Mathematics at the speed of light

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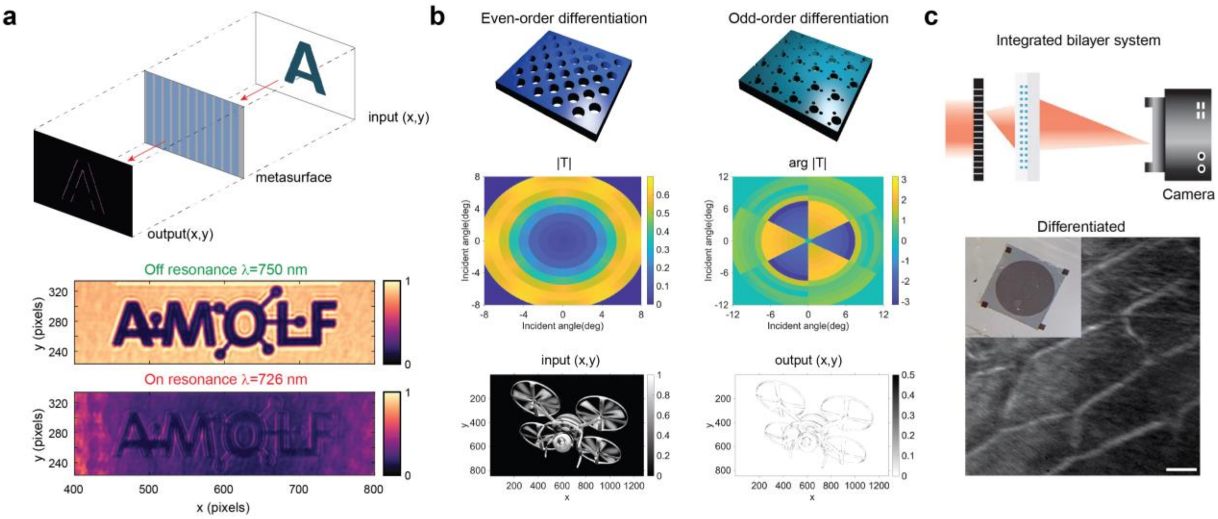
The advent of new technologies, such as augmented reality, autonomous driving, and many other emerging techniques, requires on-the-fly processing of large data files, such as images, at an increasing rate. Image processing is usually performed digitally but the speed and power consumption limits of standard microelectronic components have become a true bottleneck. The unprecedented control of light propagation over a subwavelength thickness that has been recently enabled by optical metasurfaces opens entirely new opportunities for analog optical computing. In fact, *computing metasurfaces* may benefit from the speed and low power consumption in optics while being amenable to on-chip integration, thus enabling hybrid optical and electronic data processing on a single chip.

In recent studies [1,2], we introduced dielectric metasurfaces that perform optical image edge detection in the analog domain using a subwavelength geometry that can be readily integrated with detectors. The metasurface is composed of a suitably engineered array of nanostructures designed to perform either 1st- or 2nd-order spatial differentiation. To do so, Fano resonances are used to engineer the metasurface's nonlocality and hence tailor its angular response in order to implement a linear mathematical operation of choice. This particular transmission response is due to the interference between a broad Fabry-Perot resonance determined by the thickness of the structure and sharper quasi-guided resonances that can be launched along the surface. Furthermore, it is possible to extend these concepts to two-dimensional operations (e.g. Laplacian and 1st order directional derivative), and for unpolarized incoming signals, by exploiting highly rotationally symmetric lattices. Finally, a monolithic 2D design that includes also the imaging system as a metalens has been experimentally demonstrated[3].

These results pave the way to exciting opportunities for hybrid optical and electronic computing systems that operate at low cost, low power, and can be directly integrated on chip.



a. Top: conceptual schematic of optical computing metasurface. Bottom: experimental second-order image differentiation. Optical microscopy image of the metasurface output for resonant (λ = 726 nm) and off-resonant (λ = 750 nm) illumination.

b. Top: schematic view of the metasurfaces for the even- and odd-order differential operations. Middle: Transmission amplitude and phase for the metasurfaces performing two-dimensional 2^{nd} (left) and 1^{st} (right) order differentiation respectively. Bottom: output after the 1^{st} order differentiator (right) for the input in the left panel

c. Top: Schematic of the imaging set-up. Bottom: Imaging results for differentiated onion cells. The scale bar is 50 µm. Inset: Optical images of the nanophotonic differentiator. Readapted from Ref.[3]

1. A. Cordaro, et al. Nano Letters 2019 19 (12), 8418-8423 (2019)
2. H. Kwon et al. ACS Photonics (2020)
3. Y. Zhou et al. Nat. Photonics 14, 316–323 (2020).