# Resolving light-matter interactions on the nanoscale

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**Abstract**

A phase-sensitive near field optical microscope with both polarization and time-resolution capabilities is introduced. Measurements and applications of this tool that are relevant to the field of metamaterials, including the ability to detect and separate both the electric and magnetic fields, are reported.

## 1. Introduction

As we perfect our ability to precisely engineer materials on the nanoscale new and exciting possibilities, such as the ability to focus light beyond the diffraction limit or to cloak an object, become accessible [1]. And, while there has been tremendous progress in this field in recent years, there are still many uncertainties about the way in which light interacts with nanosized structures. For example, several theories on the interaction of electromagnetic radiation with sub-wavelength holes in metal films that leads to extraordinary transmission have been proposed but experimental verification is incomplete.

In this regard, phase-sensitive near field optical microscopy is a powerful tool that enables the visualization of electromagnetic radiation well beyond the diffraction limit, and can therefore be used to probe light-matter interactions on the nanoscale. Further, and as we have shown, this technique can be adapted to be polarization sensitive, or to enable time-resolved measurements of the near field [2,3]. Consequently our approach offers insights into the fundamental processes that can be found throughout metamaterial studies.

In this talk we discuss the new insights into light-matter interactions on the nanoscale obtained with this technique.

## 2. Phase-sensitive near field microscopy

In our measurements a pulled fiber, coated with aluminium, is used to sample the near field of a structure. The spatial resolution is determined by the aperture of the fiber, which is typically ~200 nm in diameter (Fig. 1). This signal is then interfered with a reference signal that is modulated by an AOM and detected with a lock-in amplifier; this results in a signal that is proportional to the electric field sampled by the probe, including its phase. By using this information we are able to map out the complex electric field associated with a variety of nanometer sized structures ranging from photonic crystal waveguides and cavities, to plasmonic nanowires. We are even able to demonstrate active control of the light-matter interactions of such structures [4].

We are also able to separate this signal into the different polarization channels, which allows us to map the polarization dependencies of the near fields. This feature is particularly important if the probe is not symmetric in the plane of the sample and, for example, is etched with a slit; in particular, this allows us to separate between the electric and the magnetic fields [2]. Hence, we can map out the magnetic fields associated with various structures, an ability that is crucial to the development and understanding of magnetically active metamaterials.

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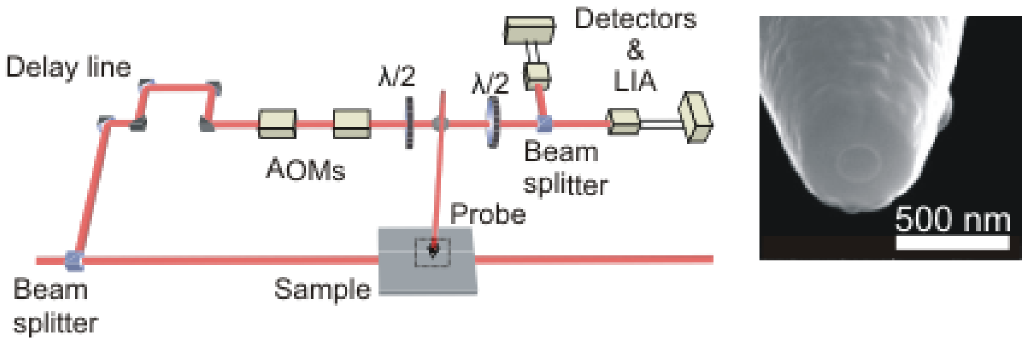


Fig. 1: A schematic of the phase-sensitive near-field optical microscope (left) and an SEM image of the tip of a typical near field probe (right).

Finally, by introducing a time-delay between the signal and reference branches we are able to time-resolve the evolution of the near fields [3,5]. This allows for the study of the temporal dynamics of nanostructures, and may yet play an increasingly important role as active plasmonic and metamaterial systems are developed.

## 3. Conclusion

In conclusion, a myriad of structures and phenomena can be studied using the capabilities of our phase-sensitive near-field optical microscope, and here we have attempted to give a flavour of these works. This tool is particularly well suited to investigations of nanometer scale objects, and can even be used to differentiate between the electric and magnetic fields of a system. Hence, it has been used to investigate many phenomena that are at the heart of the field of metamaterials.

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