https://doi.org/10.1038/s41566-022-01102-y

Metaoptics for the consumer market

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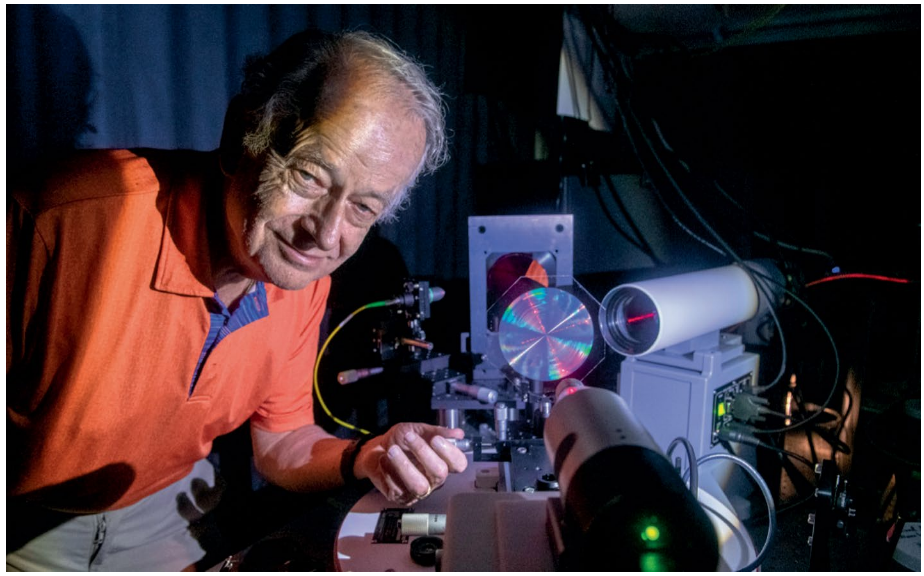
Metalenz, a spin-out company from Harvard University founded in 2016, has launched its first metasurface-based product. *Nature Photonics* spoke with co-founder Federico Capasso about the company and its plans for flat optics.



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Can you tell us about how Metalenz was born?

Once, my great friend Professor Jim Anderson [Professor of Atmospheric Chemistry at Harvard] asked me: "Federico, I want to put your QCLs [quantum cascade lasers] on a drone, but can you get rid of the lens?" That honestly sounded to me like a crazy question. But then it seeded, and later led to what is, in a sense, a flat lens that we used to collimate a QCL. In fact, it's a like a contact lens for a laser. The next step was our paper on the generalized laws of reflection and refraction. At that point, we realized that we could essentially make a [metasurface] lens. We did it with plasmonics first, so it was inefficient, but we showed that we could get diffraction-limited performance. That was very exciting. We then moved to dielectrics and realized that lithography could be used to make both the electronics and the optics. That's when we decided to push ahead because it could be a game changer. We needed to start an actual company. Of course, this was done initially with EBL [electron beam lithography], but that didn't stop us from starting the company. In the meantime, we demonstrated fabrication of cm-scale lenses with DUV [deep-ultraviolet] stepper lithography, which should afford high-volume manufacturing. We realized that we could utilize an existing tech platform, the major semiconductor foundries, to make both optics and electronics. This is really the vision that drove us initially, then Metalenz developed rapidly. In six years, we went from first demo to starting a company for high-volume applications.

What are the key drivers for flattening optical elements?

One of the key drivers is that the existing platform of semiconductor technology allows you to stack the optics on top of the electronics, so you can make things thinner and reduce the form factor. This is a geometrical argument that eventually leads to lower costs. But there are also fundamental aspects. Take a camera. You can ask why there are so many lenses. The wavefront that typically comes out from a lens has field curvature, while the sensor is flat, so you introduce an aberration. You can make a metalens telecentric, meaning that the transmitted intensity is almost uniform up to the edges of the image so that you can match the flatness of the CMOS sensor with the far field of the metalens. This gives you an advantage in signal-to-noise ratio because you don't need too much power to see up to edges, as you normally do with refractive lenses. With a single lens, as opposed to typically 4–5 plastic lenses needed in a camera module, you can correct all the key aberrations, except for the chromatic one.

Multifunctionality is another powerful aspect of metaoptics, and I have two meanings of multifunctionality. One is that you can replace many components, the other one is that metasurfaces provide you with control knobs for the polarization, the incident angle, and the wavelength. By using these knobs, you can create entirely different functions while, in some cases, replace a whole battery of lenses with a single flat one.

What flagship products is Metalenz currently developing?

One of the largest applications that Metalenz is targeting is 3D sensing. Essentially, you create many dots of light and reflect them off a scene. By looking either in the time domain or by using structured light, you can sense the object and get information on depth, distance and shape. Conventional front-facing dot pattern projectors consist of an array of VCSELs [vertical cavity surface emitting lasers] and relatively complex refractive optics. In Metalenz's Orion project, you also have a VCSEL array, but then use a single metalens with an aperture. That's a dramatic simplification. A traditional world-facing [rear] camera for depth sensing is even more complex but has lots of applications in AR/VR [augmented reality/virtual reality] or automotive, a fantastic new market.

We have also recently announced another product line, PolarEyes, which is based on a new polarization-sensitive camera demonstrated in my group. The camera uses a single metasurface to replace the huge complexity of current polarization-sensitive cameras. Traditional polarization cameras are non-existent as consumer products because they are incredibly complicated. You have to analyse Stokes parameters, so you need to do amplitude or time division. With flat optics, we can use a single metasurface as a lens and a polarization sensor. If you see images in polarized light, you see a level of detail that you simply cannot see with conventional imaging. Polarization could be important for machine vision,

Volume 17 | January 2023 | 6–7 | 6

for inspection of materials or in autonomous vehicles to look at the state of the road, for instance. In fact, we have another platform, Gemini, which allows to interrogate the scene with multiple polarizations. These are very interesting functionalities that are not easy, if not impossible, to implement with conventional refractive or diffractive optics.

Can you tell us about the recent partnership with STMicroelectronics?
Companies, such as smartphone developers, use ToF [time of flight] systems in world-facing cameras to create a 3D map of the environment. Since the ToF system is active for a significant amount of time, it reduces battery life. Metaoptics improve ToF signal-to-noise ratio, which can allow the system to maintain the same resolution with lower power from the transmitter. The partnership with STMicroelectronics is about ToF modules made by them and including our metaoptics, essentially for world-facing cameras. The application space for these modules is pretty vast: mobiles for depth sensing, AR/VR, health and wellness, even shopping applications in the future; essentially anything that requires 3D mapping of the environment. I think this is going to be very significant. In just the first year there are going to be millions of these ToF modules in the actual market, which is very encouraging to say the least. Given that Metalenz is fabless and we use existing platforms, this is an important cornerstone. With STM, we are talking about some of the world's biggest foundries as it's a major company that also shared our vision from the beginning.

What are some of the challenges faced by the company in its journey to market?
Initially, it was not obvious what potential applications were. It's tempting to say we would like to have a broadband lens that is achromatic and so forth. However, it took us about one year to realize that, thinking of the market, we needed to move to applications where broadband operation is not required. It turns out there are huge markets in the areas of sensing that require only a single wavelength, and this is how the front-facing camera, the ORION product, came out. Then, as a start-up, we are aware that most start-ups go through the so-called valley of death, where they get near extinction. I don't think we went that close, but we were really stuck at some point. We had a leadership problem and managed to switch the CEO. Leadership is important, and I do believe that, in the end, people make the difference, which means vision and ability to get a team. Too often, we tend to overlook this.

Do you believe there is space for co-existence between metaoptics and traditional optics?
Sure, there is. Sometimes people ask me a question which is a good one, but also naïve: can you do as well as refractive optics? Let me tell you something: metaoptics wins hand over fist over diffractive optical elements. However, it depends on the size, and the application tells me what performance I need. People also often ask if we can make large metalenses. We are working towards larger-area [metalenses], but it's not clear what we are mainly targeting yet, so that's an area that will continue to be dominated for a while by refractive optics. Then, although I'm not enough of an expert, I think there may be some significant applications in microscopy. In OCT [optical coherence tomography] for example, we can really look inside tissue with metalenses. I think the medical application will be a specialty frontier. Overall, metaoptics will certainly capture large markets, but not all of them. There will be peaceful co-existence between refractive optics and metaoptics.

What are the outstanding challenges for metalenses?
One challenge is to make a broadband achromatic lens, basically to correct chromatic aberrations over a broad spectral range. In particular, the difficulty in making an achromatic broadband lens is the size, so you have to work around it. Applications have been in the making, but it's not a high-volume market yet. For instance, one application for polychromatic metalenses is AR/VR, where you typically look at 3 narrow bands in the blue, green and red, and you want to have the same focal length. So the broadband aspect is definitely a challenge. When we embark on a new technology for new applications we have to ask whether there are showstoppers from the point of view of physics. I do not see showstoppers for metaoptics except if you want to really go large area and achromatic. However, look at refractive optics. It can do broadband, but at a price. You need multiple different glasses or different plastics with different shapes. At the end of the day, you also need to look at the financial side. You can have a very clever solution, even with high performance. But to trade-off cost and performance you better have an extraordinary performance to justify a significantly higher cost.

Where do you see metalenses in ten years?
I think a big area for the future is free-form optics. Free-form optics is now niche. We can essentially make metasurfaces that have the functionality of free-form optics. This is still research, but I am confident we are going to see a lot of applications. The other big area is arbitrary wavefront engineering. Metasurfaces can do vectorial wavefront shaping, and the ultimate frontier is the engineering of singularities of light. We are now asking a very general question: can we generalize singularities [of vortex beams] and make a singular sheet of light? A sheet of light with zero intensity and of arbitrary shape, with undetermined phase. We can make structured light, but also structured dark, and structured dark is not subject to the diffraction limit. I also want to say something about the impact of design. I think that the future is going to be co-design of hardware and software, they're going to work together for new imaging systems. This is still research, but I believe that things will move faster than we would normally expect because we are using a huge technology platform that is already there, the semiconductor foundry. Metasurfaces will have a huge impact and finally they will bring the promises of metamaterials to the real world. Metasurfaces will make it, they are already making it.

Interviewed by Giampaolo Pitruzzello

Published online: 22 December 2022