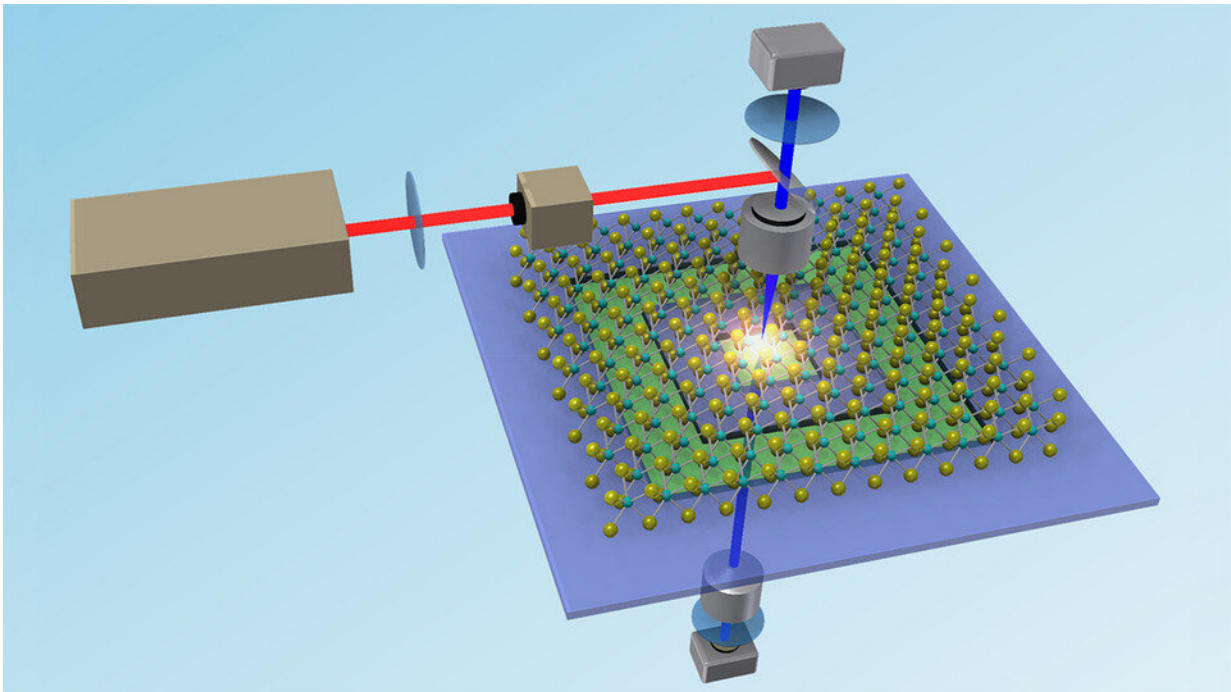


'Strange effect' raises possibility of smaller, smarter optical filters

April 29 2020, by Scott Schrage



A rendering of the experimental setup used by Nebraska's Xia Hong and her colleagues. Light is reflected down to the nanostructure of molybdenum disulfide (yellow and teal lattice) and PZT (blue and green). Wavelengths reflecting from the surface are captured by the top detector as transmitted wavelengths pass through the PZT to the bottom detector. Credit: Xi Huang / Dawei Li

Polarization, in sync. On the macro, everyday level, it reads as an

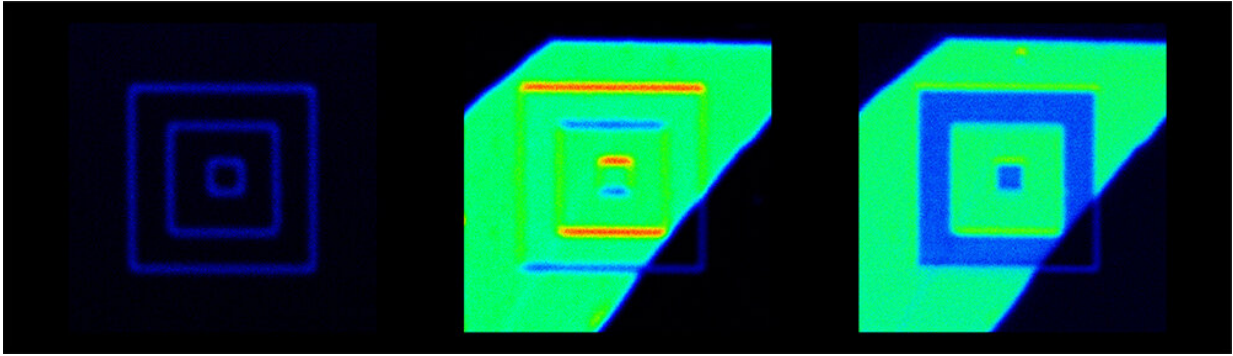
oxymoron. To the University of Nebraska–Lincoln's Xia Hong and her fellow nanoscientists, though, the apparent contradiction makes a kind of harmonious sense. And it might just spur the development of smaller, more versatile optical filters that are especially adept at playing with a trick of the light.

That trick occurs when two packets, or photons, of [light](#) strike a material and eject another photon—one with double the energy and half the wavelength—from the material. Because wavelengths differ across the electromagnetic spectrum, the phenomenon can transform incoming infrared waves into waves of blue light, for instance, or that visible light into ultraviolet.

But not just any material can pull off the trick, known as second-harmonic generation. One material that can: an atom-thin layer of molybdenum disulfide. Hong has spent several years exploring the phenomena that emerge from pairing molybdenum disulfide with so-called ferroelectric materials, whose alignment of positive and negative charges will flip when exposed to an electric field.

Last year, she and her colleagues were studying how the optical behavior of single-layer molybdenum disulfide responded when it was placed atop a ferroelectric material called lead zirconate titanate, or PZT.

"We weren't expecting much," said Hong, associate professor of physics and astronomy, "but we saw this very, very strange effect."



Light signals reflected from PZT (left), reflected from the molybdenum disulfide-PZT nanostructure (center), and transmitted through the nanostructure (right). The center image, taken without filtering for polarized light, illustrates the alternated boosting (red) and dampening (blue) of second-harmonic generation at the PZT domain walls. Credit: Nature Communications / Springer Nature

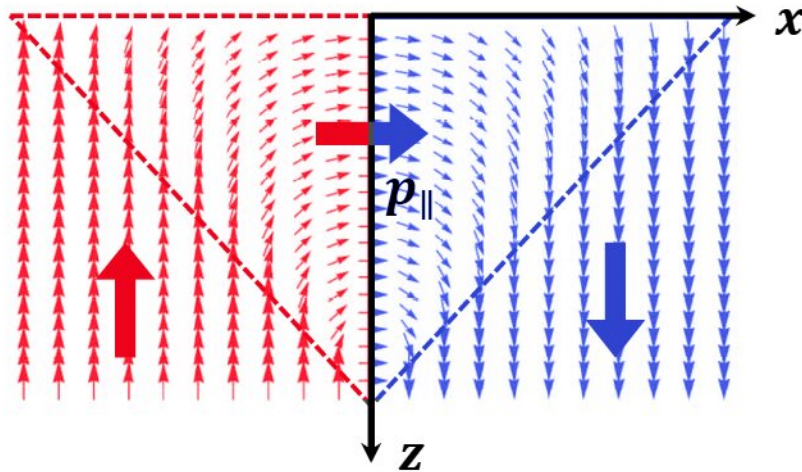
Instead of observing second-harmonic generation uniformly across the surface, the team noticed that certain segments were boosting the phenomenon even as others dampened it. The researchers also realized that the unexpected pattern emerged at the PZT's domain walls, where a section with positive [polarization](#)—upward-facing positive charges separated from downward-facing negative charges—met a section with negative polarization. Not only that: The intensity of the reflected second-harmonic generation alternated by wall, so that the first, third and fifth wall boosted it while the second, fourth and sixth were dampening it.

Given that the pattern was missing in either material alone, the researchers figured it must originate from some interaction of the two. On closer inspection, they discovered that vortex-like swirls of the positive and [negative charges](#) at the top of the PZT walls—similar to the tornadic rotation that can occur when warm and cool air converge—were contributing to the effect.

When that rotation matched the polarization of the overlying [molybdenum disulfide](#), so that the former swirled clockwise as the latter was aligned left to right, or vice versa, the reflected second-harmonic signal nearly quadrupled in intensity. When those polarizations ran counter to one another, the reflected signal virtually disappeared.

The polarization of the incoming light mattered, too. An electric field surrounding a ray of unpolarized light, such as that coming from the sun, will haphazardly jut out in all directions. The [electric field](#) of polarized light, by contrast, will stick to one plane—vertical, horizontal—or rotate around the ray in a predictable, cyclical way. Though incoming light that was polarized at certain angles did produce a clear second-harmonic pattern upon reflecting, the signals disappeared when the team adjusted the light's polarization to other angles.

As for the wavelengths that passed through the nanostructure, rather than reflecting from it? The team found an intensification-mitigation pattern for those, too. Rather than depending on the match or mismatch of polarization between the materials, though, the second-harmonic generation responded to the polarization of the PZT patches alone. When light was polarized at certain angles, the PZT patches with positive polarization boosted the signal, whereas the negatively polarized patches dampened it. And adjusting the light's polarization could reverse the relative strengths of those signals.



Credit: Nature Communications

Hong said the nanostructure's sensitivity to polarized light, combined with the ability to flip the PZT's polarization either electrically or mechanically, makes for something unusual: an optical filter that could be programmed and reprogrammed in a matter of seconds.

"It's nanoscale, and it can be controlled," Hong said. "So you could say this is a smarter way of filtering, because you can reconfigure it. It's not a done deal. I can write the polarization like this, I can erase it, (then) I can write it in a different way.

"I think the key is really that it's a very simple technique."

The technique's versatility could prove useful in quickly characterizing materials or substances, Hong said, especially the properties that influence second-harmonic generation or dictate responses to the polarization of light. Though the technique isn't really suited to the routine, macro-level applications of polarized filtering—"This is clearly

not something to make your polarized glasses with," she said—Hong did muse about a related possibility.

"If you wanted to make a 3-D movie at the microscale," she ventured with a smile, "this is probably the way to do it."

Hong and her colleagues reported their findings in the journal *Nature Communications*.

More information: Dawei Li et al. Polar coupling enabled nonlinear optical filtering at MoS₂/ferroelectric heterointerfaces, *Nature Communications* (2020). [DOI: 10.1038/s41467-020-15191-2](https://doi.org/10.1038/s41467-020-15191-2)

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