Breakthrough curved sensor could dramatically improve image quality captured with digital cameras

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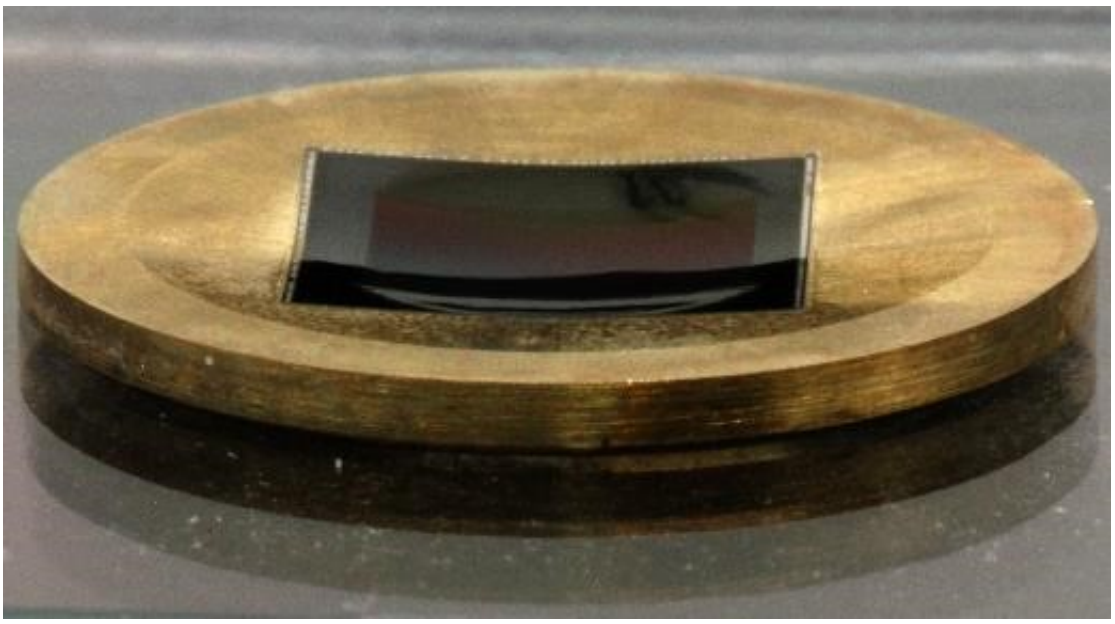

Researchers developed a way to create spherically curved image sensors by three-dimensionally bending off-the-shelf image sensors. When incorporated into prototype cameras, the curved sensors produced greatly improved image quality compared to high-end commercial cameras. Credit: Microsoft Research

If you've ever tried to take a picture in a dark restaurant, you know that it is difficult to get a clear, quality image. In the future, cameras might not struggle under these conditions thanks to a newly developed method for spherically curving the flat image sensors found in today's digital

cameras.

"Our approach to curving commercially available image sensors could make it possible to have a new class of camera that would be very small, but have image quality that would be comparable to image sensors found in much larger cameras," said Brian Guenter, leader of the Microsoft Research team. "In addition to improving consumer cameras, curved sensors could be used to create better cameras for surveillance, head-mounted displays and advancements in autonomous vehicle navigation.

Most of today's cameras use lenses made of multiple optical elements that correct for various optical errors, or aberrations, and that also manipulate the image so that it can be detected by a flat sensor. Using a curved, rather than flat, image sensor means the optical elements have to do less work to correct and flatten the image, making it possible to use fewer optical elements. This not only translates to smaller, faster and less expensive lenses but also makes it easier to improve other properties of the optical components.

"When using curved sensors, it is possible to correct aberrations in a much more efficient way, making it easier to create very wide angle lenses that produce sharp images across the entire field of view or to create fast lenses that produce better images in low light," said Neel Joshi, a member of the research team. "It is also more straightforward to make cameras that exhibit uniform illumination across the entire image."

In The Optical Society journal *Optics Express*, researchers from Microsoft Research and research-and-development laboratory HRL Laboratories LLC, report that their new method can create image sensors with three times more spherical curvature than reported previously. They have been able to incorporate one of the sensors into a prototype camera. Compared to today's high-end commercial single-lens reflex camera (SLR) cameras, the camera with the new sensor produced

higher resolution images across the entire field of view.

"Although the benefits of using curved sensors have been known for some time, our work now makes it practical to create cameras with curved sensors," said Richard Stoakley, a member of the research team. "Adding spherical curvature to an off-the-shelf image sensor can be done for a reasonable cost and in a way that shows significant benefits."

Creating the ideal camera

The new approach for creating curved sensors grew out of a question the researchers asked themselves about seven years ago: "What would an ideal camera be like?" They decided such a camera would take pictures under very low light, be very small, and produce extremely sharp pictures.

"At the time, it wasn't possible to make a camera like that," said Guenter. "We thought that if we could improve a camera's optics by creating a faster lens, we could potentially use a smaller sensor while still gathering enough light to get a good picture. That motivated us to begin investigating curved sensors as a way to potentially achieve breakthrough performance."

To make curved sensors, the researchers placed individual sensors cut from a thinned CMOS image-sensor wafer into custom-made molds and then used pneumatic pressure to push each sensor down into the mold. Other attempts at curving a sensor have typically involved gluing the edges down and trying to push on the center of the sensor. However, this creates points of high stress that cause the sensor to shatter before it reaches the target level of curvature.

The researchers coaxed significantly more curvature out of the sensors by letting them float freely during the bending process, which allowed

stresses to dissipate gradually. They also used a specially shaped mold that very slowly builds stress around the chip's edges as it is pressed into the mold. Microsoft contracted HRL Laboratories, which has semiconductor fabrication capabilities and equipment, to help solve some of the specific physics challenges involved in bending the sensors.

"This work involved extensive amounts of experimentation," said Joshi. "Every single surface involved has to be carefully treated to exhibit the exact properties necessary for the sensor to end up with the right amount of stress without breaking."

Tests showed that curving the sensors did not change any of their electrical or imaging characteristics. When used in a prototype camera with a specially designed f/1.2 lens, a curved sensor exhibited a resolution more than double that of a high-end SLR camera with a similar lens. Toward the edges of the image, the curved sensor was about five times sharper than the SLR camera.

Although most cameras exhibit decreased light detection around the corners of the imaging sensor, the researchers showed that the curved sensors lost almost no light. This was a significant improvement compared to the decrease of around 90 percent measured for the commercial SLR camera.

"We showed that you can take an off-the-shelf sensor, curve it and dramatically improve the performance of the optical system," said Guenter. "This can be done with relatively low costs and effectively no downside."

Curved sensors for mobile phones

Although the prototype camera reported in the paper is about the size of a small consumer camera, the researchers say that the lenses could be

made small enough for mobile phones and tablets. It should also be possible to build machines that could mass produce these curved sensors, allowing the additional processing to be incorporated into existing sensor manufacturing in a way that would amortize well in volume production.

The researchers are now working to see if further improvements might produce sensors with even more curvature. They also want to experiment with curving sensors that operate in infrared wavelengths, which could be useful for telescopes, 3D spatial mapping, biometric authentication and various scientific applications. Although they caution that it is unlikely that commercial products featuring the curved sensors will be available soon, they are interested in working with other companies to further improve the sensors and to perform the strenuous robustness testing that would be needed to prepare for mass production.

"I think we have opened the door for an entirely new class of lenses," said Stoakley. "I'm excited to see how our group and others use curved sensors to achieve even more improvements in camera quality through innovative lens design."

More information: Brian Guenter et al, Highly curved image sensors: a practical approach for improved optical performance, *Optics Express* (2017). DOI: 10.1364/OE.25.013010

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