safe and effective prevention and transmission-blocking measures, would be a tremendous boon to afflicted populations, whose socio-economic challenges are exacerbated by this debilitating disease. The world would be a healthier community of nations if this goal were to be achieved. The current study demonstrates the power of coordinating the multifaceted research activities required to achieve such a goal. ■

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OPTICAL PHYSICS

Speedy electrons exposed in a flash

A link has been established between high-frequency light emissions and electron oscillations induced in an insulator by a laser. This is a key step in efforts to make electronic devices that work faster than is currently possible. SEE LETTER P.359

MICHAEL CHINI

The speed at which electronic devices can function is determined by the frequency at which alternating electric currents can be driven in the device. One approach that might surpass the present frequency limit is to drive currents using the nonlinear response of electrons to the oscillating electric field of light. On page 359, Garg *et al.*[1] report key advances in efforts to realize this goal: the use of intense laser pulses to induce currents controllably at frequencies more than 100 times higher than the present limit, and an approach that allows the associated electron oscillations to be measured.

Optics and electronics have always been closely intertwined — light is, after all, an electromagnetic wave. Our ability to measure and control light fields has advanced tremendously in recent decades, and laser-based telecommunication has been commonplace since the late 1990s. By contrast, there are still gaps in our ability to control alternating electronic currents, which remain limited to frequencies of about 100 gigahertz (1 GHz is 10^9 Hz). Finding a way to use the response of electrons to the electric-field oscillations of a strong light field (several hundred terahertz; 1 THz is 10^{12} Hz) to drive alternating electric currents at even higher frequencies has been an elusive goal.

High-speed circuits rely on the fast conversion of a (typically semiconducting) material from an insulating to a conducting state. The conversion is associated with electrons jumping between energy bands in the material — that is, from the valence to the conduction band. Once in the conduction band, electrons can be steered by light or by a voltage, resulting in an electric current.

The timescale for the conversion is set by quantum mechanics: insulators and wide-band-gap semiconductors can undergo switching between energy bands at high speeds because of the large energy separation between the valence and conduction bands. It is perhaps unsurprising, then, that the excitation of charge carriers in a bulk insulator (such as the silica nanofilms used by Garg *et al.*) might enable the generation of high-frequency currents. In fact, evidence for switching speeds close to 1 PHz (10^{15} Hz) was previously reported by researchers from the same institution[2,3]. The next challenge was to measure the oscillatory motion of the electrons, and thereby characterize the frequency of the resulting currents.

Garg *et al.* addressed this challenge starting from the realization that accelerating electrons can emit light known as high-order harmonics[4], which directly reflect the motion of the oscillating electrons. To link this motion to high-frequency currents, it is first necessary to prove that high-order harmonics are generated only from electron motion within the conduction band, and not from electrons falling from the conduction to the valence band. The authors did this by measuring the relative timing of the different frequencies of light emitted from a silica nanofilm, using a device known as an attosecond streak camera.

The researchers observed that the generated light is emitted in a single burst lasting less than 500 attoseconds (1 as is 10^{-18} s), and

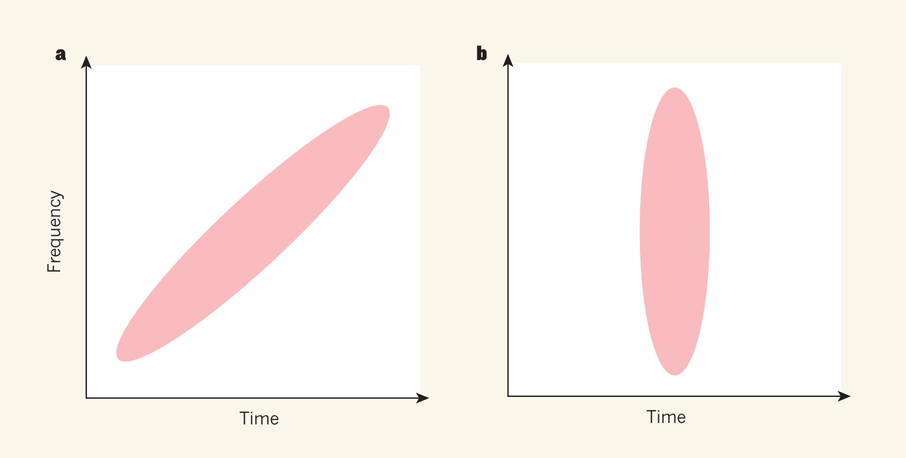

Figure 1 | Differences between high-order harmonic emissions from solids. When solids are irradiated with intense light pulses, electrons jump between the material's energy bands, from the valence band to the conduction band, and can go on to emit light known as high-order harmonics. **a**, If the electrons emit light by dropping back to the valence band, the time taken between the excitation and light emission is longer for high-frequency light than for low-frequency light. **b**, Alternatively, electrons can generate light while remaining in the conduction band. In this case, emissions of different frequencies are all produced at the same time. Garg *et al.*[1] report that the second case is true for high-order harmonics produced when a silica nanofilm is irradiated using an optical laser — a finding that opens up opportunities for measuring electrons oscillating at multi-petahertz frequencies (1 PHz is 10^{15} Hz).

that there is almost no delay between emissions produced at different frequencies. These observations clearly agree with models in which electron motion occurs in a single band (Fig. 1). Electrons moving between bands would instead result in a 'chirped' emission, in which high-frequency light is emitted later than low-frequency light.

The findings provide links between a study[2] that separately demonstrated laser-induced, high-speed switching of an insulator between conducting states, and an investigation[5] that reported high-frequency light emission from laser-irradiated insulators. In other words, the new results show that the phenomena reported in those previous studies originate from the response of electrons in the conduction band to laser pulses. The results also open the way to the use of high-order harmonics as a tool for electronic metrology. Furthermore, Garg *et al.* report that the observed response of electrons to the strong light field is extremely nonlinear: the emitted light extends into the extreme ultraviolet region of the spectrum, which is more than ten times the frequency of the driving light field, and corresponds to energies nearly three times that of the band gap of silica. This extends the range of frequencies at which electronic measurements can be made to well beyond the frequency of the laser light, into the multi-petahertz regime.

Harnessing the potential of optically induced currents and multi-petahertz electronic metrology will be challenging. The observed light emissions, and the currents from which they are produced, are extremely sensitive to subtle variations in the driving laser's waveform, and it is not yet clear whether the observed link between high-order harmonic emission and single-band currents applies in materials other than silica. It also remains to be seen whether the laser-pulse parameters affect the mechanism of current production — although there is evidence suggesting that other mechanisms dominate when longer-wavelength lasers are used[6].

Realization of light-wave-driven devices such as attosecond transistors, which could both switch and drive currents at multi-petahertz frequencies, will require a better understanding of the mechanisms that cause damage and heat accumulation in materials exposed to strong light fields, and of atomic-scale electron motion in solids — in particular how the electronic band structure of a material is modified in strong light fields. Nevertheless, the first hurdles have been cleared: Garg and colleagues' measurements show not only that multi-PHz currents can be reproducibly and controllably generated, but also that they can be measured in real time using attosecond optical techniques. ■

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50 Years Ago

The question of how cells estimate their location within the body is closely related to that of why cells of a developing organism become differentiated … We are now investigating the mechanism involved … using abdominal segments of the pupa *Galleria mellonella*. A previous investigation showed that the scale patterns in *Galleria*[1] … are oriented by a concentration gradient of an unknown diffusible substance[3]. The substance seems to be produced at one margin of the segment and destroyed at the other[4] … To move the concentration gradient to some other part of the segment, pieces of skin were rotated in the larvae by 180° … The concentration gradient, the existence of which is confirmed by these results, obviously has two functions: (1) to orientate the scales by its direction, (2) to supply the cells … with necessary information about their distance from segment margins and to induce the corresponding cuticular structures.
From *Nature* 22 October 1966

100 Years Ago

The Psychology of Relaxation. By Prof. G. T. Patrick … In the author's view … forms of human behaviour are, at bottom, illustrative of a single principle. The activities and relations of civilised life imply the upbuilding and functioning of extremely complex mental mechanisms full of tensions, restraints, and inhibitions. To maintain these always in operation is an impossible task. From time to time, therefore, the complexes break up, and man falls back with relief into conduct expressive of simpler mental structures organised and consolidated in the far distant days of the race's childhood: he plays, he laughs, he swears, he fights.
From *Nature* 19 October 1916

CELL BIOLOGY

The organelle replication connection

Live-cell imaging reveals that a functional interaction occurs between two different organelles: contact between the endoplasmic reticulum and mitochondria is needed for mitochondrial DNA replication and division.

ELENA ZIVIANI & LUCA SCORRANO

The most fundamental difference between prokaryotic and eukaryotic cells is the presence of membrane-bounded organelles in eukaryotic cells. Organelles, such as mitochondria, chloroplasts and the endoplasmic reticulum, allow eukaryotic cells to form microenvironments in which biological processes can be spatially and temporally regulated[1]. The nuclear genome encodes most organellar proteins, although certain organelles, such as mitochondria and chloroplasts, contain some of their own genetic information. Coordination between the organellar genome and the nuclear genome is therefore required to ensure correct DNA content, DNA replication and protein translation. Writing in *Science*, Lewis *et al.*[2] investigate whether mitochondrial DNA is replicated at random or at specific locations within the cell, using a live-cell microscope-imaging approach to monitor mitochondrial DNA replication in human cells.

Organelles are enclosed by a lipid bilayer that forms their external boundary. The