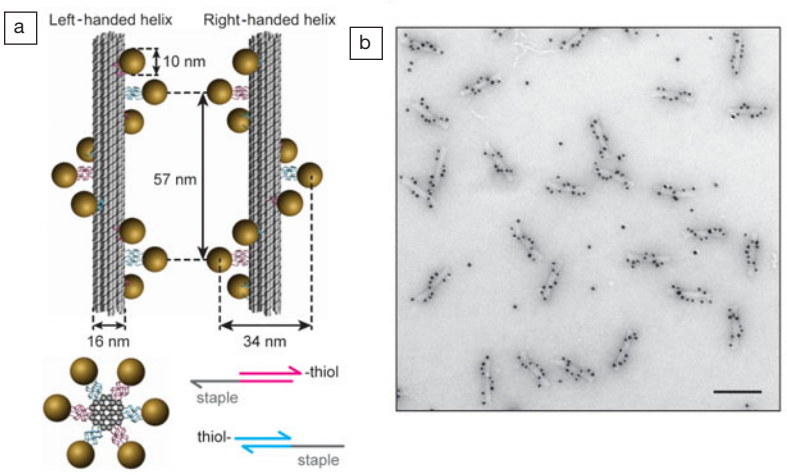
Nano Focus

Gold nanoparticle helices show chiral interaction with visible light

The interaction between light and surface plasmons in metal nanoparticles allows for interesting new optical materials, provided that the nanoparticles can be arranged in precise architectures. Molecular self-assembly provides a promising method for building such plasmonic structures, as shown by A. Kuzyk from the Technical University of Munich, R. Schreiber from Ludwig-Maximilians University (Munich), Z. Fan from Ohio University, and their co-workers, who used DNA origami to assemble helices of gold nanoparticles. Their letter in the March 15 issue of *Nature* (DOI: 10.1038/nature10889; p. 311) describes how these structures interact with polarized light in a similar way to chiral molecules, but at easily tunable wavelengths in the visible spectrum.

The rational synthesis of a DNA strand which will fold into a target three-dimensional structure, known as DNA origami, was used to provide a scaffold for generating a helical arrangement of nanoparticles. These 16 nm diameter DNA bundles possess nine attachment sites, arranged in one full turn of a 57 nm pitch helix, to which the gold particles (10 nm) were attached by thiol-DNA linkers. Solutions of either all left- or all right-handed helices were then studied using circular dichroism, revealing a difference in absorption between right and left circularly polarized light. As predicted theoretically, coupling of plasmon waves along the helices results in increased absorption of specific polarizations of light, and left- and right-handed helices show a mirror-image peak/dip close to the surface plasmon resonance frequency at 524 nm.



(a) Left- and right-handed helices of nine gold nanoparticles that are attached to the surface of a DNA origami structure by thiol-modified DNA linker strands, and (b) a transmission electron microscope image of left-handed gold helices; scale bar 100 nm. Reproduced with permission from *Nature* **483** (2012), DOI: 10.1038/nature10889; p. 311. ©2012 Macmillan Publishers Ltd.

Coating the nanoparticles with a shell of silver (~3 nm thick), which has a shorter wavelength plasmon resonance than gold, unsurprisingly caused a blue shift in the absorption peak. The optical response of the solutions could then be fine-tuned to intermediate absorption frequencies by electroless deposition of a mix of gold and silver, or by mixing helices of different metallic compositions together. The different responses of the left- and right-handed helices could even be visualized macroscopically by passing linearly polarized white light through droplets of the two solutions, which rotate the polarization in opposite directions. The sample could then be oriented so that red light is transmitted by one solution but not the other.

The team also envisage the development of fluids containing oriented helices which could lead to enhanced optical signals, and possibly the production of materials with negative refractive index based on similar structures. This research illustrates in particular how DNA origami can be an effective tool for the engineering of nanoparticle architectures with sufficient precision for optical and plasmonic applications.

Tobias Lockwood

Nano Focus

Figures of merit developed for conductors in metamaterials and plasmonics

Research in metamaterials and plasmonics both involve the study of light in electromagnetic structures. Metamaterials are engineered structures, which are not found in nature, that have an ability to guide light around objects rather than reflecting or refracting it. Plasmonic systems, in turn, exploit surface plasmon polaritons (SPPs), which are electromagnetic waves with wavelengths shorter than the incident light that can propagate at metal–dielectric interfaces. Although incorporation of metamaterials and plasmonics into practical devices promises many exciting applications, their use is limited by significant dissipative losses. These occur because the noble metals used in these photonic structures are poor conductors at high frequencies. Recently, P. Tassin and colleagues at Ames Laboratory—US DOE and the Department of Physics and Astronomy, Iowa State University, and co-researchers at the Institute of Electronic Structure and Lasers, Heraklion, Crete, Greece, have addressed the question of what makes a good conductor for metamaterials and for plasmonic systems. To this end, they have derived two different figures of merit, one for each type of electromagnetic structure.

In their article recently published online in *Nature Photonics* (DOI: 10.1038/NPHOTON.2012.2), Tassin and co-researchers consider metamaterials as an array of subwavelength conducting elements, which effectively captures the physics of the most commonly studied systems. The researchers derived an expression for the dissipated power fraction as a function of four independent parameters. However, only two parameters depend on the material's properties—the dissipation factor, ζ, and the kinetic inductance factor, ξ, which are proportional to the real and imaginary parts of the resistivity, respectively. A small ζ allows for large currents, while a small ξ prevents saturation of the resonance frequency. Furthermore, at frequencies where the permeability is −1, the dissipative loss depends, to a good approximation, only on ζ. This establishes it as a good figure of merit for conducting materials in resonant metamaterials, although geometrical factors are important when comparing samples of different thicknesses.

The researchers said that although charge-neutral graphene displays minimal resistivity in the mid-infrared and visible band, it is not a good candidate for metamaterial applications because ζ and ξ for graphene are several orders of magnitude larger than those for gold. Similarly, silver performs better as a conducting material at terahertz frequencies than high-T_c superconductors because it has significantly smaller ζ and ξ values. Transparent conducting metal oxides, such as indium tin oxide and aluminum tin oxide, have also recently been proposed for use in metamaterials, but the researchers found that their microwave resistivities are two orders of magnitude larger than the optical resistivity of silver.

For plasmonics, the researchers use the ratio of the propagation length to the surface plasmon wavelength as the measure of loss performance. The larger kinetic inductance of biased graphene makes it a better candidate for plasmonic applications than charge-neutral graphene. However, the researchers also showed that the propagation length is, at best, on the order of a few SPP wavelengths, which is too short for most plasmonic applications.

The researchers also discussed why alkali–noble intermetallics, such as KAu and LiAg, are not good candidates for use in metamaterials, although they said, "These examples show, nevertheless, the possibility of band engineering to tune the resistivity of alloys," and that, "it is worth continuing the research effort to develop better conducting materials, because of the considerable improvement such materials would bring."

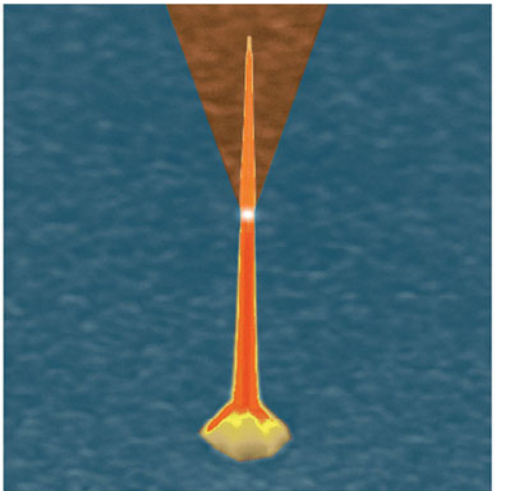
Steven Trohalaki

Nano Focus

Tailored nanowire with embedded quantum dot yields bright single-photon source

Single-photon sources with near-unity light-extraction efficiencies (η) are ideally required for processes relying on the transfer of quantum information between two remote stationary quantum bits, such as quantum cryptography or the development of a quantum computer. Moving toward this goal, M.E. Reimer and co-workers, from the Delft University of Technology and M.A. Verheijen and E.P.A.M. Bakkers from the Eindhoven University of Technology, The Netherlands, have recently succeeded in developing a highly efficient method of collecting single photons. As reported in the March 13 issue of *Nature Communications* (DOI: 10.1038/ncomms1746), the researchers have fabricated a high-efficiency single-photon source based on a nanowire with controlled shape, which they suggest will pave the way toward a single-photon source with near-unity light-collection efficiency.

The researchers designed a tapered nanowire as a waveguide where a single $InAs_{0.25}P_{0.75}$ quantum dot was precisely positioned on its axis such that it can collect photons as they are generated. This was achieved by growing InP nanowires using low pressure metal–organic vapor-phase epitaxy (MOVPE) methods, and then synthesizing the $InAs_{0.25}P_{0.75}$ quantum dot at a specific time such that it was incorporated at approximately half the nanowire length. Finally, the temperature was raised to suppress axial growth and favor shell formation, which allowed the nanowire geometry to be shaped to an optimum nanowire diameter of 160–220 nm at the quantum dot position, with a tapering angle toward the tip (~2°) (see Figure). This design overcomes the principal drawback of existing devices where quantum dots are randomly positioned in the nanowire, leading to a drastic reduction in the collection efficiency. Furthermore, with this very small nanowire taper the researchers also avoided unwanted reflections at the semiconductor–air interface.



A stream of single photons is directed toward the tapered nanowire waveguide tip with high efficiency (42%). The single quantum dot positioned in the middle of the nanowire couples to the fundamental waveguide mode with efficiencies exceeding 95%, such that the photons are emitted along the nanowire axis. The nanowire diameter is approximately 200 nm.

A final important feature of this novel nanostructure design was the integration