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Microscopic glass blowing used to make tiny optical lenses

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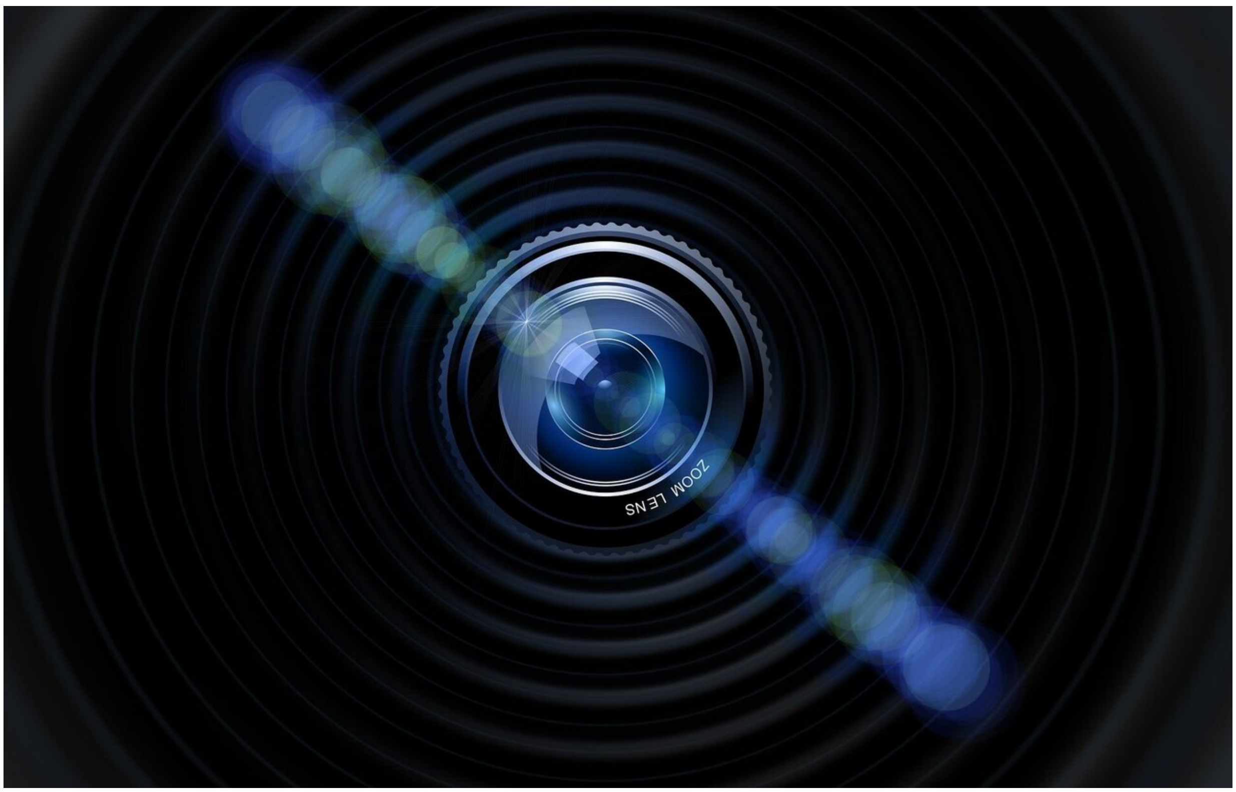

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Inserting air into hot glass to form a bubble has been used to make glass objects since Roman times. In new work, researchers apply these same glass blowing principles on a microscopic scale to make specialized miniature cone-shaped lenses known as axicons.

Axicons are used to shape laser light in a way that is beneficial for optical drilling, imaging and creating optical traps for manipulating particles or cells. These lenses have been known for more than 60 years, but their fabrication, especially when small, is not easy.

"Our technique has the potential of producing robust miniature axicons in glass at a low cost, which could be used in miniaturized imaging systems for biomedical imaging applications, such as optical coherence tomography, or OCT," said research team member Nicolas Passilly from FEMTO-ST Institute in France.

In The Optical Society (OSA) journal *Optics Letters*, the researchers describe the new fabrication approach, which is based on the same processes used to make large numbers of photonic and electronic circuits in parallel on semiconductor wafers. The researchers used their approach to create glass axicons with diameters of 0.9 and 1.8 millimeters and showed that they successfully generated Bessel beams.

"Wafer-level microfabrication allows the axicons to be integrated into more complex microsystems created also at a wafer-level, leading to a system made of a wafer stack," said Passilly. "This type of integration comes with better optical alignments, high performance vacuum packaging and much lower-costs for the final systems because a large number can be processed simultaneously."

Creating a microlens

When used with a laser, axicons create a beam of light that begins as a Bessel-like beam—a non-diffracting beam with maximum intensity on its axis—and then turns into a hollow beam further away from the axicon. Bessel-like beams feature a depth of field that can be orders of magnitude larger than that of a beam focused by a traditional rounded lens with a similar diameter. The beam's high depth of field allows optical drills to reach deeper and creates higher quality OCT images. For optical tweezers, both the Bessel-like and hollow portions of the beam can be used to trap particles or cells.

Techniques traditionally used to make glass axicons can produce only one lens at a time. Although less expensive axicons can be made in polymer, these can't withstand high temperature processes such as wafer-level fabrication or be used in applications that require high levels of light power.

"Polymer axicons can't be used in optical drilling, for example, because the instantaneous light power is comparable to the power of a nuclear plant but with an extremely short duration," said Passilly.

Micro glass blowing has been previously used to make microlenses, but it usually involves gas expansion from a single reservoir. The researchers developed an axicon fabrication method that combines gas expansion from multiple reservoirs to produce the optical component's conical shape. The technique shapes the surface from underneath leaving a high-quality optical surface, unlike commonly used methods like etching transfer from a 3-D mask that engrave the wafer from above.

To carry out the new micro glass blowing method, the researchers deposited silicon cavities in concentric rings that were then sealed with glass under atmospheric pressure. Placing the silicon and glass stack in a furnace caused gas trapped in the cavities to expand, creating ring-shaped bubbles. These bubbles pushed out the glass surface to form cone shapes and then the opposite side was polished away to leave only the shaped lenses.

"Although all the processes we used are standard for microfabrication, we applied these techniques in non-standard ways to make miniature glass axicons," said Passilly. "The technique could be applied to create other shapes, even ones without cylindrical symmetry."

More information: José Vicente Carrión et al, Microfabrication of axicons by glass blowing at a wafer-level, *Optics Letters* (2019). DOI: 10.1364/OL.44.003282

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