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REVIEW ARTICLE

Development and prospect of near-field optical measurements and characterizations

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Abstract Scanning near-field optical microscopy (SNOM) is an ideal experimental measuring system in nano-optical measurements and characterizations. Besides microscopy with resolution beyond the diffraction limit, spectroscope with nanometer resolution and other instruments with novel performances have been indispensable for researches in nano-optics and nanophotonics. This paper reviews the developing history of near-field optical (NFO) measuring method and foresees its prospects in future. The development of NFO measurements has gone through four stages, including optical imaging with super resolution, near-field spectroscopy, measurements of nano-optical parameters, and detections of near-field interactions. For every stage, research objectives, technological properties and application fields are discussed.

Keywords scanning near-field optical microscopy (SNOM), near-field optical (NFO) measurement, super-resolution imaging, near-field spectroscopy, nano-optics, nanophotonics

1 Introduction

How to investigate experimentally interactions between light and matter in optical near field? How to characterize directly performances of nanophotonics devices at the nanoscale? How to obtain conveniently a wealth of information on structural and dynamical properties of materials with super resolution? The scanning near-field optical microscope (SNOM) is the most ideal experimental measuring system to solve above questions. The term ‘near-field’ reflects the fact that it deals with evanescent field whose electromagnetic field decays exponentially from the surface. Only with the development of SNOM, has it become possible to study such kind of fields directly and visually. The first SNOM system was invented to image with resolution beyond the diffraction limit. With the rising of researches in nano-optics and nanophotonics, more techniques were combined with SNOM system to measure diverse parameters of a nano-optical field, including phase, amplitude, polarization, vector, magnetic field, optical force, dynamics and spectrum at the nanoscale. Compared with conventional optical measuring methods, such a near-field optical (NFO) instrument provides an approach to obtain a deeper and more intuitive understanding of physical phenomena ranging from nanomaterials to living cells. Nowadays, SNOM has become an indispensable tool in studying nano-optics and nanophotonics. It is beneficial to review the developing history and the prospect of NFO measuring techniques.

NFO measuring system has been developed for more than three decades and has gone through four stages: 1) optical imaging with super resolution, 2) near-field spectroscopy, 3) measurements of nano-optical parameters, and 4) detections of near-field interactions. For every stage, research objectives, technological properties and application fields will be discussed.

2 The first stage: optical imaging with super resolution

The very early work in near-field optics was focused on super-resolution imaging. To break the diffraction limit, many efforts were devoted to develop imaging techniques in optical near field. The original idea was proposed by Synge, an Irish scientist, in 1928. He wrote to Einstein a letter and described a scheme of scattering optical near field by a gold nanoparticle, and then the optical image could be obtained by raster scanning the particle over the sample surface while continuously recording the detected

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light intensity. By this method, the resolution was limited not by the wavelength of light, but by the size of the particle, and everything came to depend on technical perfections [1].

With more than 60 years of development, the technical obstacles were gradually overcome. In 1984, Dieter Pohl and Aaron Lewis as the pioneers in near-field optics reported their achievements in the key experimental techniques in NFO microscopy, including fiber probe, nanometer separation regulation and scanning mode, and built the first experimental setup for NFO imaging [2]. The resolution was surprisingly $1/20\,\lambda$ beyond Rayleigh diffraction limit. Their contributions opened a new era of optical imaging. Then NFO imaging and measuring systems were rapidly developed. The acronym SNOM (or NSOM) was created later in 1988 to emphasize the analogy to scanning electron microscopy (SEM), scanning tunneling microscopy (STM), and other scanning microscopies. Today, SNOM has become a well-known tool for super-resolution imaging and characterizing nano-optical field, and is widely used in various fields.

A typical SNOM system is shown in Fig. 1(a). It consists of several components, among which the most critical one is NFO probe used to convert evanescent field into propagating field. The other two units are also important: one is separation regulation subsystem in shear-force mode, which is used to control distance between probe and sample surface in the nanometer accuracy; the other is scanning subsystem, which is used to scan a fiber probe over a sample or scan a sample under a probe. To operate a SNOM system, an essential part is an optical configuration, including light sources, detectors, mirrors, filters, couplers and other related optical components. With the different illuminations of the light sources in Fig. 1(a), SNOM can work in different modes, such as transmission mode, reflection mode, and total internal reflection (TIR) mode. Besides above optics, electronic control system, comprising amplifier and controller, etc., is also required.

A NFO probe, which detects light and/or illuminates sample, plays a vital role in SNOM, because imaging resolution is greatly determined by the size of probe tip, and the efficiency of whole system is closely related to tip shape and probe materials. The design of NFO probe ranges from a tapered optical fiber to a silicon/quartz micro-machined tip mounted on the cantilever of an atomic force microscopy (AFM). The former design usually forms an aperture probe, and the latter is generally used as apertureless probe. Great efforts have been devoted to fabrication and production of NFO probes in the past decades. Now, several kinds of probes with high quality are commercially available although they are expensive. Recently, novel probes based on surface plasmon polaritons (SPPs) and special optical antenna structures attract major interest in NFO techniques.

A SNOM system with an aperture probe is called “transmission-type SNOM” or a-SNOM, since detected/illuminating light is transmitted through the probe. A metal coating is generally deposited at the tip apex in order to reduce the leakage of light. This approach overcomes the problem of the far-field background associated with tip irradiation and therefore leads to a high signal-to-background ratio. However, in order to keep transmission efficiency, the size of tip cannot be reduced too much, which makes resolution improvement limited. Correspondingly, another type of SNOM system with an apertureless probe is called “scattering-type SNOM” or s-SNOM, since the probe is used as a local scatterer and partially converts evanescent field into propagating radiation. Such a probe, usually made by metal or metallized structures, is sensitive to the longitude component of the optical field localized at the tip. This characteristic differs from that of an aperture probe which is more sensitive to the transverse field component. A scattering-type SNOM typically has a higher resolution with smaller probe tip, but the interpretation of the recorded information is complicated. One can use the tip to provide a local-excitation source for a spectroscopic response of samples, thus enabling simultaneous spectral and sub-diffraction spatial measurements, but it depends sensitively on the magnitude of the field-enhancement factor. The local-excitation scheme is commonly referred to as tip-enhanced NFO microscopy, and it is discussed in more detail in the next section.

With SNOM system, optical super-resolution image and nanoscale topography image can be obtained simultaneously. The optical intensity in the near field of many types of materials, such as biology materials, organic materials, low-dimensional materials and metamaterials, is measured with resolution beyond the diffraction limit. All kinds of nanostructure, e.g., nano-rods, nano-wires, nanoparticles, nano-apertures, and so on, are also characterized. The most attention is attracted on the phenomena of SPPs. The development of SNOM techniques contributes to the recognitions of the behavior of SPPs, including excitation, conversion, localization, propagation, scattering, interference and focusing, and helps ones to validate design methods and performances of SPP devices. In addition to in-plane characterizations, SNOM can also be used to measure out-of-plane features. A phase-modulation device based on SPPs and its measurement results are shown in Figs. 1(b)–1(d) [3]. With the intensity distributions at different distances from the device surface, the image in the cross section is reconstructed and the property of the directional beaming is characterized explicitly.

Above the first stage of NFO measurement techniques is outlined briefly. The main object of this stage is to detect the NFO intensity distributions and to obtain super-resolution images. Thus SNOM system is developed, and the technologies, including probe fabrications, working modes, separation regulation (control) and scanning in the nanoscale, etc., are investigated and perfected technically in detail. Several types of commercial SNOM systems are available and can meet general demands of super-resolution imaging now, which have excellent performances although require high level of operation skills. Now SNOM has been a kind of popular and powerful instrument in many laboratories of physics, chemistry, biology, electronics, materials, and so on.

3 The second stage: near-field spectroscopy

Optical spectroscopy provides a wealth of information on atomic and molecular structures, vibrations and dynamics properties of materials. The combination of optical spectroscopy with SNOM enables the spectral spatial resolution to be extended into the nanometer scale. As one of the pioneers of near-field spectroscopy, Hess et al. got near-field, far-field and spatially averaged near-field photoluminescence (PL) spectra of quantum well using optical antenna localized enhancement method [4]. The results show that near-field spectroscopy offers unique attributes in addition to high spatial resolution. In particular new optical transitions ordinarily forbidden in far-field spectroscopy may now become allowed [4].

As mentioned above, a SNOM system with an apertureless tip can provide a local-excitation source for a spectroscopic response of samples, and thus is used as “tip spectroscopy”. This approach has been applied to two-photon excited fluorescence, single-photon excited fluorescence, Raman scattering, and coherent anti-Stokes Raman scattering (CARS) [5]. With strong surface enhancement at a metal tip, many attentions are attracted to tip-enhanced Raman spectroscopy (TERS), as Raman scattering probes a much more detailed spectrum that can be uniquely linked to the chemical composition and molecular structure of a sample [6–9]. Here, the field enhancement at the laser-irradiated probe effectively increases the Raman scattering cross section of a molecule, thus Raman signal can be enhanced by orders of magnitude. Now, TERS has become a very powerful and widely-used tool in many fields, such as physics, chemistry, biomedical science, nano-materials science, plasmonics, nano-metrology, especially in the fields of nano-optics and nano-spectroscopy.

TERS systems, generally including a sharp metal/metalized tip, tip-sample separation regulation unit, excitation/collection optics, scanning unit, Raman spectroscopy and controlling unit, have been built up in worldwide laboratories. To date, metal/metallized tips, such as metal tips of STM [10], metal-coated silicon cantilevers of AFM [11], metalized fiber tips of SNOM [12], and wires sticking on tuning forks [13], have been used as localized sources. However, other geometries with optimized resonant-antenna properties are likely to be employed in the future [5]. Tip-sample separation regulation has been controlled in different ways with tunneling effect, atomic force and shear force, which provide a wide range of working distances between tip and sample surface: from several angstroms in STM mode to several tens of nanometers in shear-force mode. Excitation/collection optics has been achieved in transmission mode and reflection mode. A variety of values of

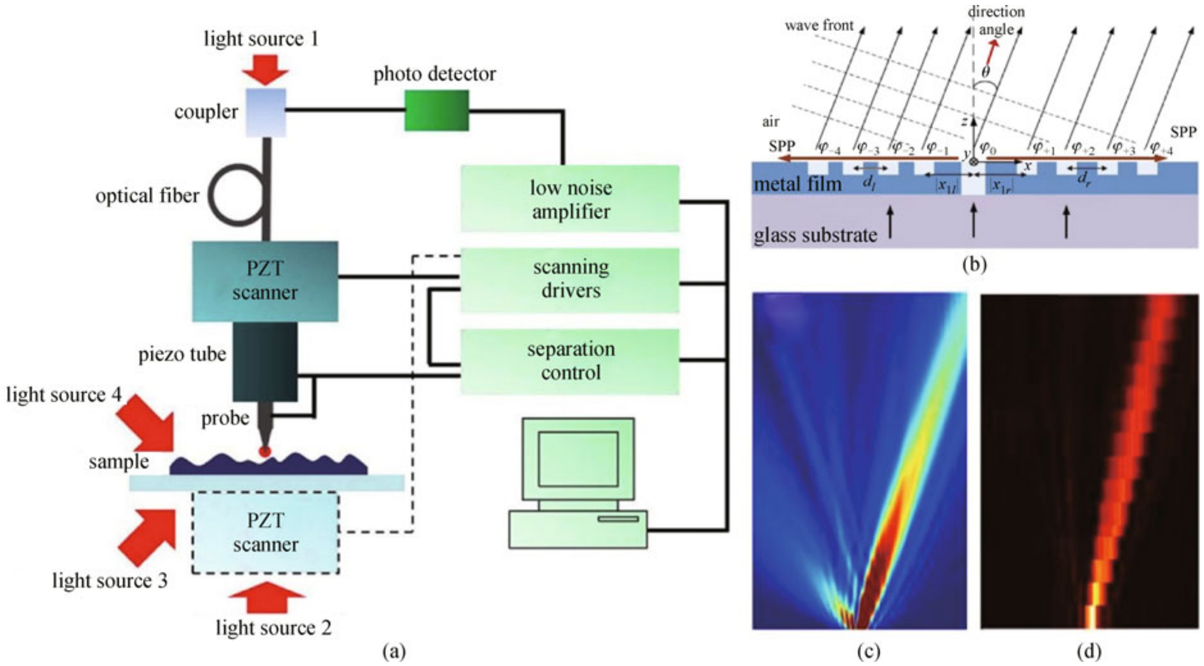
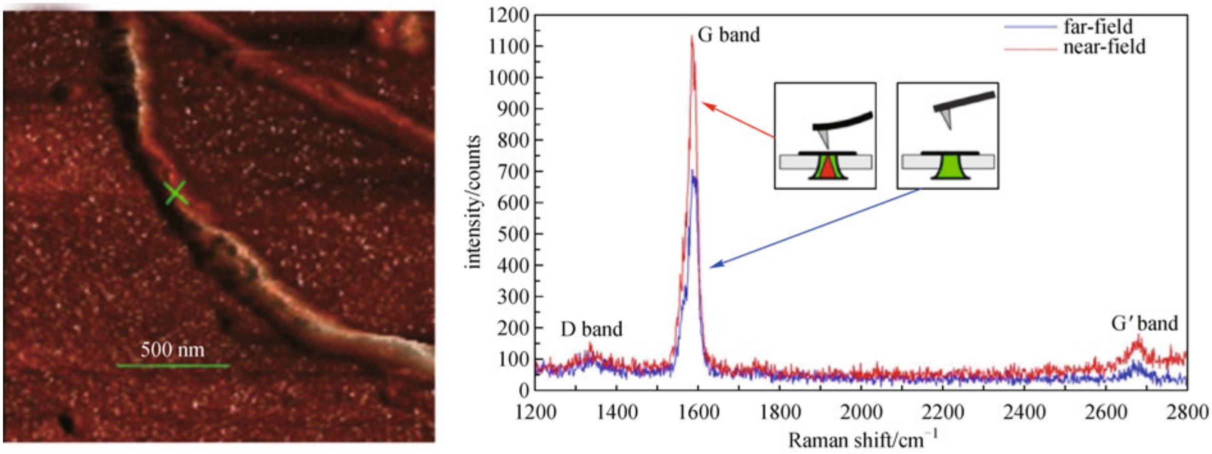


Fig. 1 (a) Typical SNOM system; (b) directional beaming device [3]; (c) and (d) are simulation and experimental results of the emitting light from the device, respectively [3]



(a)

(b)

Fig. 2 TERS result of a bundle of SWCNTs [21]. (a) Topography of the bundle of SWCNTs [21]; (b) comparison of far-field and TERS signals from the spot marked by a green cross in (a) [21]

scattering intensity, signal-to-noise ratio, and resolution have been reported.

Research on TERS can be classified into two aspects. One is the understanding of TERS with a focus on its detection sensitivity and enhancement factor, which is devoted to detect single molecule [14]. The other concentrates on the applications in many fields, e.g., charactering single-walled carbon nanotubes (SWCNTs) [15–18], sequencing RNA strands [19], and studying nanoscale structures in a single bacteria or cell [20]. In Fig. 2, the results of the characterizations of a bundle of SWCNTs obtained with our home-built TERS instrument are shown [21]. When the tip approaches into the near field, the Raman signal is enhanced while the background noise observably suppressed.

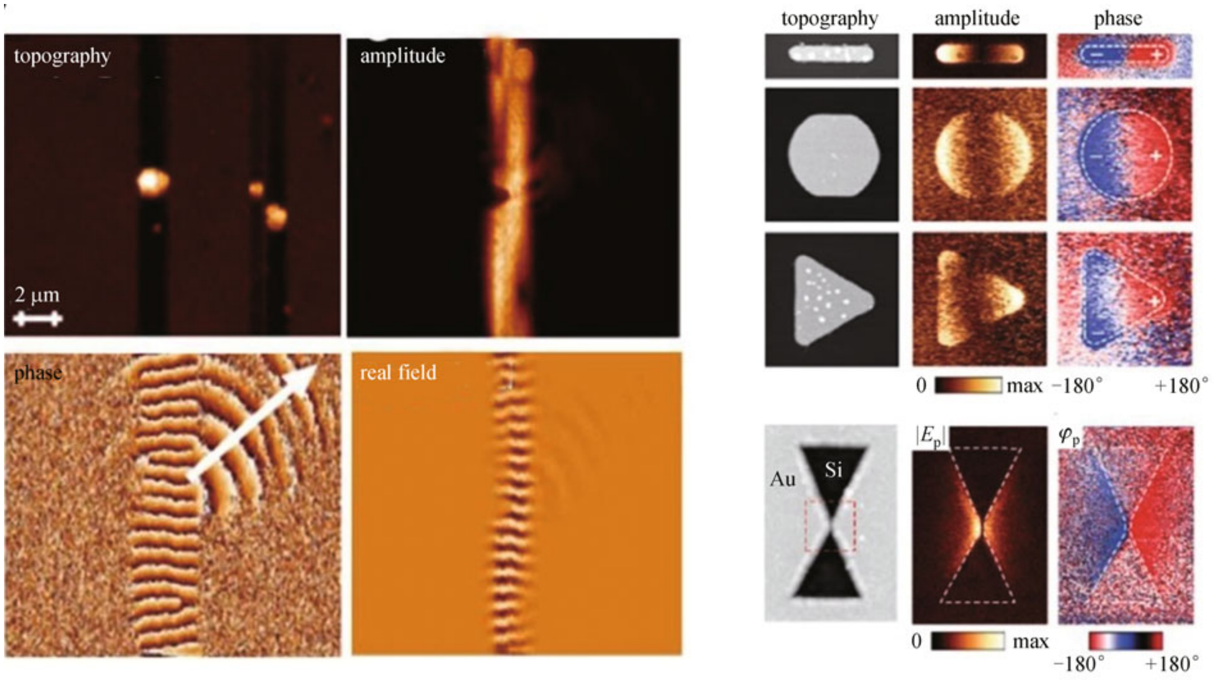
Here summarize the second stage. The main object of this stage is to obtain near-field spectrum with a high spatial resolution. The combination of SNOM tip with spectroscopy has been powerful and promising in nanoscience and technology, especially in fields of single molecule detection, nano-materials, biologic materials, semiconductor materials and nano-mechanics. Near-field spectroscopy techniques originated in 1990s, and with its rapid development, most conventional spectroscopy techniques have their corresponding parts in near-field optics, such as near-field fluorescence spectroscopy [22], near-field fluorescence correlation spectroscopy [23], time-resolved near-field fluorescence spectroscopy [24], near-field PL spectroscopy [25], near-field infrared (IR) spectroscopy [26], near-field Raman spectroscopy [27], etc. Among them, TERS is the most promising one. Spectral analysis and mapping are two fundamental parts in TERS; furthermore, the role of mapping is of great significance in spectrum recognition, which is very difficult and complicated in conventional Raman spectroscopy. Nowadays several types of commercial TERS systems are available, and can perform Raman spectrum measurement/mapping together with corresponding morphology data in the nanoscale. Several domestic groups have built and used TERS systems in their researches, and some beautiful experimental results have been reported to show the distinctive performances of their systems, although these systems are costly and require high level of operation skills. The main technological difficulties scientists facing may include that the enhancement is currently too weak for applications in biology. Thus, future work must be aimed at optimizing the field enhancement by improving probe structures or exploring finite-sized geometries inspired by classical antenna theory [5]. Besides, it is necessary to develop the simultaneous detection of two or more types of near-field spectra for performing more thorough and comprehensive analysis, as has been presented by Meixner's group who measured both near-field PL and TERS of molecular semiconductor films [28].

4 The third stage: measurements of nano-optical parameters

To characterize and represent an electromagnetic field exactly, only electric field intensity is not sufficient. The physical parameters of a nano-optical field at least include amplitude, phase, polarization state and the corresponding magnetic field, etc. Phase and amplitude information in near field are crucial not only for understanding of near-field physical mechanism, but also for design and optimization of nanophotonics devices based on phase-modulation principles, such as plasmonic-focusing devices [29], focusing-control devices [30–33], directional-beaming control devices [3], etc. The basic method to measure amplitude and phase is by means of SNOM tip and heterodyne interferometry (THI) [34–36]. Phase and amplitude measurements and mappings in the nanoscale have been realized, which verify experimentally the basic principles and mechanisms of light-matter interaction, and benefit design and optimization of nanophotonics devices. THI systems have been developed in several leading laboratories on the world. A typical system generally consists of a highly stable laser source, a delicate and reliable heterodyne interferometer, a SNOM tip, phase- and amplitude-detecting unit, scanning and mapping unit and so on. The data of optical intensity, phase, amplitude, topography and position can be acquired simultaneously. Using such a system, some beautiful and exciting experimental results of several types of nano-optical fields have been presented. Figure 3(a) shows the topography, amplitude mapping, phase mapping and the real field composed by amplitude and phase of an optical waveguide [37]. White arrow expresses the weak directional leakage. Besides, the characterization results of other nano-structures such as nano-rod, nano-particle, nano-triangle [36] and bowtie [38] are reported (see Fig. 3(b)). Also, the information on topography, amplitude and phase of the nano-optical fields are given.

The amplitude and phase measurements can be made not only in plane, but also out of plane. The measurements along the direction normal to the sample surface allow us to experimentally determine more features of nano-optical field. The experimental results of TE-mode optical field propagating from a grating are shown in Fig. 4 [34]. The point of this work lies in the contour plots of the phase at different distances from the grating surface. The interactions of light with the micro-structures change the amplitude and phase distributions of the incident field, and they imply information on the structures and provide some clues on the mechanism of the field conversion by a SNOM tip. The experiments have demonstrated that THI is a powerful method for measuring both the amplitude and the phase of a nano-optical field.

Polarization state and vector magnitude of an electromagnetic field at any spatial spot are also key physical quantities because a real electromagnetic field is a vector field. It is possible to reconstruct a 3D vector field distribution with measuring local polarization and orientation of a field vector at every spot in the nanoscale. Such an ability is of fundamental importance for understanding almost all near-field phenomena. A general polarization state at a spatial spot under test can be represented by a complex vector that traces out an ellipse [39]. To characterize this ellipse, a measurement must be sensitive to the vector's direction [40]. A gold-nanoparticle-functionalized tip makes it possible to simultaneously determine both the direction and the magnitude of a local field [40,41]. The gold nanoparticle can be described by a simple dipole model and provides an isotropic polarization response. Based on a scattering-type near-field microscopic technique, a 3D vector mapping in certain space can



(a) (b)

Fig. 3 Measurements of phase and amplitude. (a) Characterizations of an optical waveguide [37]. The topography, amplitude maps, phase maps and real field composed by amplitude and phase are obtained; (b) Characterizations of nano-rod, nano-particle, nano-triangle [36] and bowtie [38]

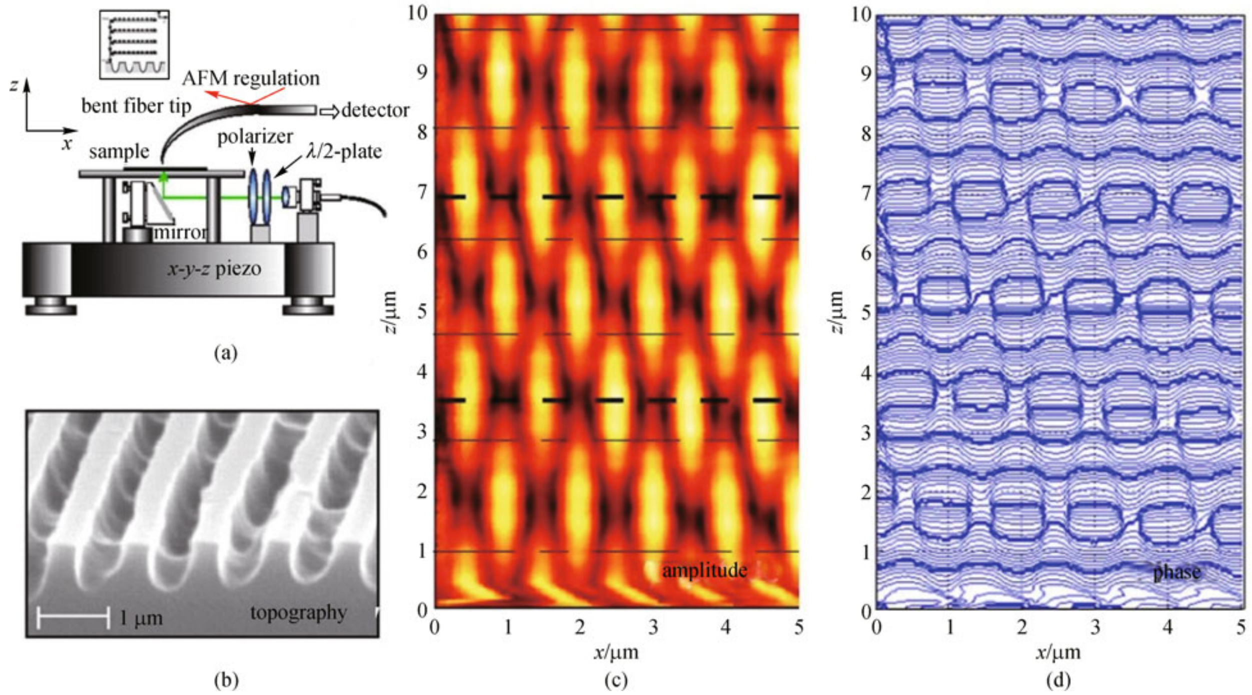


Fig. 4 TE-mode optical field emerging from a grating [34]. (a) Experimental system [34]; (b) topography of the grating by SEM [34]; (c) and (d) are normalized amplitude mapping and the contour plot of the phase [34]

be obtained. The vector field mapping of a SPP standing wave, which is generated by two counter-propagating SPP waves created by two adjacent nanohole gratings perforated on a gold film, is shown in Fig. 5(a) [40]. The incident polarization is along the *x*-axis, and the scattered light from the gold-nanoparticle-functionalized tip is analyzed by a polarizer located in the *y*-axis. The theoretical and experimental results of the vector plots centered on a total electric-field intensity minimum are shown in Figs. 5(b) and 5(c), respectively [40].The measurements help ones to explore deeper research and more insight physical mechanisms.

It is also important to mention measurement of magnetic field. When detecting light in the near field, only the electric field is perceived; its magnetic component is still unknown. Burresi’s group has taken one important step in this field [42]. They use a split probe to measure the magnetic- and electric-field distributions of a propagating light with subwavelength resolution. The split-ring probe, with the symmetry broken by introducing a single gap in the side of the metal coating probe, can convert the magnetic field into electric field for detection. The experimental setup is shown in Fig. 6(a). Two orthogonally polarizing components are detected with a phase-sensitive SNOM described as above. The normalized distributions of the electric- and magnetic-field are shown in Fig. 6(b). Yellow dashed line indicates π/2 phase shift of the two wave fronts. This is the first direct experimental evidence for the electromagnetic principle prediction.

In the summary of the third stage, measurements of the whole optical parameters in localized near field, including intensity, amplitude, phase, polarization distributions, vector field and magnetic field, are the main objectives. Thus, some matured techniques, e.g., heterodyne interferometry, and special probes, e.g., metal nanoparticle-functionalized probe and split probe, are creatively modified and skillfully combined with SNOM system. These improvements extend abilities of near-field measurements from super-resolution imaging to more comprehensive characterizations of nano-optical field, nanostructures and nano-materials. Although the development of nano-optical parameters measurements is of considerable importance to explore scientific problems and design nanophotonics devices, scientists still have a long way to go as facing a series of tremendous technical challenges, such as preparations of functionalized probes, combinations of special probes and complex systems, synchronous control and easy switch of all units, extraction and detection of weak signals, reconstruction and analysis of data, compatibility and stability of whole system, etc. However, it can be expected that these difficulties will be overcome one by one in near future, and these near-field detection techniques will certainly promote researches in nano-optics and nanophotonics.

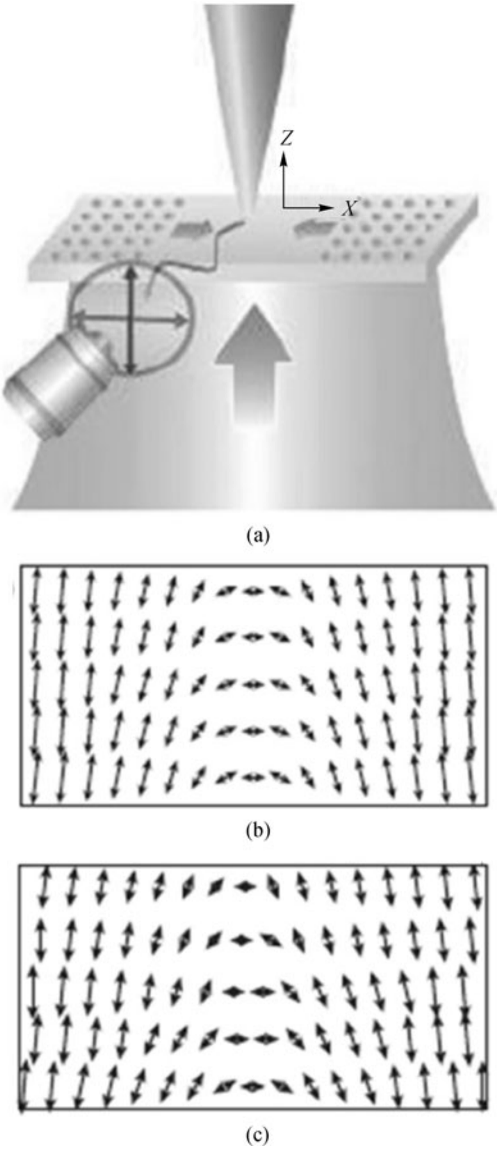


Fig. 5 Vector-field mapping of SPP standing wave [40]. (a) Experimental setup [40]; (b) and (c) are theoretical and experimental results of vector plots centered around a total electric-field intensity minimum, respectively [40]

5 The fourth stage: detections of near-field interactions

Research on the interaction between light and matter is growing and will become one of the most important aims in nano-optics and nanophotonics in the coming decade. The special characteristics of the new research will be based on the combination of fundamental methods of near-field optics and innovated approaches. As mentioned above, this technical combination can obtain the characterizations of the comprehensive optical parameters in localized near field, and thus provides a powerful tool for investigations of the interactions between light and optical antennas, plasmons, metamaterials, and so on.

Optical antennas can couple propagating far fields into localized near fields and vice versa, and are used for local control of the light-matter interactions, such as surface-enhanced Raman scattering (SERS), TERS, chemical and biologic sensing. Also, optical antennas can control the behavior of SPPs and consequently become an attraction in nanophotonics circuit. The concept of the optical antenna has its roots in near-field optics [43–45]. At the first time, a gold particle is proposed to function as an antenna to image in near field [43]. In the following years, optical antennas in the form of sharply pointed metal tips were used in near-field microscopy and spectroscopy [44]. These experiments gave birth to what is today known as SNOM and TERS. In search of a NFO probe with a higher efficiency, in 1997 a bowtie antenna at the end of a waveguide is presented [45]. After that, antenna structures were grown on the end faces of aperture-type near-field probes. Following these developments, various geometries of antennas are reported. Among them are bow-tie antennas [46], monopole antennas [47], particle antennas [48], Yagi–Uda antennas [49], gap antennas [50], cross antennas [51], and so on.

There is a considerable body of literatures on microscopy and spectroscopy aided by antennas. Although antennas established important groundwork, they still wait for systematic experimental verifications. A direct visualization of field distributions around antennas using SNOM has been demonstrated in mid-IR for micrometer-sized structures, but the absence of ultra-small probes impedes the extension of this technique to optical antennas for the visible [52]. To increase the spatial resolution, Bouhelier's group employed a sharp tip to locally scatter the two-photon excited luminescence signal generated by the antenna under study [53], and the results are shown in Fig. 7. Optical antennas are the most recent offspring of near-field optics and technology. The nanoscale dimensions of optical antennas bring with them associated characterization challenges, and there is a lot of work waiting to do [49].

Another hot research field is relevant to metamaterials, negative index and left-hand materials. With their potential for spectacular applications, like superlensing and cloaking, metamaterials are a powerful class of nano-structured materials. All these applications rely on the metamaterial acting as a homogeneous material [54]. To fully understand how metamaterials can be applied on the nanoscale, to explore the physical mechanisms, and to design, improve, modulate and control such artificial materials, it is crucial to describe their near-field behaviors. All of them need new and novel measuring methods based on near-field optics and nano-optics.

A pioneering effort gained the first glimpse of the meta-atoms in an array of split-ring resonators that operates in IR regime [55]. Very recently, some new results have been presented. By employing near-field phase-sensitive optical microscopy as mentioned above, the phase distribution of

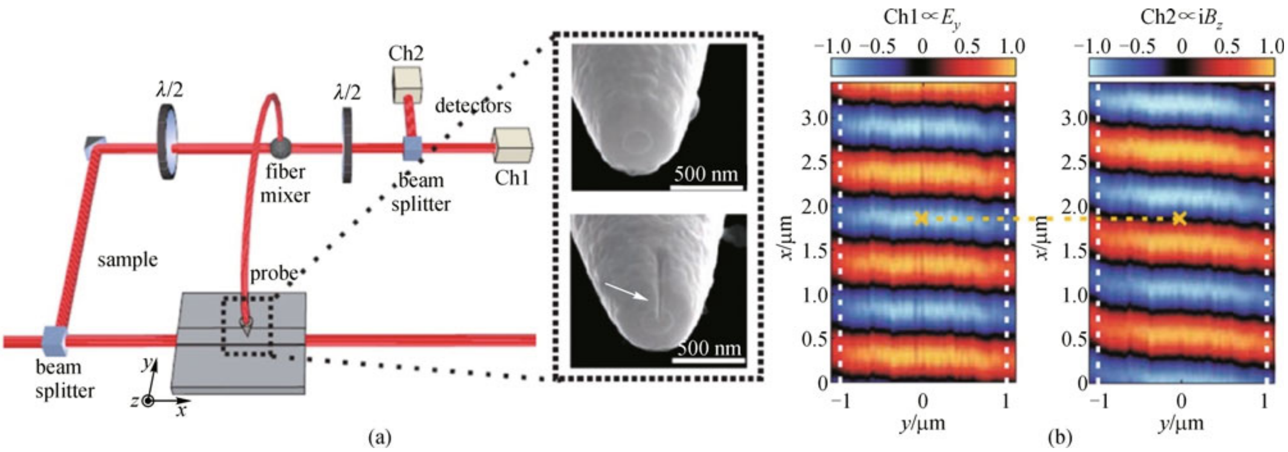


Fig. 6 Measurement of magnetic field with a split-ring probe [42]. (a) Schematic of phase-sensitive near-field microscope and inserts are scanning electron micrographs of two aluminum-coated near-field probes. The top one is a highly cylindrical standard probe, and the bottom one is a split probe, in which an air gap in the metal coating (arrow) has been created [42]; (b) normalized distributions of electric- and magnetic-field obtained experimentally [42]

the wavefronts within a unit cell corresponding to the nano-structures of a metamaterial's sample is mapped, and its evolvement as a function of distance from the structure is investigated, as shown in Fig. 8 [54]. The results show that in the near field, the sample cannot be considered as a homogeneous medium since large optical phase and amplitude variations are observed. To better understand the optical response of such metamaterial in the near field, its optical properties should be described by optical constants that depend not only on optical frequencies but also spatial Fourier components. These findings might have important consequences for the use of metamaterials for nanoscale applications [54].

Now summarize the fourth stage. The control of optical fields in the nanoscale is one of the most important research subjects in plasmonics and nanophotonics. The systematic methods for characterizing interactions between nano-optical field and nano-structures are indispensable to validate theoretical predictions, to test nanofabrication procedures, and to provide feedback for design improvements. Thus developing new tools that perform measurements by complex, heterogeneous nanometer-scale systems becomes the main objective in this stage. The combination of SNOM and other novel techniques not only makes it possible to detect more physical parameters, but also enable ones to have a deeper understanding to mechanisms of light-matter interactions. These developments open a new era for nano-photonics toward practical applications.

6 Conclusions

In this article, the development of NFO measurements and

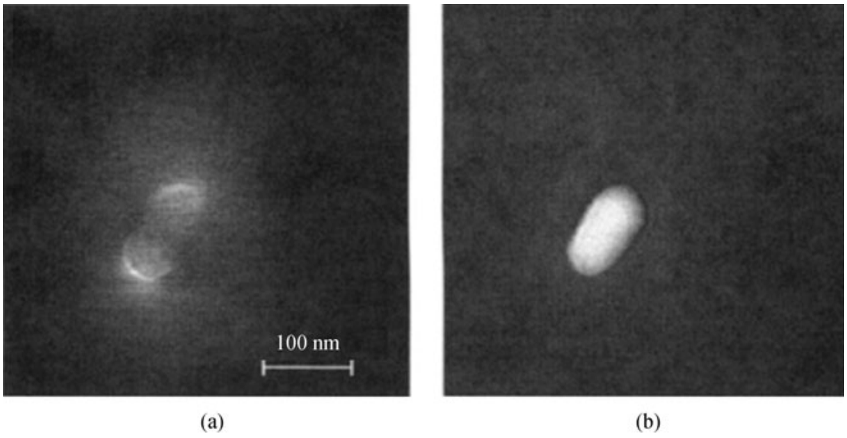


Fig. 7 Characterizations of an elliptical cluster of gold particles imaged with a stationary gold tip [53]. (a) Two-photon excited PL image [53]; (b) topography [53] of the cluster

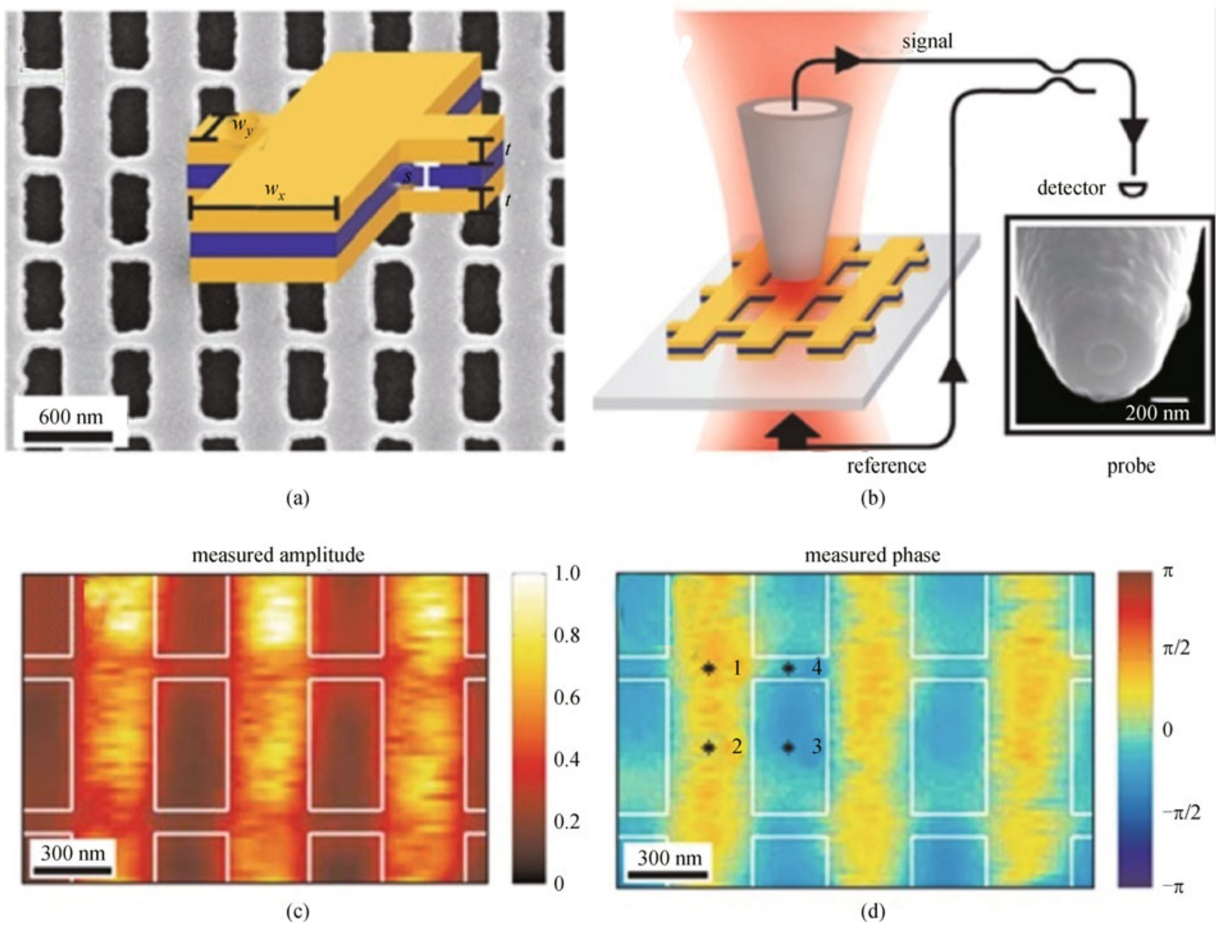


Fig. 8 Characterizations of a double-fishnet negative index metamaterial structure [54]. (a) Top-view electron micrograph of the structure, and the inset shows a 3D sketch of a metamaterial unit cell [54]; (b) scheme of experimental setup and metamaterial sample and the inset shows an electron micrograph of a coated probe used in this investigation [54]; (c) and (d) are measured near-field images of amplitude and phase. Superimposed white rectangles indicate metamaterial's structure [54]

characterizations are reviewed. It is shown that near-field detection techniques provide valuable methods for investigations of nano-optics and nanophotonics. Near-field optics deals with optical interactions on a subwavelength scale. In this sense, nonradiative interactions are of key interest. Near-field optics received important inspiration from the early work in nano-plasmonics, which was mainly aimed at answering open questions in SERS, and from studies of energy transfer. And then, the presentation of Synge emerged at a later time. Originally developed as a microscopy tool, near-field optics has steadily matured not only in the quest for ever-higher resolution of molecules, plasmons, and localized fields, but also with the concomitant advances of technologies. To obtain detailed and thorough understanding to near-field interactions, the combination of SNOM and some novel techniques provides powerful tools to characterize comprehensive optical parameters in near field, such as amplitude, phase, polarization, vector field, magnetic field and spectroscopy, which makes NFO measurements and characterizations greatly promoted and improved. From today's perspective, techniques of near-field measurements and characterizations have a lot in common with classical antenna theory extended into the optical regime and this is where it connects to the current second wave of nano-plasmonics.

In the words of Nobel Laureate Rosalyn Yalow, "New Truths become evident when new tools become available." Through the development and implementation of new microscopy and spectroscopy techniques, the knowledge has been increased on optical phenomena ranging from atomic and molecular structures to the performances of nanophotonics devices and circuitry. These advances aside, numerous scientific and technical challenges still remain [5]. These challenges will encourage and push scientists forward to develop more creative and elaborate systems to realize perfect nano-optics measurements and characterizations. Its principles and techniques are likely to be adopted in the future commercial instrumentations.

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