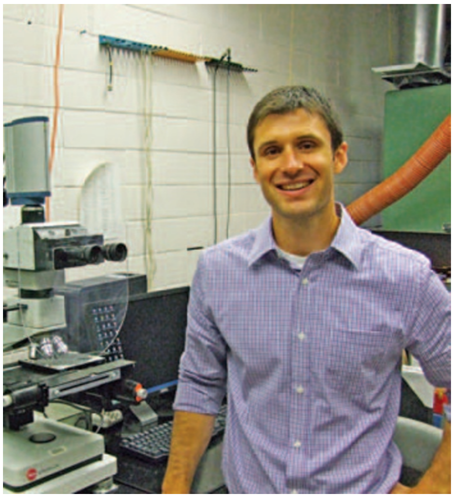
interview

Breaking free

Luminescent solar concentrators have long been hampered by reabsorption losses. *Nature Photonics* spoke to Noel Giebink about how to circumvent this effect.



ISRAEL RAMIREZ

Noel Giebink (pictured), Gary Wiederrecht and Michael Wasielewski have overcome previous concentration limits by exploiting 'resonance shifting' in luminescent solar collectors.

■ Why do we want to concentrate sunlight?

Sunlight reaches Earth at around a kilowatt per square metre, and as a society we require much higher power densities than this. In the context of photovoltaics, concentrating sunlight can reduce both material requirements and production costs because it allows the same amount of power to be generated from a smaller solar-cell area. Most people are familiar with geometric optical concentration using lenses and mirrors. For this technology, the level of achievable concentration is inversely proportional to the acceptance angle of the incoming light. If high concentration ratios are desired, this requires the Sun to be tracked as it moves across the sky. A rooftop-mounted lens or mirror that does not track the Sun is limited to a concentration ratio of around 5 Suns — meaning that the intensity of incident sunlight is increased by a factor of five — and that's probably being generous.

■ What about luminescent solar concentrators?

Luminescent solar concentrators (LSCs) were introduced around four decades ago as an alternative to conventional concentrators. The idea is that you have a slab of transparent material embedded with a fluorescent dye, or some other luminescent material, that absorbs the sunlight and then re-emits it, Stokes-shifted, at longer wavelengths. Around 75% of the re-emitted light is trapped by total internal reflection and guided towards the slab edges, where the solar cells are situated. Increasing the size of the slab allows more light to reach the edges, thus providing a concentrating effect. This type of concentration is fundamentally different from that of the conventional geometric optics approach because of the inherent downshift in photon energy. Although some energy is lost between absorption and re-emission, the downshift is what allows LSCs to avoid the limitation on acceptance angle and hence achieve high concentration ratios without tracking the Sun.

■ Why don't we see LSCs used in practice?

One of the reasons you don't see LSCs mounted on rooftops is that they compare poorly to other concentrator technologies. Although the thermodynamic limit predicts that LSCs can achieve concentration ratios in excess of 100 Suns — 20 times larger than you can get with lenses or mirrors without tracking the Sun — in practice you don't get anywhere near that. The best concentration ratio demonstrated for an LSC so far is around 10. One of the fundamental reasons for this discrepancy is the loss of photons due to reabsorption by the emitters. After the LSC has absorbed and re-emitted light (~75% of which is trapped by total internal reflection), there is a fairly high probability that it will be reabsorbed and then lost through various processes. The light can be lost to non-radiative recombination or it may escape the waveguide completely if re-emitted again. Photons can also escape the waveguide through material imperfections. Thus, increasing the size of the concentrator increases the chance of reabsorption or scattering out of the waveguide before the light reaches the edges, and this ultimately limits the achievable concentration ratio.

■ How do you get around these losses?

We use a technique that we call 'resonance shifting' to get around the reabsorption bottleneck. We start out with a leaky waveguide — a luminescent film separated from a glass substrate by a thin, low-refractive-index spacer layer. Light is emitted into discrete modes of the thin film, where it evanescently couples to the glass at corresponding sharply defined angles. By slowly varying the luminescent layer thickness across the concentrator, light returns after bouncing off the substrate bottom to find a new waveguide thickness with different modal resonances. Reabsorption is lower for non-resonant light than resonant light because the optical field decays through the spacer so that only its evanescent tail samples the luminescent layer. Essentially, we 'compress' the loss experienced at all angles into a single angular range while allowing the light to propagate at a different angular range.

■ What is the result of this approach?

The primary benefit of reducing reabsorption loss is that it allows the concentration ratio to increase continually with panel size. The light output from our resonance-shifting concentrator improved as we increased the slab dimensions, reaching a maximum improvement factor of approximately 2.4 in concentration ratio. It is not yet clear how far this technique can be pushed. There is still a lot of optimization to do, and it's not yet clear what the best resonance shifting strategy may be. Although our concentration ratio was still increasing even at the largest panel size, economics will certainly need to be considered at some point. For example, the glass itself becomes prohibitively expensive at large sizes. I think one of the main advantages of our approach is that it is simple and easy to produce, which is a key criterion for any innovation that aims to decrease the cost of solar power in a meaningful way.

INTERVIEW BY DAVID PILE

Noel Giebink, Gary Wiederrecht and Michael Wasielewski have an Article on resonance shifting in luminescent solar concentrators on page 694 of this issue.