NANO-OPTICS

Orient yourself

Most optical probes measure the size of the electromagnetic field, but not its direction. A new development in near-field imaging now makes it possible to map vector fields on the nanoscale as never before.

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One of the first truths we learn in optics is that light is nothing more than intertwined electric and magnetic vector fields. As vectors, these fields are characterized by a size (modulus) and a direction in space. However, most of the optical probes designed to detect light are only sensitive to the intensity of the electric or magnetic fields, in other words, the square of the modulus. On page 53 of this issue, Lee and co-workers[1] report an experimental technique that can capture and map the vectorial nature of the electric fields down to the nanoscale. This could lead to important applications in physics and biochemistry.

The technique is based on the scanning near-field optical microscope (SNOM), invented twenty years ago by two independent groups — Dieter Pohl and colleagues at IBM–Zurich and Aaron Lewis, then at Cornell University, and co-workers. In the original experiments, the two teams shone light through a sharp dielectric tip that was covered with metal[2,3]. Because the opening of the tip is smaller than the wavelength of the light, evanescent, or non-propagating, electromagnetic waves are generated at the very end of the probe. By placing the tip just above the surface of a sample, these evanescent waves can be transformed into propagating ones when scattered by the nanoscale features on the sample. A detector placed in the far-field region can record this scattered light and, by scanning the tip over the surface, an optical image of the object can be constructed. Thanks to the evanescent nature of the light emerging from the tip, the resolution of a SNOM is not limited to half the wavelength of the incident light, as in conventional optical microscopes. In principle, there is no fundamental barrier to the resolution that can be obtained with such a device.

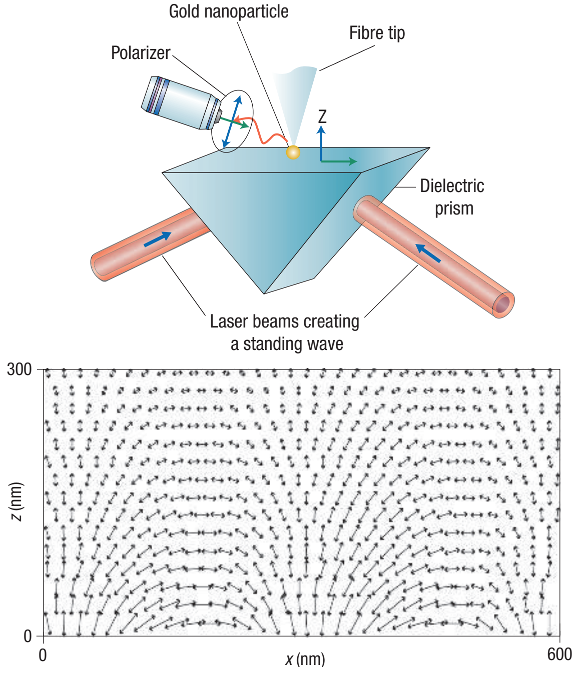

Figure 1 The vector-field imaging apparatus devised by Lee *et al.* combines an apertureless SNOM with a polarizer, which allows it to map both the strength and direction of electric-field vectors.

The potential to push optical microscopy beyond the diffraction limit triggered the development of several SNOM configurations. In the 'apertureless' SNOM[4] there is no aperture at the end of the probe; the tip is used simply as a means of scattering incident light. By attaching a gold or silver nanoparticle to the end of the dielectric tip[5], subtle changes can be detected in the local field through the dipolar moment of the particle, which is induced by the incident light.

The ingredient added to the apertureless SNOM by the Korean–German team[1] is simple and clever: a polarizer is placed immediately before the CCD camera that is used to collect the light scattered by the nanoparticle (see Fig. 1). For each probe-tip position used during the scan process, the polarization angle is rotated between 0° and 360° in 10° increments, and a complete map of the vector state of the electric field at the tip position is built up.

Why is it so important to identify the components of the electric field? For one thing, it tells us how light behaves in the vicinity of subwavelength structures. In-depth knowledge of the electric-field vector on the nanoscale could help in the design of miniaturized optical components that may replace their electronic counterparts in the future. In addition, near-field vector imaging is also important in biosensing applications because the interaction between light and biological molecules strongly depends on the orientation of the electric field. By extracting this information we can uncover new effects at play.

With their microscope, Lee and co-workers have constructed detailed electric-field maps for light in three simple set-ups. First, for evanescent standing waves generated by total internal reflection of two counter-propagating beams inside a dielectric prism; second, for surface plasmons at a gold–air interface; and, finally, for surface plasmons produced when light passes through a single slit cut into a thick metal film. One would expect that the image resolution is related to the diameter of the nanoparticle (about 100 nm in this case) but, rather surprisingly, comparisons of the experimental field maps obtained from theory suggest that the attainable resolution is much better, at least in the three geometries investigated. Further analysis will be needed to understand the origin of this unusually high resolution.

In these studies, the electric field is two-dimensional, that is, its vector components lie in one plane. The researchers suggest that by using two independent, orthogonally oriented polarizers, they could achieve full three-dimensional imaging of the electric-field vector. If this idea works, their technique will become an efficient experimental tool with which to explore the complex electric fields that arise when light interacts with matter on the nanoscale.

References

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PLASMONICS

Superfocusing of terahertz waves

The promising field of terahartz imaging has long been limited by poor resolution. Researchers now believe that the intriguing properties of surface-plasmon polaritons on corrugated wires could help beat the diffraction limit and inspire a new generation of terahertz photonic devices.

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Spectroscopy and imaging in the terahertz (far-infrared) band of the electromagnetic spectrum are now benefiting diverse areas of science[1] and starting to find important commercial applications. For example, the pharmaceutical, medical and security industries are exploring the idea of using the technology to measure the thickness of tablet coatings, detect skin cancer and image weapons hidden beneath clothes.

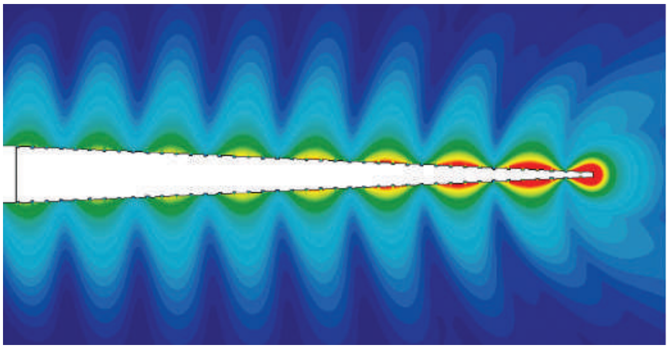

Figure 1 Calculated electric-field distribution of an SPP on a corrugated cone[2]. Note that a subwavelength 'superfocus' is evident at the tip of the 2-mm long structure. The false colour scale represents the magnitude of the electric field over a (logarithmic) scale of two orders of magnitude.

Unfortunately, the long wavelength (about 300 μm) of terahertz radiation creates serious limitations for the imaging resolution, which is very poor compared with visible imaging techniques, which operate at far shorter wavelengths. This is more than an aesthetic problem for applications of terahertz imaging in nanotechnology and clinical medicine, where subwavelength image resolution is required to resolve microscopic features or perform spectroscopy on small volumes.

Fortunately, a solution may soon be at hand. Reporting in *Physical Review Letters*, Maier and colleagues from the United Kingdom and Spain propose an elegant solution to this problem using surface-plasmon polaritons (SPPs) on corrugated wires to guide and 'superfocus' terahertz radiation[2]. The results are particularly promising for the development of new types of terahertz photonic devices including a near-field terahertz endoscope with enhanced resolution.

An SPP is a coupled electromagnetic and electron-plasma polarization wave that can be excited at the surface of a metal[3]. At frequencies approaching the plasma resonance of the metal (often in the UV or visible), the unique propagation characteristics (dispersion) of an SPP open the door to a variety of interesting effects, such as the generation of intense, localized electric fields on subwavelength structures.

Great progress has been made in recent years in engineering compact 'plasmonic' devices from micro- and nanostructured metals to exploit the properties of SPPs at visible frequencies. Subwavelength localized plasmonic waveguides and plasmonic devices