error-sensing feedback loop. Feedback loops are notoriously difficult to build and tune; the art of doing so is a field of study in itself. A properly designed feedback loop must take into account the dynamics of the actuators as well as the dynamics of the laser itself[8]. Avoiding the use of a feedback loop therefore makes the feed-forward approach significantly simpler to implement.

Although the phase jitter measured by Koke *et al.* is impressively small — only 12 attoseconds — the scheme does face clear limitations. For example, the bandwidth over which corrections can be made is limited by propagation delays in the modulator crystal because the acoustic wave must travel from the transducer to the laser beam. This will probably limit the correction bandwidth to around 1 MHz. Nevertheless, it is fast enough to correct most technical fluctuations in the carrier–envelope phase.

Another issue with the feed-forward scheme is that it will only work if the offset frequency of the laser is within a limited range. There are two reasons for this limitation. The first is simply that AOMs have a finite modulation bandwidth. The second, and more fundamental, is that the angle of the deflected beam depends on the frequency of the acoustic wave. Thus, the position of the phase-stabilized beam will depend on the offset frequency of the laser, and if the offset frequency happens to be small, the deflected beam will overlap with the undeflected beam, which is used as an input to the f-to-$2f$ interferometer. Although it is fairly easy to adjust the offset frequency of the laser to bring it into the range in which the scheme works, the offset frequency typically exhibits slow drift on a timescale of minutes-to-hours. Thus, for this scheme to be useful, a feedback loop will probably still be needed. It could be a simple and slow loop, however, which would make it easy to implement.

The feed-forward scheme will probably be most useful to researchers in the fields of extreme nonlinear optics or attosecond science, in which pulses are required to have well-defined electric fields. Furthermore, because the exact timing of the pulses is not critical, neither is the repetition rate of the laser. On the other hand, optical frequency metrology and optical atomic clocks use the precise frequency combs produced by phase-stabilized lasers to measure optical frequencies, or to convert from optical to radiofrequencies. Because the frequency of individual comb lines is extremely sensitive to the repetition rate, these applications put more emphasis on controlling the line frequency than the offset frequency. Indeed, some comb-based approaches to metrology do not bother controlling the offset frequency at all, but instead only measure it. The scheme of Koke *et al.* corrects only the offset frequency and not the repetition rate, and thus using the comb for optical frequency metrology would still require a feedback loop. ❐

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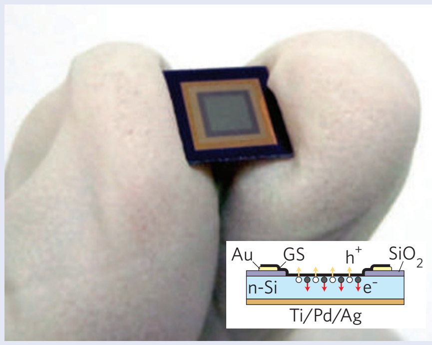
PHOTOVOLTAICS

Graphene–silicon solar cells

Graphene — a single layer of carbon atoms arranged in a honeycomb lattice — is already attracting interest for its various applications in electronics and optoelectronics, including its use as a transistor, photodetector and saturable absorber of light. It now seems that silicon photovoltaics may also benefit from this interesting material by exploiting it both as a semitransparent electrode and an antireflection coating.

Xinming Li and colleagues from Tsinghua University and Peking University in China have now reported a graphene-on-silicon solar cell with promising, albeit unoptimized, characteristics (*Adv. Mater.* doi: 10.1002/adma.200904383; 2010). In particular, their cell has an efficiency of ~1.65%, an open-circuit voltage of ~0.48 V, a short-circuit current density of ~6.5 mA and a fill factor of ~56% when measured under the well-known 'air mass 1.5 global illumination' conditions.

In essence, the team constructed a Schottky junction solar cell by depositing a graphene sheet (GS, pictured) onto an n-silicon wafer. First, the n-silicon wafer, covered with a 300-nm-thick SiO_2 layer, was patterned by photolithography and wet-etching of oxide to obtain a square window with a junction area of 0.1 cm^2. The backside electrical contact was formed from Ti/Pd/Ag deposited on the lower surface of the n-silicon wafer. The frontside contact consisted of small regions of Au sputtered onto the SiO_2, on top of which a graphene layer of thickness 10–100 nm was deposited, creating a conformal coating with the Au layer and the underlying n-silicon wafer.



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The researchers explain that in addition to its role as a semitransparent upper electrode and antireflection layer, graphene's intrinsic electric field properties aid electron–hole separation and hole transport. The built-in field helps guide photogenerated holes and electrons towards the graphene sheet and n-silicon, respectively.

Although the efficiency of their graphene-on-silicon solar cell is currently quite low, the researchers envisage that it can be improved by optimizing the conductivity and transparency of the graphene films used, and by using surface passivation of silicon to improve the graphene/n-silicon interface.

"This concept demonstrates a new class of photovoltaic device that has the merits of low cost and easy fabrication, leading to a new trend in the development of carbon-based solar cells," say the researchers.

RACHEL WON