To investigate this possibility at the genetic level, the investigators sequenced 48 liver transcriptomes of lizards collected before and after the storms. They acclimatized lizards from different points along a latitudinal gradient to a common temperature (30°C) for 14 days and then compared genomic profiles of 57 coexpressed gene modules before and after the event and at different sites. The comparisons yielded two main findings. First, a large change in 14 genomic regions occurred across the winter, but only at the southern and most severely affected site. Second, three of the coexpressed gene modules varied with latitude. Winter survivors at the southern site displayed a shift toward the more northerly populations, whereas the northern populations themselves showed no change, presumably because winter conditions there were less severe.

> ***"Will evolutionary change be short-lived and transitory, or will it substantially contribute to the persistence of species?"***

What are the genes in these modules, and what are their functions? Some of the differentially expressed genes are known to participate in the maintenance of synaptic function and neurotransmission, as well as the neurotransmitter inhibition that is crucial to the maintenance of muscle tone (*4*). These functions are plausibly linked to increased cold tolerance.

Thus, Campbell-Staton *et al.* establish a strong case for the most likely target of natural selection by performing physiological research on a fitness-related trait combined with molecular sleuthing (*4*). A follow-up study is needed to investigate the multiple functions of these genes in anole lizards in Texas.

The study is restricted to a single generation; like the pioneering (*8*) but controversial (*9*) study of house sparrows (*Passer domesticus*) in Rhode Island that survived or died in a severe snowstorm in 1898, it does not document evolution directly. This can be accomplished, however, by following the fates of measured and individually marked adults through a period of stress, together with the offspring produced by the survivors, in order to quantify both natural selection on ecologically important traits and the evolutionary consequence in the next generation (*3*). Large animals such as lizards are suitable for this kind of study, and so are plants. An alternative approach is to use genome-wide sequencing of a population before and after an extreme stress, and then in the descendant population (*10*).

On the face of it, selection for increased cold tolerance has nothing to do with global warming. Yet, there is a connection. A geophysical perturbation in one region can have contrasting effects in other regions owing to the teleconnections that link them in a geospatial network. For example, El Niño warming of the eastern Pacific brings heavy rains to Peru and Ecuador but drought conditions to Panama.

A straightforward prediction of gradual warming is a shift in the distribution of animals and plants to higher latitudes and elevations, either by differential dispersal or through local adaptation (*2*, *7*, *11*). By contrast, there is limited theory to guide expectations of how climatic extremes will affect evolution (*7*, *12*). As the study by Campbell-Staton *et al.* brings home, episodic extremes are unpredictable in occurrence; moreover, their effects are heterogeneous. Will evolutionary change be short-lived and transitory, or will it substantially contribute to the persistence of species?

Answers will depend on the magnitude of deviations from average environmental conditions, how long extreme conditions persist, and on the pattern of intervals between successive events. They will also depend on many biological factors, including prior exposure of the organisms to extremes, their behavior, how phenotypically plastic they are, the degree to which they are genetically variable in fitness-related traits, demographic factors such as lifespan and dispersal (gene flow), and the ramifying effects on other members of their food webs (*3*). All of this means that linking extreme events and evolutionary responses presents investigators with substantial challenges. Yet, the importance of doing so can only grow as extreme events become more frequent and extreme. ■

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PLASMONICS

A low-loss origami plasmonic waveguide

DNA assembles silver and gold nanoparticles for fast and efficient energy transfer

By **Fiorenzo Vetrone** and **Federico Rosei**

Computers consume large amounts of energy because the electrons that carry information dissipate heat as they move through chips. Optical computing platforms, which transfer information using photons, would mitigate the losses incurred through heat generation. Glass fibers can transport light across large distances with virtually no loss, but they are unsuitable for length scales below 1 μm because propagation is based on classical optics, which requires the size of the medium to be larger than the photon wavelength. Roller *et al.* (*1*) have now addressed this size challenge by demonstrating a low-loss nanoscale plasmonic waveguide based on a heterogeneous trimer composed of gold-silver-gold nanoparticles (Au-Ag-Au NPs). This concept validates the possibility of using such heterogeneous assemblies as energy-transfer elements through near-field interactions, while avoiding the typically high dissipation associated with plasmonics.

The reported low-loss waveguide may be relevant to both optical information processing and energy harvesting. In photosynthesis, chloroplasts convert the energy of sunlight into chemical energy through dipole interactions (Förster resonance energy transfer, or FRET) (*2*). Although FRET in nature is very efficient, it is incoherent and therefore dissipative. "Plasmonic" waveguides in theory could transfer energy through the linear arrangement of metal NPs forming a homogeneous wirelike architecture (*3*). Plasmons—collective oscillations of charge density that occur, for example, in Au and Ag

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NPs—interact strongly with light and can concentrate electromagnetic energy (*4*).

Although plasmons are coherent, the high scattering of electrons in metals results in substantial energy dissipation and short lifetimes for the transfer process (*5*). Roller *et al.* (*1*) propose a model system for a lossless plasmonic waveguide based on a heterogeneous trimer composed of one Ag NP sandwiched between two identical Au NPs (see the figure, top panel). The plasmon resonance energy of the intermediary Ag NP (~2.8 eV) is greater than that of the Au NPs (~2.3 eV), making it too high to be occupied. The Ag NP participates in the energy transfer as a quasi-resonant virtual state (virtual transmitter). In addition, the distance between the Au NPs is too large for energy transfer to occur between them. Their plasmons are in phase (or resonance), but they are too distant to couple. Very little heat is generated in the Ag NP, yet the Au NPs are still perfectly coupled.

Conventional optical waveguides are continuous and information is transmitted with light pulses. By contrast, a plasmonic chain represents a discrete waveguide, in which binary information "bits" are stored and transferred as plasmons localized on individual NPs. The energy transfer occurs between consecutive storage elements in the heterotrimer and propagates over longer distances (~100 nm versus ~1 nm) and with 1000 times the speed of FRET in photosynthetic light-harvesting systems (a few femtoseconds versus a few nanoseconds). The experimental realization of this architecture requires exact control over the spatial arrangement of the three NPs.

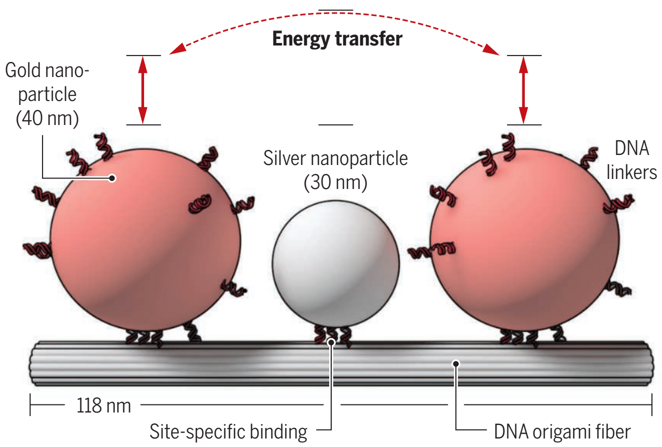
The plasmonic waveguide satisfies the essential requirements for photon transport between components, namely high transfer efficiency and low energy losses in the transmitting element (Ag) as well as fast transfer times. Previous efforts to develop plasmonic nanoscale transfer devices from heterogeneous metals largely focused on top-down lithographic techniques to fabricate linear arrays of metal nanostructures (*3*). However, in lithography, spatial control is limited to scales above tens of nanometers, and the crystallinity of the nanostructures formed is imperfect. The very narrow size distribution of colloidal metal NPs may overcome such limitations, if there is a strategy to precisely position and lock the NPs in place.

Efficient plasmon transfer

Roller *et al*. assembled a trimer of nanoparticles that transfers a plasmon efficiently from one end to the other.

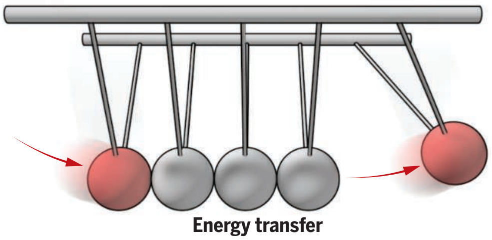
Proper placement

A silver nanoparticle embedded between two gold nanoparticles ensures ultrafast energy transfer with almost no dissipation. The nanoparticles are attached to a "DNA origami" fiber for precise positioning.



A mechanical analog

The heterogeneous plasmonic waveguide is reminiscent of a Newtonian cradle. Additional silver nanoparticles in the middle could extend the distance over which energy can be transferred with low energy loss.



DNA nanotechnology allows for an accurate arrangement of nanoscale objects, driven by noncovalent interactions (*6*–*8*). Heterogeneous nanoscale architectures, generally referred to as "DNA origami" (*9*–*11*), can be created by functionalizing NPs with orthogonal DNA strands (*12*). Roller *et al.* used DNA origami to position three NPs in a precise linear arrangement (see the figure, top panel). They exploited an ~8000-nucleotide viral single-stranded DNA (ssDNA) as a scaffold that folds into a designed shape by the binding of ~200 short, synthetic ssDNA "staple" strands. The precision of the DNA origami assembly relies on defining the exact location of each staple strand and DNA base.

Efficient and ultrafast energy transfer with low dissipation was demonstrated by comparing dark-field scattering spectroscopic measurements obtained from the heterogeneous trimer versus homogeneous dimers (Au-Au NPs). The resonance wavelength shifted by 37 nm, from 549 nm for the homodimer to 586 nm for the heterotrimer, along with a factor of 4 increase in peak intensity. Thus, the Ag NP transfers the energy efficiently and coherently between the outer Au NPs. Theoretical computations revealed that only 10% of the total dissipation occurs in the Ag element. Classic electromagnetic theory showed excellent agreement with far-field scattering experiments and also yielded local energetic properties, which are not accessible in the scattering experiments. The lifetimes of the plasmon and energy transfer were estimated to be approximately 8 and 4.7 fs, respectively, making this process orders of magnitude faster than FRET and occurring at ~7% of the speed of light in vacuum.

Roller *et al.* showed that the Ag NP in the trimers acts as a virtual state allowing for ultrafast excitation transfer with practically no energy dissipation. This elegant concept brings us one step closer to realizing lossless energy transfer between more distant nanoscale components. Transfer of energy over longer distances could be achieved by embedding additional Ag NPs between the Au NPs. This architecture, which is reminiscent of a nanoscale Newtonian cradle (see the figure, bottom panel), would strongly suppress the dissipation inside the connecting Ag NPs but would efficiently mediate the energy transfer between the Au NPs. Ultimately, this new class of low-loss plasmonic waveguides may prove useful in other areas of plasmonics research such as, for example, hot-electron photochemistry. ■

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