diclofenac formulated for human use widely on sale for the treatment of cattle (*8*). These findings, coupled with coordinated efforts by nongovernmental organizations (NGOs) and governments, led to further restrictions and remedial efforts. By 2008, diclofenac contamination had fallen substantially (*7*), largely as a result of two factors: awareness-raising work by NGOs and government departments with the public, pharmaceutical industry, and veterinarians; and the identification and promotion of the alternative drug meloxicam, which is effective for treating cattle but does not harm vultures (*9*).

A suite of studies of the latest vulture population trends suggests that these efforts are working and that the vulture declines have slowed or even stopped. In India, all three critically endangered *Gyps* vultures did not decline between 2007 and 2011; one species, the oriental white-backed vulture, may have increased slightly (*10*). Population models indicate that these changes match predictions from the measured reduction in carcass contamination (*7*, *10*). The oriental white-backed vulture population in Nepal has also increased since the ban, and the decline of this species in Bangladesh has slowed since the more recent ban there. A long-billed vulture population in Pakistan, which was declining before the ban in 2006, has now increased substantially (*11*).

It seems that carefully targeted research—combined with political commitment and government-NGO cooperation—is making a real difference for the subcontinent's vultures. Yet, recovery will likely be partial and take decades. Continued monitoring of vultures and of veterinary drugs and their toxicity is necessary to measure the effectiveness of interventions and suggest modifications where necessary.

This need for vigilance and adaptive management is underscored by the increased use of several other veterinary drugs with unknown effects on vultures: aceclofenac, a precursor of diclofenac that is highly likely to be toxic (*12*), and ketoprofen, which was shown to be toxic to vultures 3 years ago (*13*) but is still permitted for veterinary use in India. The governments of the vulture range states have moved much faster and more effectively than did western governments when responding to the environmental impacts of organochlorine pesticides identified by Rachel Carson, but sustained scientific scrutiny is vital, as is continued political resolve.

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APPLIED PHYSICS

Metamaterials with Quantum Gain

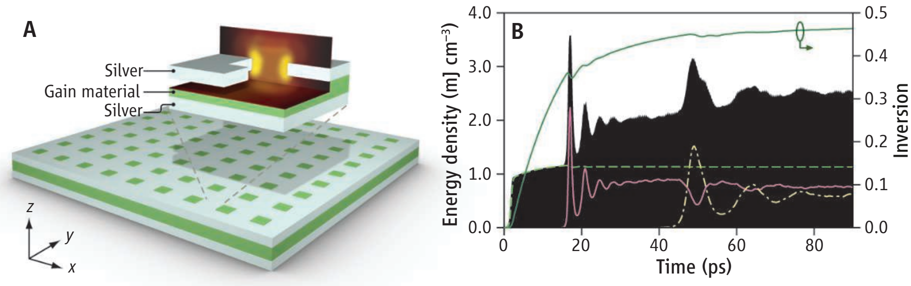
Ortwin Hess and Kosmas L. Tsakmakidis

Integrating amplifying media with metamaterials allows loss-free plasmonic operation and opens a route for controlling nanoscale quantum emitters.

Optical metamaterials and nanoplasmonics offer extreme control and localization of light within volumes that can be smaller than a cubic light wavelength by more than three orders of magnitude, but they suffer from appreciable dissipative losses. This weakness is thought to constitute the prime impediment before many of the envisaged applications can succeed in practice. However, recent breakthroughs in the theoretical understanding and experimental fabrication of gain-enhanced metamaterials and nanoplasmonic heterostructures promise to overcome these hindrances, while allowing for new ways to control spontaneous and stimulated emission of light on the nanoscale (*1*, *2*).

Resistive losses in nanoplasmonic metamaterials arise from the interaction of the incident photons with the quasi-free conduction electrons of the metals, thereby constituting an inherent feature of the response of metal-based nanodevices. For truly subwavelength plasmonic structures, these losses follow universal laws; that is, they do not depend on the particular geometric configuration but only on the metal used (usually noble metals) (*3*). Meanwhile, there has been an increased emphasis on two-dimensional (2D) metasurfaces, which are much more convenient to fabricate than their full-3D metamaterial counterparts but can steer light in equally dramatic ways, well below the fundamental diffraction limit and over broad, flat areas (*4*).

In such a 2D nanostructure with laser dyes (gain medium) incorporated into its fabric (see the figure, panel A), the objective is to obtain optimum coupling of the plasmonic excitations to the gain molecules, so that maximum harnessing of the gain medium can be achieved—a requirement due to the high losses. When the pattern of the nanoholes periodically perforating the two silver nanofilms is engineered such that the desired plasmonic resonance coincides with



Playing for gain. (**A**) An illustration of the gain-enhanced optical metamaterial, with a magnified unit cell and an example of plasmonic field enhancement at two vertical planes inside the cell. (**B**) Energy and average inversion (green solid line, right axis) inside the lasing nanofishnet over time. The signals, time-averaged over 0.4 ps (black), are decomposed into the pump mode (green dashed line), the bright mode (red solid line), and the dark mode (yellow dash-dotted line).

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the emission wavelength of the dyes, full loss compensation and amplification can be achieved, even in the exotic negative refractive index regime (*5*–*7*). By extending the duration of the incident probe pulse such that the energy inside the nanostructure becomes constant with time, the quantum plasmonic amplifier can operate transiently and also in a steady-state mode (*8*).

If the gain supplied by the active medium is sufficient to overcome both dissipative and radiative losses, then the structure can function as a coherent emitter of surface plasmons over the ultrathin 2D area, deep below the diffraction limit for visible light (*1*, *9*). Here, controlling the spontaneous emission rate is crucial (*10*) as both bright and dark plasmonic lasing states exist, giving rise to a strong, nonlinear competition. Which one eventually dominates can be controlled by the design and excitation of the metamaterial (see the figure, panel B). In this example, where bright plasmonic emission dominates, the bright-mode energy (red solid line) builds up initially, followed by picosecond-period relaxation oscillations and steady-state emission, interrupted (at ~50 ps) by an instability of the dark mode (yellow dash-dotted line) until again steady-state emission is reached.

These 2D active nanostructures can function as powerful on-chip light sources, either coherent (nanolasers) or incoherent (light-emitting diodes, LEDs), delivering intense optical power. Although the typical plasmonic cavity Q factors are rather small (~50), the attained Purcell factors (a measure of the spontaneous emission rate enhancement that varies as Q/V_m) can be large because the mode volume V_m can be extremely small. A major goal in the field is to enhance the Purcell factor so as to accelerate spontaeous emission to the degree that it becomes faster than stimulated emission, so that ultrafast, low-energy LEDs can be attained and integrated within nanoscale circuits (*11*).

Large Purcell factors can also be obtained in plasmonic slow-light heterostructures for special cases where the group velocity of the plasmons is close to zero (*1*). Computations reveal that at these zero–group velocity points, full lasing operation can be reached in completely uniform (minimalistic) structures that do not require a cavity to confine light (by reflections or Bragg scattering) because successive light pulses can be stopped and strongly localized (*12*). Without any cavity walls restricting the lasing mode size to be above the diffraction limit, the mode can be pushed into a deep-subwavelength regime, with sizes (in 2D) of $\lambda^2/1000$ being realistically attainable. Because spontaneous emission can be efficiently channeled into the stopped-light mode, the result is low-threshold operation.

The marriage of nanoplasmonic metamaterials with quantum gain media represents an exciting frontier in nanophotonics and nanoscience, and is a precursor of active, intergrated quantum nano-optics. Bringing gain in the nanoscale will open a platform for practical, loss-free nanodevices—not only electro-optic modulators and intense light sources, but also plasmonic waveguides and nanosensors exploiting intensified plasmonic hot spots for single-emitter spectroscopy or nanoscale lithography.

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GEOCHEMISTRY

Impact and Extinction

Heiko Pälike

Precise dating shows that the Chicxulub impact coincided with the mass extinction at the K-Pg boundary 66 million years ago.

During the past 540 million years, five major mass extinctions have occurred on Earth. Several of them have been linked to volcanic eruptions during the formation of large flood basalts (*1*, *2*). However, the situation is not clearcut for the most recent mass extinction at the Cretaceous-Paleogene (K-Pg) boundary (~66 million years ago), when nonavian dinosaurs became extinct. Around the time of the K-Pg boundary, a series of large eruptions formed the Deccan flood basalts. However, in 1980, Alvarez *et al*. (*3*) argued that the K-Pg boundary coincided with the impact of a large asteroid or comet. On page 684 of this issue, Renne *et al*. (*4*) provide new evidence that the age of Chicxulub asteroid impact and the K-Pg boundary coincide precisely.

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Alvarez *et al*. based their initial hypothesis on elevated concentrations of iridium and other platinum-group elements and the occurrence of shocked quartz, tektites, and tsunami-like deposits in samples roughly dated to the time of the K-Pg boundary. Telltale deposits of an impact by an extraterrestrial body around the time of the boundary have now been found globally. These deposits decrease in intensity and thickness away from a proposed impact site at Chicxulub in the Gulf of Mexico (*5*). Nevertheless, the debate about the precise sequence of events has continued. Different views persist about the relative timing of the K-Pg boundary and the impact deposits, on the one hand, and the role played by large continental flood basalts and volcanism, on the other hand.

For the hypothesis that the K-Pg mass extinction was caused or triggered by an impact to be true, there must be absolute correspondence between the K-Pg boundary and the impact. Detailed sedimentological analysis and stratigraphy, together with accurate geochronological dating, therefore allow the hypothesis to be tested. Renne *et al*. now apply state-of-the-art geochronological dating methods to new data collected from impact deposits and the K-Pg boundary. They resolve the existing uncertainty about the relative timing of the events.

Some of this uncertainty arose from a mismatch between the two main methods used for radioisotopic dating. One method measures the relative abundance of decay chain products of uranium/lead (U/Pb) in zircons formed in magma chambers and preserved in bentonites; the other measures potassium/

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