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Metasurfaces go mainstream

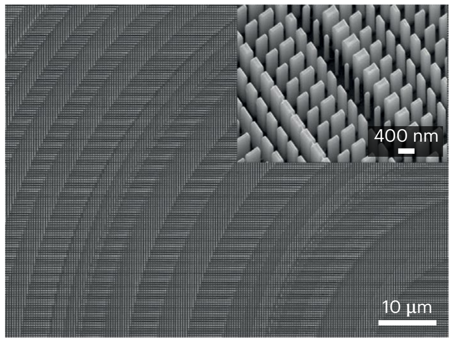
Early research towards bulk metamaterials and exotic properties has been supplanted by work on thin metasurfaces ripe for commercialization, as outlined in this Focus issue.

Researchers often define metamaterials as manmade composite or structured media that exhibit properties that are not naturally available, such as negative refraction. However, 'unnatural' properties are not a requirement for a media to be a metamaterial. Now, metamaterials with less exotic optical property values, tailored into devices to achieve the functionality of optical components in a compact format, or with new or superior capability, is arguably proving more useful than exotic effects.

Subwavelength structuring of materials for engineered wave propagation characteristics is not a new concept. In 1948 Winston Kock, while working at Bell Laboratories, introduced the concept 'artificial dielectrics' for microwaves. He used arrays of subwavelength metallic fins, or balls with thin conducting coatings and the work included equations for the effective refractive index. Various lens types were demonstrated and in 1949 Kock and Harvey showed that the idea worked in acoustics too; in 1954, loudspeaker manufacturer JBL commercialized acoustic lenses. Even today, artificial dielectrics made from subwavelength metal fins are again a topic of research, for example for THz lenses.

However, it was the 1967 'negative index' work by Victor Veselago, and subsequent works decades later by Sir John Pendry and others on 'perfect lenses' and 'invisibility cloaks', that fertilized the field we now know as metamaterials. Early works confirmed the predicted effects such as negative refraction, but the metamaterials field seemed hampered by the difficulty of fabricating many layers of resonators on top of each other to create bulk three-dimensional (3D) metamaterials. The inherent losses related to propagation through thick metamaterials, which typically contain dissipative metals, also didn't help.

But do we always need bulk 3D metamaterials to achieve useful functionality? No. The strength of interaction of electromagnetic waves with a single subwavelength-thickness layer of resonators can be strong; enough for beam steering, lensing and similar applications with a single metamaterial layer, or 'metasurface'. The difficulty in fabricating bulk metamaterials actually steered the field to fruitful territory, and the desirability of ultra-thin optical components, often called flat optics, is undeniable. This issue of *Nature Photonics* is a Focus issue on metasurfaces.



While it's true that metasurfaces have been 'on the block' for some time, there is a now impetus towards commercialization. Can metasurfaces 'make it' against conventional options and tradition? Geoffroy Lerosey, co-founder and CSO of Greenerwave – a company that makes energy-efficient smart metasurfaces – believes that the answer is yes (see the Focus issue for a Q&A with Lerosey by David Pile). Greenerwave is now partnered with an automotive company to have reconfigurable metasurface-enabled RFID technology in vehicles in 2023. In early 2024 they hope to have a satellite communications antenna on the market. They also announced a radar system being developed with Plastic Omnium as well as millimetre-wave technology in co-operation with Japanese companies AGC and NTT Docomo. All of these products are underpinned by energy-efficient reconfigurable metasurfaces. In a Review Article in the Focus issue, Tian Gu, Hyun Jung Kim, Clara Rivero-Baleine and Juejun Hu review reconfigurable metasurfaces and highlight the possibilities for spaceborne remote sensing, active beam steering and light field displays.

The cost of fabrication may be crucial to the commercial success of metasurfaces. George Palikaras – President and CEO of Meta Materials Inc., a Nasdaq-listed company – explains in a Q&A with David Pile in this Focus issue that they can make materials "at the scale of kilometres in length, and single-digit dollars per square metre, with tens-of-nanometres accuracy". The company has also announced a large contract with a G10 central bank to produce security features for bank notes. In the interview Palikaras explains their plans from aerospace and automotive to healthcare, with frequency regimes ranging from microwave to optical.

One of the most exciting applications of metasurfaces is that of thin, compact metasurface-based lenses, or 'metalenses'. Recently Metalenz – a Harvard spin-out company – announced a partnership with STMicroelectronics for fabrication of metasurface-based time-of-flight modules for cameras in consumer electronics; see the Q&A by Giampaolo Pitruzzello with Metalenz co-founder Federico Capasso in this Focus issue. The company already has product lines aimed at applications from 3D sensing to polarization-sensitive cameras.

In a Review Article in this Focus issue Amir Arbabi and Andrei Faraon review the capabilities of metalenses, including their multi-functionality and their ability to efficiently focus light tightly. They also provide some perspective on outstanding challenges as well as the key application areas for metalenses.

We also have a Review Article in this Focus issue from Dragomir Neshev and Andrey Miroshnichenko on smart vision enabled by metasurfaces. Today many devices, including robotic systems, rely on vision to operate. This review outlines the frontiers of the application of metasurfaces, and their promise of multiple optical functionalities, to the challenges of smart-vision-enabled systems.

While the commercialization of metasurfaces is central to the content in this Focus issue, there are still physical effects to be fully harnessed. Nonlocal effects are such an example; by 'nonlocal' we mean that the field at a given point depends not only on the local properties at that point, but also on the field's value at points nearby. This results in spatial dispersion; the permittivity depends on wavevector. In a Review Article in this Focus issue Kunal Shastri and Francesco Monticone explain that nonlocal effects are not a mere technical nuisance in the context of metasurfaces, but an emerging field of interest. Nonlocality can in fact enrich metasurface responses and provide new opportunities.

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