Group develops technique to shape pulses of intense infrared light

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To capture fast-moving action in a dimly lit environment, a photographer will use the combination of a fast shutter speed and a quick burst of light.

Laser physicists employ the same principle – capturing a microscopic event of short duration by hitting it with a quick pulse of infrared light. Of course, while the action a photographer is trying to capture might last a hundredth of a second or two, the physicist's window of opportunity might last a few femtoseconds (quadrillionths of a second).

But in order to make a pulse of light short enough to capture what a physicist might want to see – say, the effect of light-induced vibration on a molecule in the retina – you need a light source that produces a broad range of frequencies. And a group led by Jeffrey Moses, assistant professor of applied and engineering physics, has developed a process for generating and shaping intense mid-infrared (mid-IR) pulses of light.

"We have the ability to create this very broadband source of mid-IR light that's intense, and we have the ability to precisely shape it," said Moses, whose group published a paper in *Nature Photonics*, "Generation and multi-octave shaping of mid-infrared intense single-cycle pulses," March 20.

Peter Krogen, Ph.D. '16, now a research associate at the Massachusetts Institute of Technology, is lead author. Other contributors included doctoral student Noah Flemens, a member of the Moses Group.

Mid-IR wavelengths are of particular importance to materials scientists, chemists, biologists and condensed-matter physicists. Recently, the advent of high-pulse-energy and ultrashort-duration mid-IR sources has ushered in a new range of nonlinear light–matter interactions, and establishing mid-IR sources that feature not only an extreme bandwidth, but also an arbitrary control of the pulse shape, is of great interest.

One method for analyzing short-duration phenomena is pump-probe spectroscopy. The first beam of laser light acts as the "pump," to generate a wanted reaction in a material, and the second is the "probe," used to analyze the reaction.

In order to create pulses of light short enough to capture these events, the light must contain a wide range of frequencies within the IR spectrum. "The more frequencies I have, the shorter a pulse I can make," Moses said.

The problem, however, is that in shaping the light for a specific purpose, you lose bandwidth. To overcome that problem, Moses and his group developed a way to create and shape a broadband, near-IR light pulse and change its "color" (wave frequency) to mid-IR while retaining its bandwidth and shape. In fact, the relative bandwidth of the near-IR wave – a measure of how short a pulse can be made compared to the smallest achievable duration at that color – is effectively increased when converted to a mid-IR wave.

The result: pulses lasting only a single cycle of the wave period, which is very close to the minimum allowed by nature.

"When we go through this process, we have bandwidth in the near-IR that's less than an octave," Moses said, "and we end up with bandwidth in the mid-IR that's more than an octave." In wavelengths, an octave is the spread between a frequency and twice that frequency.

One particular application of interest to the group is tracking the way electron energy flows in a system, such as human vision. Rhodopsin molecules in the retina absorb light and then change shape – from bent to straight – and it's this straightening that serves to send a signal through the optic nerve to the brain.

"The change in the electronic configuration of these molecules happens over tens of femtoseconds," Moses said. "We think we have the right source of light here to gain a lot more information about what's going on during that ultrashort time period."

And what can that information tell a scientist? For one thing, that process is very efficient in humans, but there are other similar biological processes – which theorists believe are regulated by a similar type of structure – that are highly inefficient.

"Using this tool, we're trying to develop a method for studying this sort of class of structures that is responsible for the way molecules respond to light," Moses said. "This could help us understand something that we're fabricating and help us make it do whatever it does more efficiently."

More information: Peter Krogen et al. Generation and multi-octave shaping of mid-infrared intense single-cycle pulses, *Nature Photonics* (2017). DOI: 10.1038/nphoton.2017.34

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