if antiferromagnetic, would be geometrically frustrated by the hexagonal configuration of the cobalts; Fig. 2), in view of the significant electron–electron repulsions typically observed for octahedrally coordinated 3*d* transition metals[8]. So if this view is correct, the cobalt superconductor could have some of the ingredients that make the copper oxide behaviour so interesting: proximity to a Mott insulator-to-metal transition coupled with spin-1/2 magnetism. The high thermoelectric power observed for the more sodium-rich $Na_{0.5}CoO_2$ compound, which is not typical of simple metals and makes it attractive for thermoelectric energy conversion applications, is further evidence that something unusual is happening in this class of materials[5,8]. For all of these reasons the sodium cobalt bronzes were predicted to be good candidates for investigation as superconductors[5,9,10].

Whatever its relationship to the high-T_c oxides may be, the discovery of the $Na_{0.35}CoO_2{\cdot}1.3H_2O$ superconductor represents a major advance, because there are so few examples of layered transition metal oxide superconductors and relatively few examples of oxide superconductors in general that do not contain copper. Because its superconductivity can easily be destroyed by removing the water molecules, and thus decreasing the interlayer separation, $Na_{0.35}CoO_2{\cdot}1.3H_2O$ could also provide insight into the relationship between dimensionality and superconductivity. Contrasts and similarities between it and the copper oxides may shed further light on the challenging issue of understanding high-T_c superconductivity. The electronic, magnetic, and structural properties of this new cobalt oxide are likely to be the subject of intense investigation for some time.

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NANOPARTICLE WAVEGUIDES

Watching energy transfer

There may be plenty of room at the bottom, but the size of conventional optical elements is restricted by the diffraction limit of light. Plasmon waveguides made from metal nanoparticle chains may allow a drastic reduction in the size of photonic devices.

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Modern technology relies heavily on photonic and optoelectronic devices for signal transmission and routing, chemical analysis and sensor applications. As is the case for electronics, increasing the speed and sensitivity of photonic devices relies on further miniaturization of photonic elements. But there is a fundamental limit to the minimum size of conventional optical elements such as dielectric waveguides. This limit is set by diffraction to be about half the wavelength of light. For visible light, this translates into a minimum element size of a few hundred nanometres — too large for fabricating nano- and molecular-scale photonic devices. Near-field optics, which exploits non-propagating (evanescent) fields rather than propagating light waves, provides a way of circumventing the diffraction (and therefore size) limit. As they report on page 229 of this issue, Stefan Maier and colleagues[1] have now directly observed energy transfer along a nanoparticle plasmon 'waveguide'. These metal nanoparticle chains may become a central component of nanoscale photonic devices.

Near-field optics, proposed around 20 years ago, provides a neat way to circumvent the diffraction limit[2]. Instead of imaging with a system of lenses, a glass fibre with a submicroscopic tip can be used to probe the light fields close to a sample surface. Because the distance between tip and sample is much smaller than the light wavelength, non-propagating light fields that are bound to the sample surface can be detected. These 'evanescent' fields decay in intensity within a fraction of the light wavelength when moving away from the surface, and carry information about sample features smaller than the value set by the diffraction limit. Owing to their non-propagating character, evanescent fields can only be detected by a local probe immersed into the near-field of the sample. The corresponding experimental device is called a near-field scanning optical microscope (NSOM).

Near-field optics is rapidly developing in new directions, owing to the realization that exploitation of evanescent light fields may pave the way towards nanoscale photonic devices. One of the most successful approaches so far relies on materials not readily associated with optics: noble metals. Metal nanoparticles can sustain resonant collective oscillations of their conduction electrons. When driven by an external light field, these electron oscillations couple to the optical excitation to form surface plasmon polaritons (SPPs) bound to the nanoparticles. The intensity of SPP fields is maximized at the nanoparticle surface and decays exponentially away from it.

What makes SPPs so attractive for near-field optics? It is partly because of their highly intense evanescent fields, which can exceed the optical excitation intensity by several orders of magnitude. Silver and gold are of particular interest due to their high field enhancement, and because their SPP resonances lie in the visible spectral range. The enhancement effect is well known and exploited in techniques such as surface-enhanced Raman scattering. But there are possibly more applications that SPPs could be used for, such as nanoscale optical devices relying on SPP near-fields. Due to the evanescent character of the involved optical fields, these would not be hindered in miniaturization by the diffraction limit.

These considerations led Quinten *et al.*[3] to propose an optical waveguide composed of a linear chain of closely packed silver nanoparticles. An external field excites the first particle of the chain, giving rise to an intense SPP near-field. If the second particle is situated within this near-field, it picks up the optical excitation, and so on along the chain. The SPP fields are well confined to the nanoparticles in the direction perpendicular to the chain — it is only along the chain that light propagates (Fig. 1). But this approach has its limitations. Even for silver and gold, SPP propagation along a nanoparticle chain is limited to a few hundred nanometres at best. So rather than acting as waveguides in the conventional sense, which support practically lossless light propagation, nanoparticle chains should be seen as local devices focusing optical fields down to nanoscale volumes.

The first direct experimental demonstration of SPP coupling between two individual nanoparticles[4] was followed by spectroscopic investigations of nanoparticle chains[5] and further theoretical considerations[6]. Now, Stefan Maier and his colleagues report the first direct measurement of SPP propagation along a silver nanoparticle chain[1]. To excite SPPs, the group used the fibre tip of an NSOM as a local light source. SPP propagation along the nanoparticle chain was probed by measuring the fluorescence intensity (collected in the far-field) from fluorescent polystyrene nanospheres that have been deposited on top of the particle chains (Fig. 1). Maier and colleagues found that the fluorescence from nanospheres sitting on top of metal nanoparticles was significantly broader than that from isolated nanospheres. This fluorescence broadening is indicative of SPP propagation along the nanoparticle chain to the fluorescent nanosphere. By mapping the fluorescence from nanospheres placed along the length of the nanoparticle chain, the authors were able to estimate the SPP propagation length to be a few hundred nanometres.

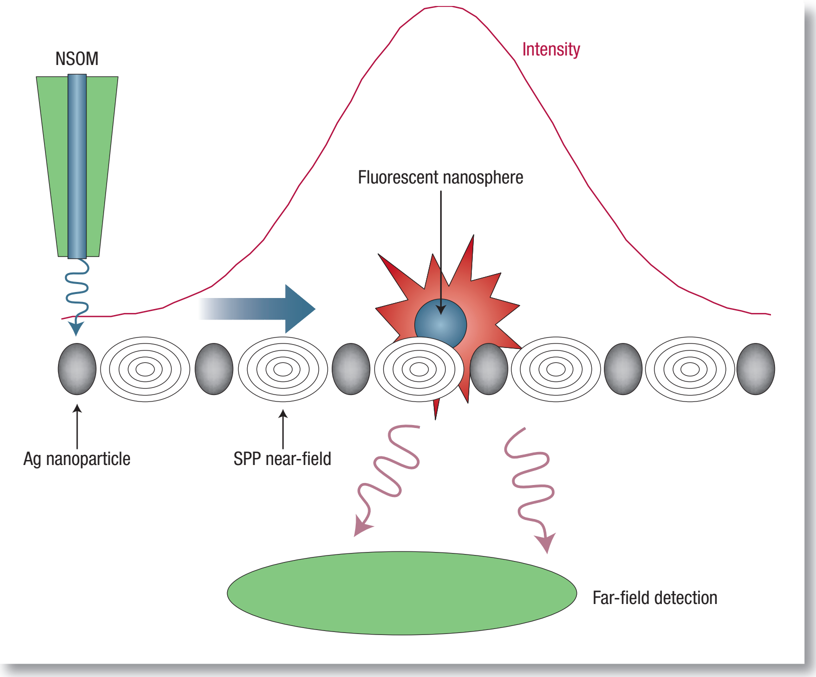

Figure 1 Excitation and detection of energy transport in metal nanoparticle chains by near-field optical microscopy[1]. The nanoparticle 'waveguide' is locally excited by light emanating from the tip of an NSOM. The electromagnetic energy is transported along the waveguide towards a fluorescent nanosphere sitting on top of the nanoparticles. The NSOM tip is scanned along the nanoparticle chain, and the fluorescence intensity for varying tip positions along the particle chain is collected in the far-field. The energy transport to the nanosphere manifests itself in an increase in width of the nanosphere fluorescence.

The good news is that SPP propagation along the nanoparticle chain has been observed. The bad news is that the observed propagation length confirms the theoretical predictions, showing extremely strong damping of the SPP propagation (around –3 dB per 100 nm). However, applications such as the short-range optical addressing of individual nanoparticles or even molecules can still be envisaged, with nanoparticle chains acting as the front end of conventional waveguides. The enhanced SPP near-field could also be used in data storage and near-field microscopy, and metal nanoparticles offer easy integration with other metal structures. SPPs exist not only as particle-bound excitations, but also as propagating waves along metal wires with micro- or nanoscale cross-sections. For such geometries, SPP propagation lengths one to two orders of magnitude larger than for nanoparticle chains have been reported[7], leaving open the possibility of entirely SPP-based optical devices.

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