpened metal wires can be used as SNOM probes. Major SNOM measuring modes are: Transmission, Collection and Reflection. Signals measured: laser intensity, fluorescence intensity and full emission spectra.

- **Scanning by sample and/or by probe**

Depending on type of sample and measurement, it is important to have capability to scan either by the sample or by the probe to obtain SNOM images.

- **Environmental control (temperature, gases, humidity, liquid and external magnetic field)**

Temperature control and air flow isolation are the key issues for measurements stability. Sample heating and controlled gas atmosphere removes the residual water layer on the sample (this is usually present in ambient conditions and affects any surface measurements). This prevents from unwanted chemical reactions on the surface and other measurement artifacts.

- **Extended spectral region (UV – Vis - IR)**

Standard supported wavelength range is 400 – 1700 nm. Customized solutions for wider ranges are possible.

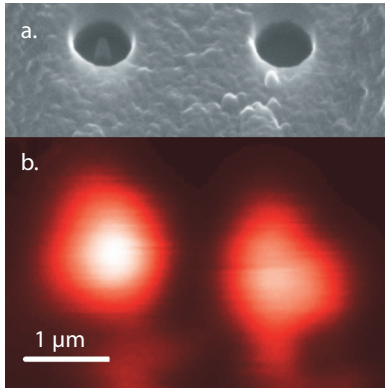
- **Easy integration with AFM & confocal Raman microscopy**

Universal NT-MDT **NTEGRA** SPM base allows one to switch easily between any types of AFM / STM / SNOM measuring heads and environmental cells. The setup can be further integrated with a Raman spectrometer to provide simultaneous AFM / Confocal Raman & fluorescence imaging in addition to SNOM.

- **Advanced techniques: Scattering SNOM, Apertureless SNOM, Tip Enhanced Raman / Fluorescence and others.**

In general, all types of optical and other effects happening between probe, sample and light can be studied by NT-MDT SNOM setup.

SNOM Imaging for Laser Studies



SNOM can be effectively used to study laser emission properties. Both near-field (right at the laser facet) and far-field (at a certain distance from the facet) emission patterns can be obtained with high spatial resolution (<50 nm). Both emission intensity and full emission spectrum can be recorded during a 2D or 3D optical scan.

Shown here is experimental investigation of the performance of an annular aperture and a circular aperture on the same very-small-aperture laser facet.

Fig. 1.

(a) Side view SEM image of a very-small-aperture-laser (VSAL) facet with an annular aperture (left) and a circular aperture (right). (b) Intensity distribution of the light emission (at 650 nm) detected at the surface of the VSAL facet.

Data courtesy: Hongfeng Gai, Jia Wang, State Key Laboratory of Precision Measurement Technology and Instruments, Department of Precision Instruments, Tsinghua University. *APPLIED OPTICS* / Vol. 46, No. 25 / 1 September 2007

SNOM for Plasmonics

SNOM is traditionally used to examine the Surface Plasmon Polaritons (SPP) behavior with high spatial resolution in all three dimensions (XYZ).

Design and Characterization of a Micron-focusing Plasmonic Device

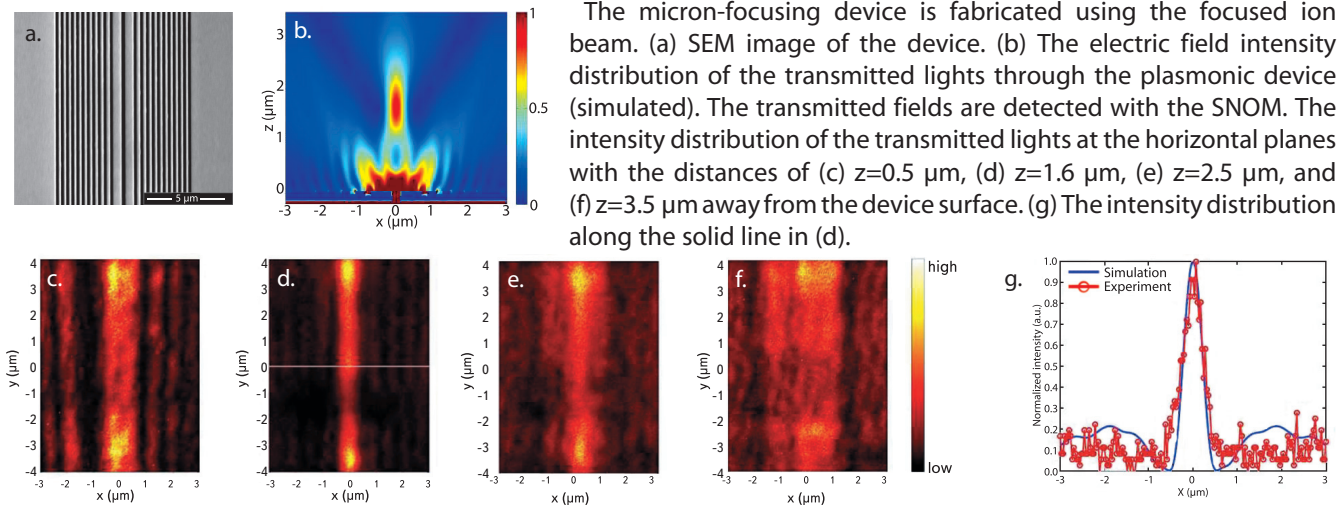


Fig. 2. Data courtesy of Dr. Fenghuan Hao, Dr. Rui Wang and Dr. Jia Wang State Key Laboratory of Precision Measurement Technology and Instruments, Department of Precision Instruments, Tsinghua University, Beijing. *OPTICS EXPRESS* Vol. 18, No. 3, 15741- 15746 (2010).

Plasmonic Fan-Out

SPP behavior is often studied in relation to conventional optical techniques such as beam splitting and wave guiding. The work conducted by Wang et al.* (Fig. 3) realizes traditional fan-out optical arrangement in a plasmonic device. An optical fan-out element typically splits a single wave into plane waves by using gratings and lenses to generate an array of light spots.

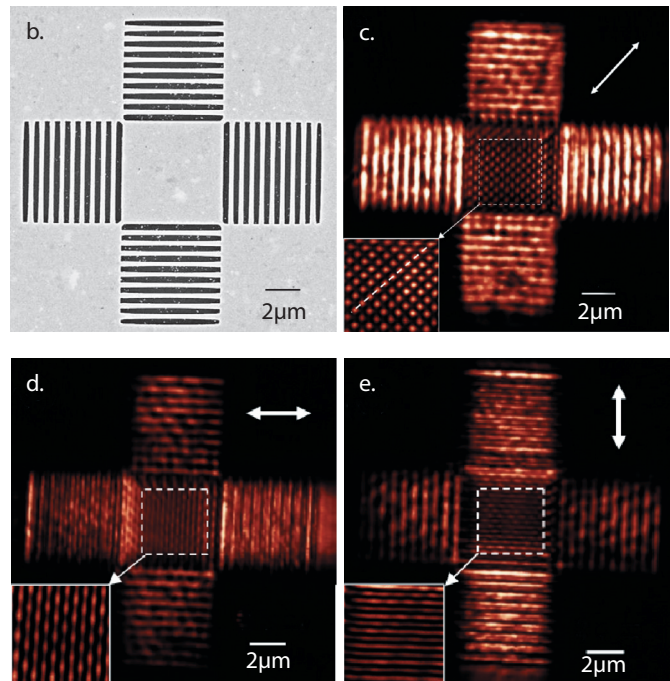
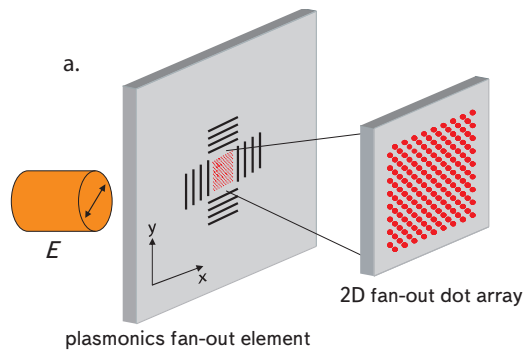
Plasmonic fan-out array was generated by structure shown on Fig. 3 (a,b). The device was produced using arrays of slits on a metal film, the slits being of less than the wavelength dimensions of the initial light. The structure consists of a 100 nm silver film deposited on a quartz substrate. The slit arrays were cut into the silver film by electron beam lithography (EBL) at a width of 265 nm to generate the highest surface plasmon response.

The near field characteristics of the SPP pattern was investigated by SNOM using NT-MDT **NTEGRA** Solaris with an aluminium coated fiber tip (nominal aperture size of 100 nm). The results of the imaging analysis are shown in Fig. 3 (c,d,e).

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Fig. 3



(a) Subwavelength slit arrays is used to generate SPP waves propagating along the metal surface and four perpendicular counter-propagating SPP waves interfered each other to form the localized plasmonic dots array. (b) SEM image of subwavelength slit arrays structure. 2D Near field images of electrical field distributions for polarization direction along diagonal direction (c), along x-direction (d), and along y-direction (e). Insets are the SPP field intensity distribution of the structure's centre area. The white arrow indicates the incident polarization direction. Excitation laser wavelength is 633 nm. Data courtesy of Dr. Wang Qian, School of Electrical & Electronic Engineering, Nanyang Technological University and Dr. Jing Bu, Dr. X.-C. Yuan, Institute of Modern Optics, Key Laboratory of Optoelectronic Information Science & Technology, Nankai University. For more details see: Wang Qian, Jing Bu, X.-C. Yuan, *OPTICS EXPRESS*, Vol. 18, No. 3, 2662-2667 (2010).

SERS substrate

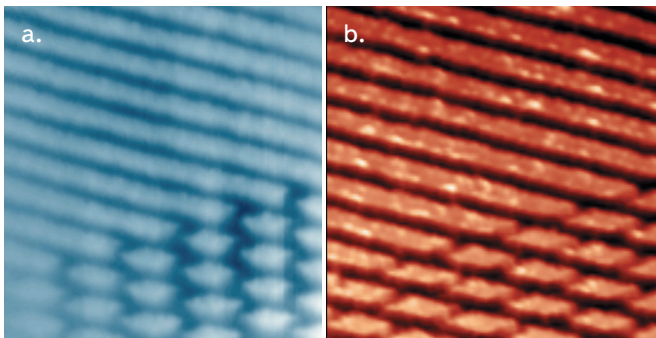
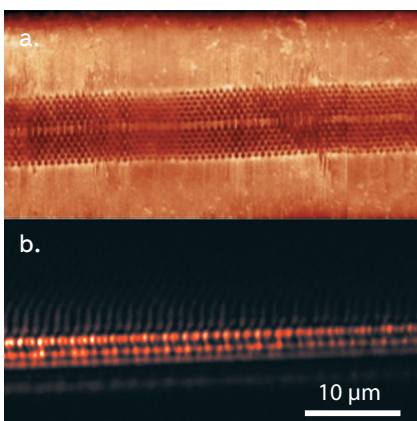


Fig. 4. SERS substrate – Au nanodiamond array on quartz. (a) AFM topography and (b) SNOM image, transmission mode. Period of the structure: 200 nm. Resolution of SNOM image: ~50 nm. Sample courtesy: Dr. Henrik Schneidewind, Institute of Photonic Technology (IPHT Jena), Germany

SNOM for Photonic Crystal Waveguides



Aperture-SNOM in collection mode can be used to correlate the electromagnetic field distribution with the surface topography of the photonic crystal. The optical near-field confined above the sample surface is collected by a SNOM tip, placed several nanometers above the sample surface.

Fig. 5. Light propagation in a one-line-defect photonic crystal (PhC) waveguide patterned into a 450 nm thick free-standing lithium niobate membrane. SNOM topography (a) and optical near-field (b) images recorded above the surface of the PhC waveguide. Data courtesy: R. Geiss, S. Diziain, N. Janunts, Institute of Applied Physics, Friedrich-Schiller-Universitat Jena, Germany, *APPLIED PHYSICS LETTERS* 97, 131109 (2010)

SNOM for Optical Fibers

Photonic crystal optical fiber

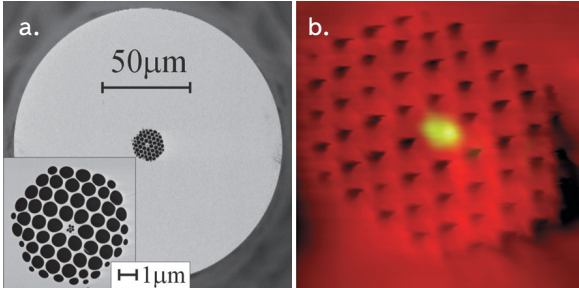


Fig. 6. (a) SEM image of the optical fiber cross-section, showing photonic crystal structure in the fiber core. (b) Overlay of topography map (red palette) and light intensity (SNOM collection) image (green palette) taken from the fiber section. Light propagating in the fiber is perfectly localized in the center of the photonic crystal structure.

Data courtesy: Yinlan Ruan, Heike Ebendorff-Heidepriem, Tanya M. Monro. Centre of Expertise in Photonics, School of Chemistry & Physics, University of Adelaide

Cr:YAG Double-clad Crystal Fiber

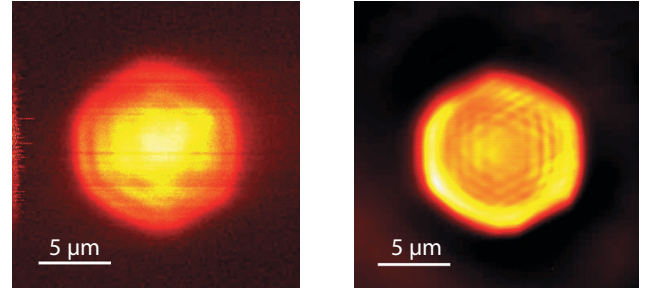


Fig. 7. Near-field imaging of strain fields within Cr:YAG Double-clad Crystal Fiber. SNOM images of (a) Cr⁴⁺ fluorescence at 1350 nm and (b) Cr³⁺ fluorescence at 700 nm.

Data courtesy: Chien-Chih Lai, Sheng-Lung Huang, Institute of Photonics and Optoelectronics, National Taiwan University, Taipei 106, Taiwan

NT-MDT SNOM Specification

SNOM & other probes
SNOM optical fibers; SNOM apertured cantilevers; All types of AFM cantilevers; Sharp metal wires
Supported standard modes
SNOM modes: Transmission; Collection; Reflection
AFM modes*: >30 modes (MFM, SKM, SCM, SRI, LFM, EFM, SThM, UFM, PFM, AFAM and others)
Detected optical signals
Laser intensity; Fluorescence intensity; Spectroscopy (full spectrum at each point)
Excitation / detection wavelength range
400 – 1700 nm; Customized solutions for wider ranges are possible
Advanced near-field modes and techniques
Scattering SNOM (s-SNOM); Apertureless SNOM (a-SNOM); Tip Enhanced Raman Scattering (TERS); Tip Enhanced Fluorescence Spectroscopy (TEFS); SNOM lithography (vector, raster); Light emission/absorption at AFM/STM gap; Polarization microscopy
Optical detectors
Photon multipliers (VIS, IR); Spectrometer with TE cooled CCD camera; Avalanche photodiodes (photon counting regime)

Scanning and feedback mechanisms
Scan by tip & scan by sample regime (100 x 100 μm)
High resonance XYZ piezotube for fast scanning (closed-loop feedback) ; Flat piezo-driven scanning stage (closed-loop feedback)
Laser based cantilever deflection detection (VIS or IR laser); Quartz tuning fork resonator force detection system (shear force & normal force regimes)
Other features
Easy upgrade/integration with confocal Raman/Fluorescence microscopy
Automated alignment of laser spot to aperture of SNOM cantilever
Very high efficiency (numerical aperture) excitation/collection optics
Environmental control: temperature, humidity, gases, liquid, magnetic field
Compatible with commercially available inverted optical microscopes

*May require different types of probes. When probes are exchanged, exact area of the sample is kept within a couple of μm precision