On-Chip Optics Makes Continuous Visible Light from Low-Power Infrared

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If you shine a red laser pointer through a glass window you wouldn't expect it to come out blue on the other side, but with a much brighter beam it just might. At high intensities light energy tends to combine and redistribute, so that red light really can produce blue.

It normally takes a lot of power to boost light into this high-intensity realm. Yet two scientists at the California Institute of Technology have found a way to do more with less, producing a continuous beam of visible light from an infrared source with less than a milliwatt of power.

"Usually this is accomplished using very brief, concentrated bursts of light," says Kerry Vahala, the Ted and Ginger Jenkins Professor of Information Science and Technology and professor of applied physics at Caltech. "To be able to do this continuously and at power levels below a milliwatt is remarkable."

Although infrared light is invisible to human eyes, it is essential to modern telecommunications, flowing through millions of miles of optical fiber. Technology to produce, amplify, and otherwise manipulate near-infrared light is well developed and readily available.

Now, Vahala and Tal Carmon, a postdoctoral scholar in applied physics at Caltech, have linked that mature technology right into the center of the visible spectrum. Their work is basic research that could leverage an established technology for new uses. "When we developed this, we knew there were a number of potential applications," Vahala says.

Yet generating continuous visible light from infrared came as a pleasant surprise. Usually researchers in infrared optics can't directly see their results. This time, Carmon says, "I just turned off the lights and you could see the effect immediately."

At high intensities, light enters the regime of nonlinear optics. We usually notice nonlinearity when there gets to be enough of something to change its environment and rewrite the rules. For example, when a freeway is nearly empty and vehicles effectively have the road to themselves, traffic will behave the same way even with twice as many cars. The only difference is that the flow will double, which is a proportional, or linear, response. But once traffic nears peak capacity, the vehicles no longer act independently, and the flow becomes miserably nonlinear.

Similarly, light beams pass right through each other at the low intensities we typically encounter, because the photons that make up the beams can usually ignore the cross traffic. At high intensities, however, photons become much more likely to collide and reassemble into other photons. Picture three Mini Coopers in dense traffic coalescing into an SUV. The big vehicles of the photon world lie at the higher-energy or blue end of the spectrum, with lower-energy photons appearing as red or even infrared light.

Nonlinear optics usually requires brief megawatt intensities, analogous to flooding the freeway with a sudden burst of traffic, but the Caltech researchers employ a different strategy. They achieve their optical congestion from a much smaller flow, by diverting traffic into a tiny no-exit roundabout.

Their traffic circle is a miniscule glass donut, a microresonator smaller across than a human hair. It accumulates power so that a mere milliwatt of infrared light flowing outside the device can sustain an internal flow of 300 watts, an amplification of 300,000. Although infrared light is essentially trapped inside, energy can still escape as visible light, when three infrared photons combine into a single photon of tripled frequency: the third harmonic.

The two researchers describe this work in the Nature Physics article: "Visible Continuous Emission from a Silica Microphotonic Device by Third-Harmonic Generation."

"Our device has several important features," Vahala says. "First it triples the light frequency, and second, it works in a wide range of frequencies. This means full access to the entire visible spectrum, and likely ultraviolet. Right now there isn't a way of doing UV generation on a chip. Tunable ultraviolet-that's exciting." Coherent UV sources have applications in sensing and also data storage where, for example, wavelength determines the physical size of the information bit on a compact disk.

The microresonator is part of a promising approach for on-chip optical devices using the silica-on-silicon platform, which is compatible with the electronics of ordinary computer chips. Integrating optics and electronics on the same chip makes the device useful for lab-on-a-chip designs, and the ability to use established fabrication techniques makes large-scale, low-cost production possible.

Source: Caltech