Concurrent polarization retrieval Method in multi-heterodyne scanning near-field optical Microscopy

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Scanning near-field optical microscopy (SNOM) is a popular tool to overcome the diffraction limit for the investigation of subwavelength-scale optical structures. For nearly 30 years, various configurations have been implemented to characterize the interactions of the electromagnetic field with nanostructures in the near field. An accurate understanding of these interactions requires a detailed knowledge of the field, including the state of polarization (SOP) in the near field. The state of polarization is easily accessible in far-field microscopy, but is challenging to measure in the near field. When the SNOM probe interacts with the near field and scatters the signal to the far field, the near-field polarization may be considerably altered. Moreover, the near-field polarization may be oriented in all three dimensions whereas far-field propagation implies a two-dimensional (transverse) polarization.

Recently, several phase- and polarization-sensitive measurements in the near field have been reported. Each of the methods introduces a polarization-selective element to a SNOM configuration to obtain polarization-resolved information and reconstruct the vector field. For example, recently M. Schnell et al. described interferometric detection of the near-field polarization state in nano-antenna gaps using a scattering-type SNOM (s-SNOM). M. Burresi et al. observed in collection mode the polarization singularities in a 2D photonic crystal waveguide with an aperture probe. In these examples, two sequential measurements are performed to obtain information for two orthogonal polarization states, enabling reconstruction of the state of polarization observed at the sample. L. S. Goldner et al. have demonstrated SNOM using a time-varying input polarization state to mitigate some of the concerns. Nevertheless, since the polarization measurements are not performed concurrently, this may introduce some measurement uncertainties due, for example, to drift from mechanical misalignment, changing condition of the probe, or time dependent phase drift.

Multi-heterodyne scanning near-field optical microscopy (MH-SNOM) enables the simultaneous detection of two vector field components associated with each of two orthogonally polarized illumination beams. This provides further information about the SOP in the near field, although still does not provide the full three-dimensional SOP. In our previous work, we extracted concurrently from a MH-SNOM measurement the state of polarization using a polarization retrieval algorithm based on criteria predicted from simulations. However, these criteria are applicable only if the near-field response of the nanostructure can be determined by another method.

In this paper, we strengthen the algorithm by freeing it from a priori knowledge of the fields. We use an isotropic region in the vicinity of the nanostructure as a calibration area, whose known polarization properties provide a global criterion to calibrate the polarization distortion induced by the detection system. Moreover, with a tunable laser source, this process could be iterated to calibrate the system characteristics over the desired wavelength operating range. This makes MH-SNOM a powerful polarization-resolved tool which can be applied to analyze any polarization-dependent nanostructure with subwavelength resolution, as long as an isotropic region is available in its vicinity. This method could contribute to the fundamental study of polarization-sensitive nanophotonic structures such as photonic crystal microcavities, waveguides, thin films, nanoparticles and other nearfield polarization-sensitive imaging applications.

Due to their simplicity in terms of the near-field distribution and strong polarization dependence, form-birefringent gratings (FBG) are optimal structures to assess the polarization-retrieval algorithm proposed here. We experimentally demonstrate this algorithm by validating it in retrieving the polarization-dependent near-field distribution on silicon FBG. Due to the symmetries inherent in this one-dimensional grating and the configuration of the illumination beam—longitudinally oriented fields with respect to the probe are not excited—the full vectorial field emitted by this structure can be detected using the MH-SNOM.

A description of the experimental set-up is first presented (Fig.1). Next, the polarization-retrieval algorithm used in this work is explained step by step. Then, the fabrication of the FBG is described. Afterward, the results of near-field measurements are discussed: we first demonstrate the method through the retrieval of the measured near-field confinement on the FBG in three spatial dimensions. Then, pseudo-far-field measurements are performed to verify the effective refractive index of the FBG. Finally conclusions are presented.

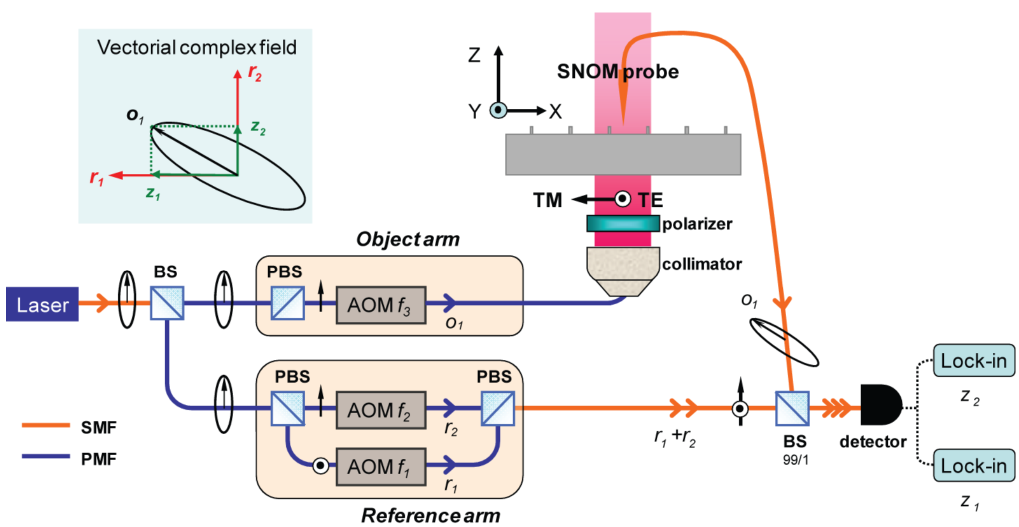

Fig. 1. Schematic diagram of the experimental MH-SNOM set-up (AOM: Acoustic Optic Modulator, SMF: Single Mode Fiber, PMF: Polarization Maintaining Fiber, BS: Beam Splitter, PBS: Polarizing Beam Splitter). Inset: object beam o_1 is projected on the reference basis $\{r_1, r_2\}$; the two resulting components are called z_1 and z_2.

The used MH-SNOM configuration: the reference arm is split at anamplitude ratio of 1:1 into two orthogonally polarized beams. Each of the three channels (one object channel, two reference channels) is shifted by a different frequency, using acoustooptic modulators. The orthogonality of the two reference signals r1 and r2 is well preserved up to the detector, where they are combined with the signal o1 from the object beam. Due to the differing frequencies between the three signals, the projection of the object beam o1 on the orthogonal reference basis {r1, r2}, called z1 and z2, can be detected simultaneously using two lock-in amplifiers. Thus, these two concurrently obtained phase-resolved field projections provide the full information of the optical field collected by the SNOM probe.

Reference:

L. Yu, T. Sfez, V. Paeder, P. Stenberg, W. Nakagawa, M. Kuittinen, and H. P. Herzig, "Concurrent polarization retrieval in multi-heterodyne scanning near-field optical microscopy: validation on silicon form-birefringent grating," Opt. Express 20, 23088–23099 (2012).