Pseudoheterodyne Detection in Nearfield Optics (SNOM)

Zurich
Instruments

Application Note
Applications: Laser Spectroscopy, Photonics, SPM/SNOM
Products: HF2LI

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Summary

This application note describes an interferometric pseudoheterodyne detection technique used in scanning nearfield optical microscopy (SNOM). The enhanced detection sensitivity compared to non-interferometric setups enables the visualization of optical nearfields in the lower femtowatt (fW) range. Furthermore the detection technique preserves optical phase information, therefore providing a deeper insight into the structures under investigation.

Application

Description

SNOM allows the visualization of optical properties below the diffraction limit. To achieve such high resolutions, the structure under investigation is probed in its close vicinity through a sub-wavelength aperture. The instrument belongs to the family of scanning probe microscopes (SPM), where scanning along the surface acquires an image of superior resolution.

The variety of applications for SNOM result in many possible setups. What all of these have in common is that the light intensities to be detected are very weak, therefore they require a sensitive detection. Nowadays established low-light detectors enable time-triggered single photon detection and linear detection with a noise equivalent power (NEP) of around 20 fW/√Hz. For even better performance in linear detection, the optical setup can be extended to enable interferometric lock-in techniques. In this approach, the weak measurement signal is mixed onto a phase-modulated or frequency-shifted reference beam and measured with a regular photodiode module. The measured interference signal has oscillating components containing optical amplitude and phase information of the measurement signal, both relative to the reference beam amplitude and phase. Knowing the reference beam amplitude and keeping its phase as stable as possible allows the extraction of the optical amplitude and phase of the measurement signal.

If the reference beam is frequency-shifted, we refer to heterodyne detection. The interference signal basically contains one frequency component, the shift frequency in the kHz range, whose detection is a common lock-in amplification task. The creation of such a low shift frequency on the other hand, requires a relevant instrumentation effort, since two acousto-optic modulators are necessary [1]. If the reference beam is phase-modulated, we refer to pseudoheterodyne detection. The interference signal then contains several harmonic components of the phase modulation frequency and at least two harmonics are needed to extract the optical amplitude and phase from the measurement signal [2]. In comparison with heterodyne detection, pseudoheterodyne detection requires more lock-in hardware, but it is possible to

select the modulator from a larger subset (electro-optical EOM, or piezo-electrical phase modulators PEPM).

Setup Description

The measurement setup is shown in Figure 1. The SNOM itself is depicted inside the grey box and controlled by an external control system (SPM controller). The setup is used to visualize light propagation inside planar waveguide structures. The fiber pointing towards the sample from the side couples light into the waveguide and the fiber tip above the sample surface collects the evanescent nearfields of the waveguide structure buried underneath.

The SNOM is incorporated into a fiber-based Mach-Zehnder interferometer with a piezoelectric fiber stretcher for phase modulation (PM) in the reference branch. The HF2LI's output of up to 10V is able to drive the fiber stretcher without additional instrumentation, with frequencies around 10 kHz. To detect the intensity of the interference signal, a general purpose photodiode module with integrated preamplifier is used. The harmonics of the interference signal are then readily available in the HF2LI lock-in unit. It is important to account for electrical delays by adjusting the electrical phases of the internal demodulation carriers so that they are in-phase with the harmonics. Due to the scanning speed of the SNOM, a small demodulation bandwidth below 100 Hz is chosen for a better signal-to-noise ratio. The large DC contribution in the measurement signal is suppressed by AC coupling for a higher dynamic range on the input. The demodulated signals are sent in real-time to the SPM controller with the auxiliary outputs of the HF2LI (Aux Out).

Detection Principle

The detected signal is composed of the sum of the interference signals at DC and by several sidebands created by the PM.

Figure 2 shows an example spectrum of the resulting interference signal. The DC component is not of interest. The harmonics are all proportional to the optical field amplitudes in the signal (**sig**) and reference (**ref**) optical interference branches, to the Bessel coefficients of the modulation amplitude a_m, and to the relative optical phase φ between sig and ref.

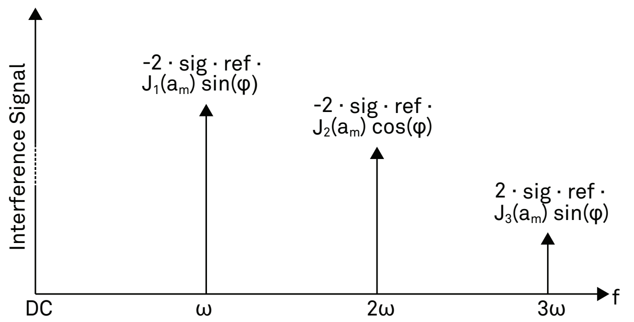

Figure 2. Spectrum of the interference signal

If the modulation amplitude is calibrated to a_m = 2.63 rad, such as $J_1(a_m) = J_2(a_m)$, the optical phase φ is the argument of the first and second harmonic. For the amplitude of **sig**, the square sum of the two harmonics, the measured intensity of **ref** and the Bessel coefficient

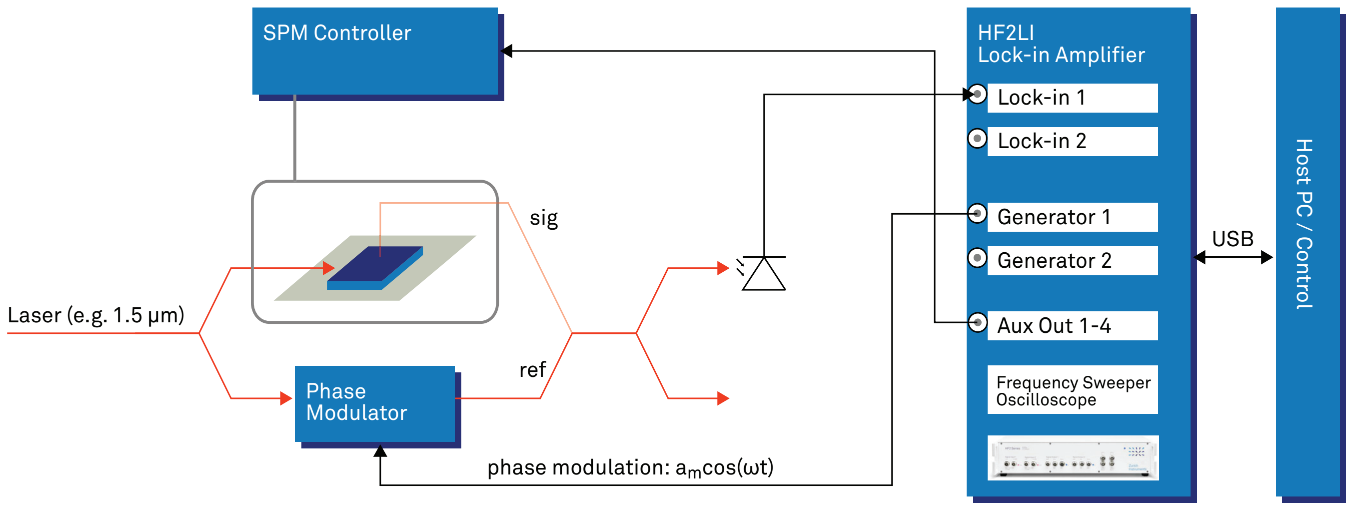

Figure 1. Diagram of the pseudoheterodyne setup without interferometer polarization controllers. The SNOM is controlled by an external SPM controller. The HF2LI provides the phase modulation with 3-4 V drive and detects the harmonics of the interference signal.

is needed. By doing this, it is important to distinguish between field amplitude and field intensity, which is the square of the field amplitude. All calculations can be performed in a post-processing step following data acquisition.

Achievements

In a collaboration with R. Brönnimann at the EMPA Dübendorf, Switzerland, the setup described is used to measure optical nearfields in the fW range. The NEP is estimated to 170 aW/√Hz, which is 2 orders of magnitude better than for linear low-light detectors. Figure 3 shows a measured intensity and phase pattern from a photonic crystal waveguide at telecom wavelengths (sample courtesy R. Houdré, EPF Lausanne). The acquisition time for the image was 30 minutes. The intensity pattern illustrates the confinement of the propagating mode. The phase pattern is also defined in regions of weak intensity at the borders of the waveguide proving the high detection sensitivity. Unwanted environmental influences to the phase pattern can be minimized by keeping the optical path as short and isolated as possible.

Conclusions and User Benefits

Amongst other phase sensitive detection techniques, pseudoheterodyne detection offers a variety of options to design the optical system towards the user's needs. For the demodulation of the resulting sidebands, the HF2LI provides an easy-to-use solution due to its capability of measuring up to 3 or 6 sidebands simultaneously. To further enhance the SNR, higher harmonics (up to 6) or the other interferometer branch could be included in the measurement result.

With an operation range of up to 50 MHz, the HF2LI combined with an EOM can modulate the phase at frequencies where the laser noise is lower than in the kHz region. With respect to heterodyne detection, the broad range allows the implementation of a heterodyne setup with only one AOM.

As with any other SPM, it is possible to add the HF2LI-PLL option to control the oscillation of the probe with a bandwidth of up to 50 kHz and provide a topography feedback signal for the SPM controller.

For advanced detection schemes in pseudoheterodyne scattering SNOM (sSNOM) [3], the HF2LI-MOD upgrade allows for detection of up to 4 sidebands around one higher harmonic of the probe oscillation frequency. If your SPM operation mode additionally requires oscillation control, it is possible to detect and track any of the 4 sidebands with a combination of the HF2LI-PLL and HF2LI-MOD options.

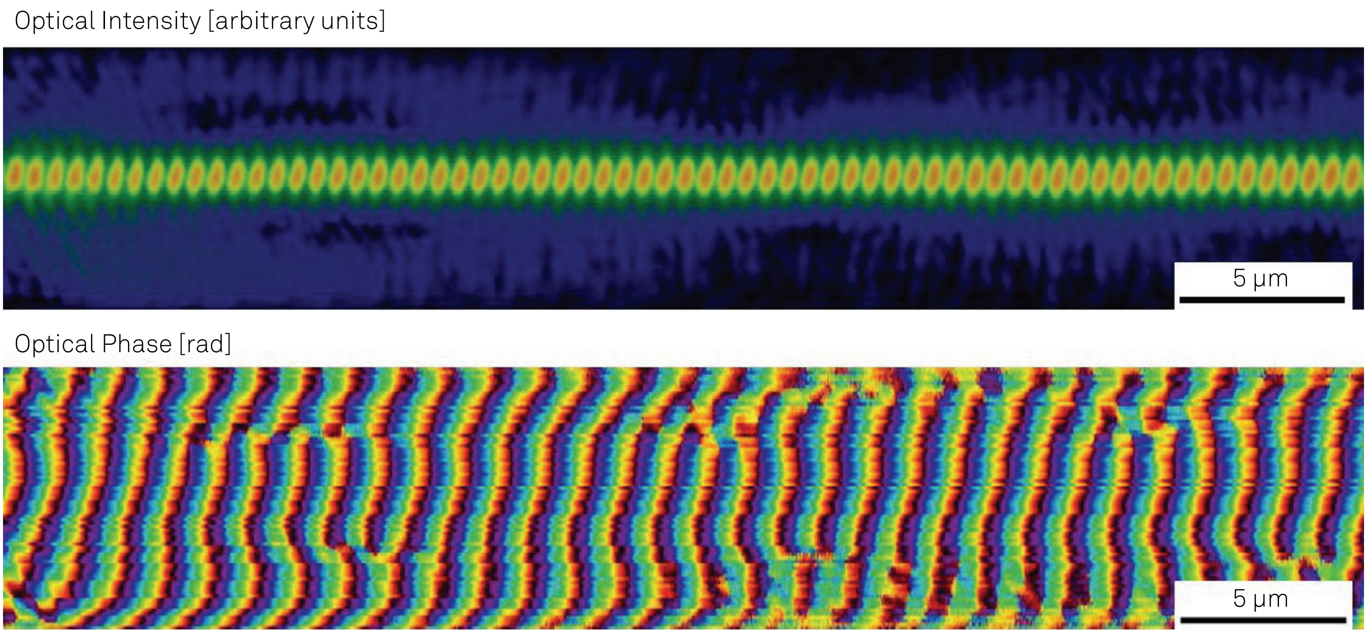

Figure 3. Intensity/phase image of a photonic crystal waveguide with 30 minutes acquisition time (sample courtesy R. Houdré, EPFL, image courtesy R. Brönnimann, EMPA)

References and Further Reading

[1] Nesci, Dändliker, Herzig, Quantitative amplitude and phase measurement by use of a heterodyne scanning near-field optical microscope, Optics Letter, Vol 26, 2001

[2] Vaez-Iravani, Toledo-Crow, Phase contrast and amplitude pseudoheterodyne interference near field scanning optical microscopy, Appl. Phys. Lett. 62, 1993

[3] Ocelic, Huber, Hillenbrand, Pseudoheterodyne detection for background-free near-field spectroscopy, Appl. Phys. Lett. 89, 2006

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