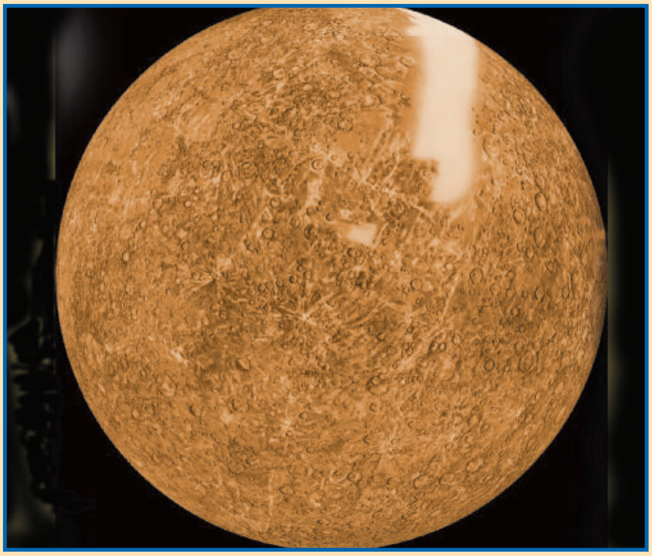
Planetary science

Magnetic Mercury



MARINER 10/ASTROGEOLOGY TEAM/US GEOL. SURV.

This beautiful picture of Mercury is compiled from images of the planet sent back by the Mariner 10 spacecraft in 1974 and 1975. The Mariner 10 data also presented several puzzles. Writing in *Earth and Planetary Science Letters* (**218,** 261–268; 2004), Oded Aharonson and colleagues revisit one of them — why, against expectations, does Mercury have a global magnetic field?

The planet's diminutive size means that it should have cooled quickly after it formed. Any molten core would have become solid, or almost completely so. A magnetic-field-generating dynamo in an outer core (as is the case for Earth) should have long since seized up. But the news from Mariner 10 meant a rethink was needed, and since then attempts to account for the magnetic field have centred on how the core might have remained largely molten.

Aharonson *et al.* examine another possibility — that the field originates from magnetization of Mercury's crust, the remnant of a powerful core dynamo early in the planet's history. After considering some of the arguments against this possibility, the authors tackle the main objection, which comes in the form of Runcorn's theorem. This holds that a uniform shell, magnetized by an internal source, cannot have an external field if the source is removed.

Aha! thought Aharonson *et al.*, what if the shell — the crust — is not uniform, and the magnetized layer varies in thickness? They discuss why this could be so, work through the relevant mathematics, and conclude that Mercury's magnetic field could be crustal in origin under certain conditions.

Core or crust? The question should be answered by the MESSENGER mission, due for launch in May. The spacecraft will make two passes by Mercury in 2007 and 2008, before going into orbit around the planet in 2009. On board are a laser altimeter and a magnetometer, which can respectively provide evidence of the planet's structure and any asymmetries in the magnetic field. The resulting data should give a definitive answer.

Tim Lincoln

Device physics

The optical age of silicon

Graham T. Reed

The silicon chip has been the mainstay of the electronics industry and it may similarly come to dominate photonics. A key component — a high-frequency optical modulator — has now been fabricated.

Research into optical circuits for communications began in the 1970s. Early visions of optical circuits were as 'optical superchips', containing light emitters, modulators, amplifiers, optical isolators, detectors and, latterly, electronic intelligence[1]. However, there are still differing views about the optimum material for such components. This is sometimes articulated in the phrase "optical circuits have yet to find their silicon" — a reference to silicon's dominance in the microelectronics industry. Despite its success as an electronic material, silicon has received rather modest attention as an optical material. But that may be about to change. As they report on page 615 of this issue, Liu and colleagues[2] of the Intel Corporation have now reached a milestone that bodes well for silicon's optical future: they have fabricated the first silicon-based optical modulator with a bandwidth that exceeds 1 gigahertz (GHz).

In technology terms, research into silicon as an optical material has been under way for a long time — since the mid-1980s. However, relatively little progress has been made in comparison with more exotic materials such as III–V compounds (indium phosphide, gallium arsenide and related compounds), the insulator lithium niobate, or even silica (which typically uses silicon as a substrate material). That is not to say that little has been achieved, but the global technical effort has largely been concentrated on materials other than silicon.

There are two main reasons for this. First, silicon does not have an inherent mechanism for the emission of light: it is an indirect bandgap material, which means that its crystal structure makes it impossible to fabricate an efficient light-emitting device, such as a laser, from this material in the conventional way. The III–V compounds, in contrast, are direct bandgap materials and for this reason are often used in semiconductor lasers.

Second, silicon does not exhibit an electro-optic effect known as the Pockels effect, the traditional characteristic for fast modulation of light (that is, encoding data onto light by selectively changing its intensity). In other materials, such as lithium niobate, modulation is typically achieved via the Pockels effect, which causes a linear change in a material's refractive index with an applied electric field. Other optical modulators use electric-field effects known as electro-absorption and electro-refraction, but these are weak in silicon. Instead, modulation in silicon is achieved through thermal mechanisms, which are relatively slow (typically kilohertz), or through the introduction of free carriers (electrons or their positively charged counterparts, holes), which in turn results in both absorption and a change in refractive index. This latter mechanism, known as the free-carrier dispersion effect, is still also relatively slow, as it is associated with the physical movement of charge within the device. Nevertheless, it has been predicted that silicon-based modulators using this effect could achieve bandwidths exceeding 1 GHz (for example, ref. 3), although in practice working devices[4,5] have been limited to about 20 MHz.

Recently, however, there have been dramatic changes in the fortunes of silicon-based optoelectronics. Examples of progress towards a silicon light source are: doping with erbium[6] to overcome the indirect bandgap in silicon; building small structures that enhance useful quantum-like effects[7,8]; and novel approaches such as dislocation engineering[9] and optical amplification through the Raman effect[10], which could result in not only an optical amplifier but also eventually an optically pumped light source. Recently, the ST Microelectronics company has announced the imminent arrival of commercial devices based on silicon light-emitting devices.

If we add to this Liu and colleagues'

announcement[2] of an effective silicon modulator, the difficulties surrounding the optical performance of silicon seem to be being demolished one by one. Their device is based on the free-carrier dispersion effect and has many similarities to a CMOS transistor. It comprises a slab of 'n-type' crystalline silicon (n-type meaning that it is doped to have an excess of negative charge carriers, electrons), with an upper 'rib' of p-type polysilicon (crystallized amorphous silicon with excess positive charge carriers, or holes). A thin insulating oxide layer separates the p-type and n-type regions (Fig. 1 on page 616). When a positive voltage is applied to the polysilicon, charge carriers accumulate at the oxide interface, altering the refractive-index distribution in the device — which will in turn induce a phase shift in an optical wave propagating through the device. This phase shift can be used to implement optical modulation. Furthermore, the response is fast: Liu *et al.* have demonstrated modulation frequencies in excess of 1 GHz with this device.

Of course, optical-system designers already require devices with bandwidths much greater than 1 GHz, but the demolition of this barrier by Liu *et al.* is significant: it is now easier to foresee the fabrication of even faster silicon-based modulators, although the technical challenge is still substantial. This could well signal the graduation of silicon from a subject primarily of academic research to a career as a viable photonic material with commercial applications. It is worth noting the affiliation of Liu and colleagues to the technology giant Intel — if Intel and other semiconductor technology companies can develop silicon as successfully optically as they have electronically, then silicon is certainly set to grow in stature as an optical material.

Furthermore, consider the fabrication infrastructure that exists worldwide for silicon processing: the legacy of the microelectronics industry is enormous. Those working with microelectronic devices are now seeking to move beyond the critical dimension of 90 nm that is the state of the art. However, most optical devices made from silicon are likely to have critical dimensions of hundreds of nanometres for the foreseeable future, which means that the infrastructure already exists for the next several generations of optical circuits, if they are fabricated in silicon. This implies that the economies of scale that we have seen for the electronics industry could one day apply to the photonics industry.

The removal of the 1-GHz barrier and the imminent arrival of the silicon light-emitter are not the only reasons for this change in the fortunes of silicon photonics: for some years silicon has been seen as an ideal substrate material for optical circuits. Its well-studied properties are excellent for a 'silicon bench', an accurately machined silicon layer on which components can be positioned, aligned and attached to the outside world. Furthermore, for the networks of the future, it will be a relatively simple task to add electronic intelligence to a silicon optical device. This cannot be said for any other photonic platform.

At present the communications industry is experiencing its most serious economic downturn so far; the need for cost-effective technology solutions is underlined more strongly than ever before. Breakthrough developments such as this fast silicon modulator of Liu *et al.*[2] suggest that a low-cost silicon optical superchip could soon be a reality.

So let us again consider whether "optical circuits have yet to find their silicon". It is already the world's favourite electronic material, and silicon could yet come to dominate the photonics industry as well. ■

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Conservation biology

Fatal medicine for vultures

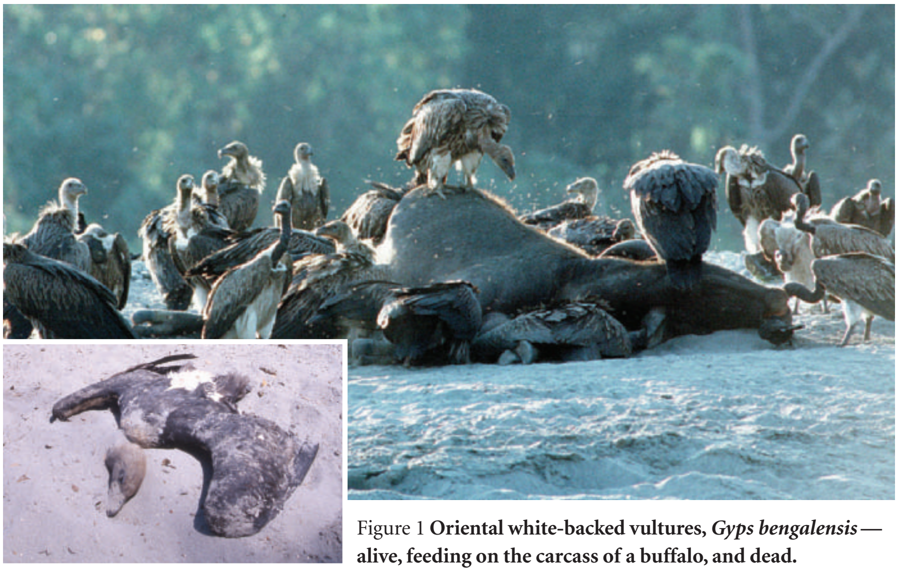
Robert Risebrough

In an echo of events that unfolded earlier in the West, declines of vulture populations in the Indian subcontinent are linked to an environmental poison. Three species of these birds approach extinction.

An unusually high death rate among three species of vulture in south Asia has been perplexing scientists for several years. The consequences have been severe, not just for the vultures themselves but also for their supporting natural and human ecosystems. Vultures are natural scavengers, cleaning up carrion of wildlife and domestic livestock, and also of cattle, sacred to Hindus, which cannot be consumed by people. Moreover, to avoid contamination of the earth, water and fire, people of the Parsi faith, descendants of the Zoroastrians of the Persian empires, have traditionally left their dead to vultures for disposal.

On page 630, Oaks *et al.*[1] offer a convincing reason for the plight of the vultures. The birds have been poisoned by diclofenac, a widely used painkiller and anti-inflammatory drug that is also an all-purpose veterinary medicine for domestic livestock in the Indian subcontinent. Diclofenac is toxic to vultures that consume the carcasses of treated livestock.

The unusual pattern of mortality was first observed in early 1997 among the Oriental white-backed vultures, *Gyps bengalensis* (Fig. 1), nesting in Keoladeo National Park in northwestern India. Birds dropped from their perches to die shortly afterwards; many remained suspended in branches until their carcasses were finally dispersed by the wind. The number of breeding pairs in the park dropped from 150 in the 1996–97 nesting


J. VAN GRUISEN/ARDEA

P. BENSON

Figure 1 **Oriental white-backed vultures, *Gyps bengalensis* — alive, feeding on the carcass of a buffalo, and dead.**