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Multifunctional And Nonlocal Metasurfaces For Optical Signal Processing

PRANJALI GAWAI[1]

SANTOSH WAGHMARE2

HEMANT KAMBLE3

Student ,department of pharmaceutical chemistry ,loknete shri. dadapatil pharate college of pharmacy ,mandavgan pharata ,shirur,pune,maharashtra[1]

Professor ,department of pharmacy , loknete shri. dadapatil pharate college of pharmacy , mandavgan pharata , shirur,pune,maharashtra[2]

Principal, department of pharmacy , loknete shri. dadapatil pharate college of pharmacy , mandavgan pharata , shirur,pune,maharashtra[3]

Abstract : In order to get around the speed and energy constraints of digital techniques, optical analogue signal processing has been receiving a lot of attention. Metasurfaces, which effectively manipulate optical signals spanning deeply subwavelength volumes, present a possible path towards achieving this objective. For beam steering, focusing, or holography, for example, where angular-dependent responses or nonlocality are undesirable properties that must be avoided or mitigated, metasurfaces have been proposed to convert spatial signals. Here, we demonstrate that signal manipulation in the momentum domain over an ultrathin platform is possible by engineering the metasurface nonlocality. In order to develop quick and power-effective ultrathin devices for edge detection and optical image processing, we investigate nonlocal metasurfaces performing fundamental mathematical operations.

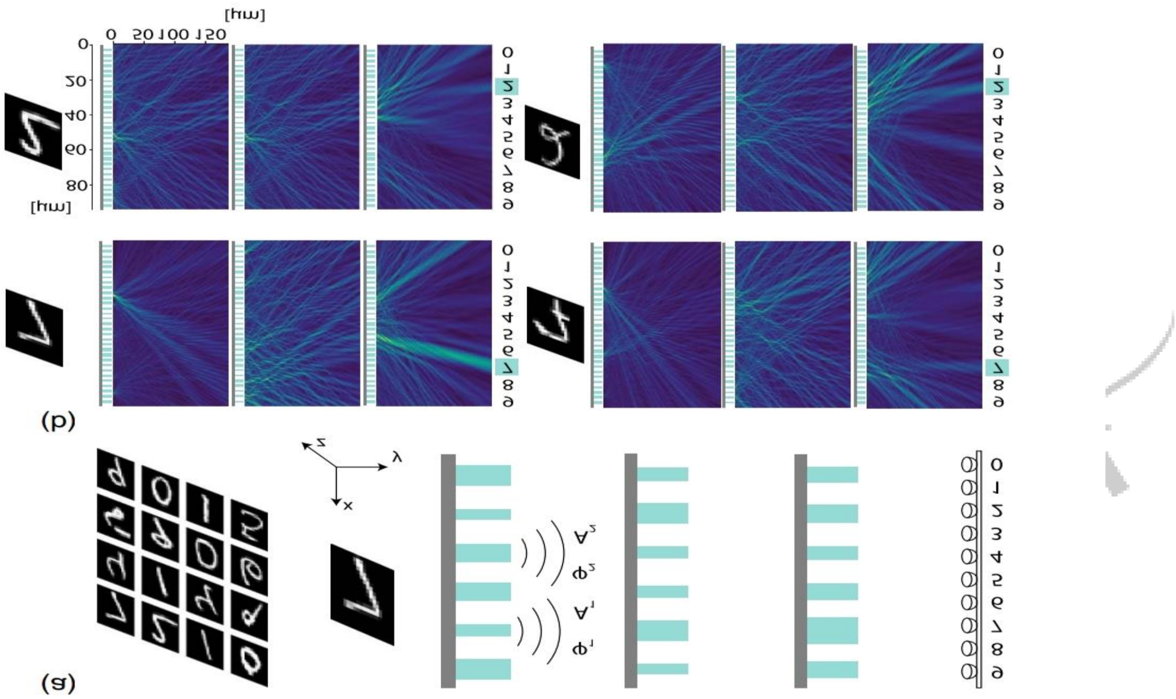
Keywords: metasurface; nonlocal; optical modulator; quasi-bound states in the continuum

Introduction

The need for integrated, quicker, and more effective systems that can change optical signals and images is growing as large-scale image processing becomes significant in many technical fields. Currently, most image processing is done either digitally using integrated circuits or analogly using large optical components. [1–3] A structured material with only one dimension is called a metasurface (the out-of-plane direction)

More than or equal to the operating wavelength [4] Contrarily, nonlocal metasurfaces frequently control optical spectra by utilising the modes supported by numerous identical neighbouring meta-units. Rarely have nonlocal metasurfaces been investigated that spatially shape optical wavefronts. Rarely have nonlocal metasurfaces been studied or shown to spatially shape optical wavefronts. A subtype of the resonant waveguide grating is a nonlocal metasurface with wavefront-shaping capabilities [5]
Sequencies of spatially extended (nonlocal) resonant modes (supermodes) supported by many adjacent meta-units. Such metasurfaces constructed by reference to a rationally designed library of meta-units have not been studied explicitly, though metasurfaces usinginverse design achieve somewhat similar behavior [6].Optical neuromorphic computing offers an alternative approach to realize artificial neural computing. It

has several potential advantages compared with digital neural computingsuch as ultrafast speed and ultralow energy consumption.Several architectures have been demonstrated based on integrated silicon photonics [7] diffractive optics [8], and nano-photonic random structure [9]. In this paper, we introduce developed to implement metasurface-based artificial neural computation by diffracting light to a desired diffraction order only at another platform. To do arbitrary phase front engineering, metasurfaces were created [10]. They achieve their optical properties by the resonant scattering of arrays of nanoscale scatterers that have been constructed on a flat surface. It can be mass manufactured cheaply and is compatible with modern nanofabrication [11]. Here, we execute neural computing using these nanoscale scatterers. It realises high-density integration by utilising the flat optics platform. We outline the design processes and show how to recognise handwritten numbers directly from images.n the MNIST [12] database. 10,000 instances are used in the test stage and 50,000 examples are used for training. The diverse handwriting styles shouldn't affect how well the neuromorphic metasurface determines the digits' values. The dataset is split into two categories. The metasurface is trained using the first group, the training set. The utility of metasurface is evaluated using the second group, the test set. The handwritten digits are illuminated by a plane wave, which then travels across the metasurface and scatters the light in a manner similar to an artificial neural network.



Metasurfaces are optically thin planar structure photonic devices

[13 , (14]. We can consider metasurfaces to be local if the independent scattering events of individual meta-units dictate device behavior, or nonlocal if many adjacent meta-units support a collective mode that governs the response of the device [3]. Generically, local metasurfaces shape the wavefront across a broad spectrum and may achieve functionalities such as lensing and holography. Nonlocal metasurfaces, in contrast, have sharp spectral control but typically without wavefront shaping capabilities, with prototypical examples including guided mode resonance filters [15] and photonic crystal slabs [16]

Parallel to this, recent work on actively adjusting nonlocal metasurfaces has shown that spectral feature location and linewidth can be tuned. Stretchable dielectric photonic crystals [17] and plasmonic lattices [18–19] have both shown mechanical adjustment of the resonant wavelength in action. Other methods involve adjusting photonic crystals by thermal [2o] or electrical [21] means. Our earlier computational work showed tunable nonlocal metasurfaces based on quasi-bound states in the continuum (q-BICs), which can be tuned for resonant frequencies using silicon electro-optic tuning [22] and quality factors using mechanical tuning [23]. Due to their lengthy optical lifetime states, nonlocal metasurfaces have the distinct advantage over local metasurfaces in terms of improved light-matter interactions, which boosts the effectiveness of small changes in refractive index. But up until now, they have been

The continuum is supported by two metasurfaces that support quasi-bound states.State boundaries in the continuum

(BICs) are states that have a momentum that matches that of free space but are nonetheless attached to a physical object [24]. BICs can be either symmetry shielded, where a symmetry incompatibility prevents a mode from coupling to free space, or accidental, where they coincidentally have a coupling coefficient to free space of zero. Here, we take into account symmetry-protected BICs controlled by a symmetry-breaking perturbation, which results in states (i.e., q-BICs) radiating to free space with designer polarisation dependency and quality factors (Q-factors) that vary inversely with perturbation strength () as Q 1/2[25, 26]. The period in k-space is halved by period-doubling disturbances, which double the period along a real-space dimension. The bandstructure is effectively folded as a result, allowing modes that were bound

thermo-optic modulators in free space

It is possible to create free-space modulators based on metasurfaces that offer a significant field overlap with the active material by using the rational design approach previously discussed. We first create silicon thermo-optic nonlocal metasurface modulators, and then we expand this idea to nonlocal wavefront metasurfaces. With a thermo-optic coefficient of 2 104 K1 in the vicinity of telecommunications wavelengths, silicon is a popular option of active material [27]. A one-dimensional (1D) grating is the most straightforward instance of a dimerized nonlocal metasurface. When performing a 1D dimerizing perturbation, we can either produce a "gap perturbation," in which every other grating finger's gap size alternates between two values, or a "width perturbation," in which every other finger's width does the same. For many applications, classifying the items in a scene is a crucial undertaking. The basic method is to use a highly pixelated photodetector to catch light from the scene and convert it to the electrical domain. Advanced algorithms are then used by powerful computers to analyse the electronic data. Power, weight, and throughput are seriously constrained by this infrastructure. Although neural network algorithms can be used to improve things, the method still needs a lot of money. Recently, a strategy based on passive metamaterials that diffract free-space optical beams has been put out to get around both restrictions (28-35). Up until it is recorded by a few low-power, quick photodetector pixels, information can be processed and transferred at the speed of light due to free-space propagation. Consequently, overall speed and energy efficiency free-space optical front ends are integrated with conventional neural networks have also been explored(36 ,37).The free-space diffraction system may also be of interest for accelerating or replacing on-chip computation, an envisioned use for optical neuromorphic computing(38 ,39)

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CONCLUSIONS

We have demonstrated how many mathematical operations can be applied to optical signals using spatially modulated metasurfaces with properly constructed nonlocal response. In the cases of first- and second-derivative operations in 1D and second-derivative operations in 2D, we have shown this. Other linear processes, such integration and picture blurring, can also be accomplished using similar metasurfaces, as mentioned in Ref. [36]. The simplicity of the sinusoidal modulation we employed in the examples in this letter places restrictions on the intricacy of the mathematical operations that can be carried out. Additional complex modulation patterns provide more d.o.f., which we are currently investigating. Our findings have use in analogue image processing, including edge detection, as well as the recently developed idea of analogue optical computing networks [23,37-38]. The Simons Foundation, the National Science Foundation, and the Netherlands Organization for Scientific Research all provided funding for this project under MURI Grant No. FA9550-17-1-0002 from the Air Force Office of Scientific Research. (40)

Reference

[1] J. Nakamura, Image Sensors and Signal Processing for
Digital Still Cameras (CRC Press, Boca Raton, FL, 2006)

[2] J. W. Goodman, Introduction to Fourier Optics (Robert &
Company Publishers, Englewood, CO, 2005).

[3] H. Stark, Application of Optical Fourier Transform
(Academic Press Inc., New York, 1982)
[4] N. Yu, P. Genevet, M. A. Kats, F. Aieta, J.-P. Tetienne, F. Capasso, and Z. Gaburro, Light

propagation with phase discontinuities: generalized laws of reflection and refraction, Science (New York, N.Y.) 334, 333 (2011)..
[5] G. Quaranta, G. Basset, O. J. F. Martin, and B. Gallinet, Recent Advances in Resonant

Waveguide Gratings, Laser & Photonics Reviews 12, 1800017 (2018).
[6] J. Yang, D. Sell, and J. A. Fan, Freeform Metagratings Based on Complex Light Scattering

Dynamics for Extreme, High Efficiency Beam Steering, Annalen der Physik 530, 1700302

(2018).

7) Y. Shen, N. C. Harris, S. Skirlo, M. Prabhu, T. Baehr-Jones, M.
Hochberg, X. Sun, S. Zhao, H. Larochelle, D. Englund, and M.
Soljačić, "Deep learning with coherent nanophotonic circuits," Nat.

Photonics 11, 441–446 (2017).

8)X. Lin, Y. Rivenson, N. T. Yardimci, M. Veli, Y. Luo, M. Jarrahi, and
A. Ozcan, "All-optical machine learning using diffractive deep neural

networks," Science 361, 1004–1008 (2018).

9) E. Khoram, A. Chen, D. Liu, L. Ying, Q. Wang, M. Yuan, and Z. Yu,
"Nanophotonic media for artificial neural inference," Photon. Res. 7,
823–827 (2019).

10) N. Yu, P. Genevet, M. A. Kats, F. Aieta, J.-P. Tetienne, F. Capasso,
and Z. Gaburro, "Light propagation with phase discontinuities: gener-

alized laws of reflection and refraction," Science 334, 333–337 (2011)

11)N. Yu and F. Capasso, "Flat optics with designer metasurfaces,"
Nat. Mater. 13, 139–150 (2014).

[12) N. Yu and F. Capasso, “Flat optics with designer metasurfaces,” Nat. Mater., vol. 13, pp. 139–150, 2014, https://doi.org/10.1038/nmat3839.Search in Google Scholar

[13) P. Genevet, F. Capasso, F. Aieta, M. Khorasaninejad, and R. Devlin, “Recent advances in planar optics: from plasmonic to dielectric metasurfaces,” Optica, vol. 4, pp. 139–152, 2017, https://doi.org/10.1364/optica.4.000139.Search in Google Scholar

[14] H. Kwon, D. Sounas, A. Cordaro, A. Polman, and A. Alù, “Nonlocal metasurfaces for optical signal processing,” Phys. Rev. Lett., vol. 121, p. 173004, 2018, https://doi.org/10.1103/physrevlett.121.173004.Search in Google Scholar

[15) S. Tibuleac and R. Magnusson, “Reflection and transmission guided-mode resonance filters,” J. Opt. Soc. Am. A, vol. 14, pp. 1617–1626, 1997, https://doi.org/10.1364/josaa.14.001617.Search in Google Scholar

[16] S. G. Johnson, S. Fan, P. R. Villeneuve, J. D. Joannopoulos, and L. A. Kolodziejski, “Guided modes in photonic crystal slabs,” Phys. Rev. B, vol. 60, pp. 5751–5758, 1999, https://doi.org/10.1103/physrevb.60.5751.Search in Google Scholar

[17] C. L. Yu, H. Kim, N. de Leon, , “Stretchable photonic crystal cavity with wide frequency tunability,” Nano Lett., vol. 13, pp. 248–252, 2013, https://doi.org/10.1021/nl303987y.Search in Google Scholar

[18] M. L. Tseng, J. Yang, M. Semmlinger, C. Zhang, P. Nordlander, and N. J. Halas, “Two-dimensional active tuning of an aluminum plasmonic array for full-spectrum response,” Nano Lett., vol. 17, pp. 6034–6039, 2017, https://doi.org/10.1021/acs.nanolett.7b02350.Search in Google Scholar

[19] Y. Cui, J. Zhou, V. A. Tamma, and W. Park, “Dynamic tuning and symmetry lowering of Fano resonance in plasmonic nanostructure,” ACS Nano, vol. 6, pp. 2385–2393, 2012, https://doi.org/10.1021/nn204647b.Search in Google Scholar

[20] T. Lewi, N. A. Butakov and H. A. Evans, “Thermally reconfigurable meta-optics,” IEEE Photonics J., vol. 11, pp. 1–16, 2019, https://doi.org/10.1109/JPHOT.2019.2916161.Search in Google Scholar

[21] C. Qiu, J. Chen, Y. Xia, and Q. Xu, “Active dielectric antenna on chip for spatial light modulation,” Sci. Rep., vol. 2, p. 855, 2012, https://doi.org/10.1038/srep00855.Search in Google Scholar

[22] A. C. Overvig, S. Shrestha, and N. Yu, “Dimerized high contrast gratings,” Nanophotonics, vol. 7, pp. 1157–1168, 2018, https://doi.org/10.1515/nanoph-2017-0127.Search in Google Scholar

[23] A. C. Overvig, S. C. Malek, M. J. Carter, S. Shrestha, and N. Yu, “Selection rules for quasibound states in the continuum,” Phys. Rev. B, vol. 102, p. 035434, 2020, https://doi.org/10.1103/physrevb.102.035434.Search in Google Scholar

24] C. W. Hsu, B. Zhen, A. D. Stone, J. D. Joannopoulos, and M. Soljačić, "Bound states in the continuum," Nat. Rev. Mater., vol. 1, pp. 1–13, 2016, https://doi.org/10.1038/natrevmats.2016.48.Search in Google Scholar

25) A. C. Overvig, S. Shrestha, and N. Yu, "Dimerized high contrast gratings," Nanophotonics, vol. 7, pp. 1157–1168, 2018, https://doi.org/10.1515/nanoph-2017-0127.Search in Google Scholar

[26) K. Koshelev, S. Lepeshov, M. Liu, A. Bogdanov, and Y. Kivshar, "Asymmetric metasurfaces with high-Q resonances governed by bound states in the continuum," Phys. Rev. Lett., vol. 121, p. 193903, 2018, https://doi.org/10.1103/physrevlett.121.193903.Search in Google Scholar

27) G. Cocorullo, F. G. Della Corte, and I. Rendina, "Temperature dependence of the thermo-optic coefficient in crystalline silicon between room temperature and 550 K at the wavelength of 1523 nm," Appl. Phys. Lett., vol. 74, pp. 3338–3340, 1999, https://doi.org/10.1063/1.123337.Search in Google Scholar

(28) Lin, X.; Rivenson, Y.; Yardimci, N. T.; Veli, M.; Luo, Y.; Jarrahi, M.; Ozcan, A. All-Optical Machine Learning Using Diffractive Deep Neural Networks. Science 2018, 361, 1004-1008.

(29) Mengu, D.; Luo, Y.; Rivenson, Y.; Ozcan, A. Analysis of Diffractive Optical Neural Networks and Their Integration with Electronic Neural Networks. IEEE J. Sel. Top. Quant. Electron. 2020, 26, 1-14.

(30) Wu, Z.; Zhou, M.; Khoram, E.; Liu, B.; Yu, Z. Neuromorphic Metasurface. Photonics Res. 2020, 8, 46-50.

(31) Li, J.; Mengu, D.; Luo, Y.; Rivenson, Y.; Ozcan, A. Class-Specific Differential Detection in Diffractive Optical Neural Networks Improves Inference Accuracy. Adv. Photonics 2019, 1, 046001.

(32) Chang, J.; Sitzmann, V.; Dun, X.; Heidrich, W.; Wetzstein, G. Hybrid Optical-Electronic Convolutional Neural Networks with Optimized Diffractive Optics for Image Classification. Sci. Rep. 2018, 8, 12324.

(33) Yan, T.; Wu, J.; Zhou, T.; Xie, H.; Xu, F.; Fan, J.; Fang, L.; Lin, X.; Dai, Q. Fourier-Space Diffractive Deep Neural Network. Phys. Rev. Lett. 2019, 123, 023901.

(34) Backer, A. S. Computational Inverse Design for Cascaded Systems of Metasurface Optics. Opt. Express 2019, 27, 30308-30331.

(35)Ryou, A.; Whitehead, J.; Zhelyeznyakov, M.; Anderson, P.; Keskin, C.; Bajcsy, M.; Majumdar, A. Free-Space Optical Neural Network Based on Thermal Atomic Nonlinearity. Photonics Res. 2021, 9, B128-B134.

36)Colburn, S.; Chu, Y.; Shilzerman, E.; Majumdar, A. Optical Frontend for a Convolutional Neural Network. Appl. Opt. 2019, 58, 3179-3186.

(37) Burgos, C. M. V.; Yang, T.; Zhu, Y.; Vamivakas, A. N. Design Framework for Metasurface Optics-Based Convolutional Neural Networks. Appl. Opt. 2021, 60, 4356-4365.)

38) Shen, Y., et al. Deep Learning with Coherent Nanophotonic Circuits. Nat. Photonics 2017,
11, 441-446.

(39) Feldmann, J., et al. Parallel Convolutional Processing Using an Integrated Photonic Tensor Core. Nature 2021, 589, 52-58.

4o) See the Supplemental Material at http://link.aps.org/supplemental/10.1103/PhysRevLett.121.173004 for details about the design of the metasurfaces in the paper, a design for integral operation and details about the calculation of the output in the 2D scenarios.