Recent Advances in Metatronics

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Modularity in electrical circuitry has played a crucial and important role in the development of the field of electronics over the past many decades. The notion of lumped circuit elements is analogous to the alphabets of a language. The same way that the collections of "letters" make words, sentences, paragraphs and statements, in electronics juxtaposing lumped circuit elements provide us with circuits with various functionalities. This has been possible in electronics due to the fact that electronic circuit elements have been much smaller than operating wavelengths and also due to the availability of metallic wires as a great conduit for conduction currents. However, in nanophotonics the concept of lumped circuit elements was not present, until in 2005 when we introduced the concept of optical metatronics, i.e., circuits with light at the nanoscale [N. Engheta, A. Salandrino, and A. Alù, *Phys. Rev. Lett*, 95, 095504 (2005); N. Engheta, *Science*, 317, 1698-1702 (2007), N. Engheta, *Physics World*, 23, 31 (2010)]. In this paradigm, nanostructures with different material properties behave as lumped optical nanocircuit elements. Arranging such nanoparticles near one another provide optical functionality similar to what one would expect from electronic circuitry. We have experimentally verified this concept in the mid-infrared in 2012 [Y. Sun, B. Edwards, A. Alu, and N. Engheta, *Nature Materials*, 11, 208 (2012)], and the later in the near infrared in 2013 [H. Caglayan, S.-H. Hong, B. Edwards, C. Kagan, and N. Engheta, *Phys. Rev. Lett*, 111, 073904 (2013)].

The field of metatronics has evolved significantly over the past decade. It has helped to introduce a variety of novel ideas in the field of nanophotonics and metamaterials, such as optical magnetism using rings of particles [A. Alù, A. Salandrino, and N. Engheta, *Optics Express*, 14, 1557 (2006)], displacement-current conduits [B. Edwards & N. Engheta, *Phys. Rev. Lett,* 108, 193902 (2012)], tuning and matching optical nanoantennas [A. Alù & N. Engheta, *Nature Photonics*, 2, 307 (2008)], wireless links in the nanoscale [A. Alù & N. Engheta, *Phys. Rev. Lett,*_104, 213902 (2010)], and analog computing at the nanoscale [A. Silva, F. Monticone, G. Castaldi, V. Galdi, A. Alu, and N. Engheta, *Science*, 343, 160 (2014)], just to name a few. We have also extended this concept to include other functional elements such as metatronic mixers [U. K. Chettiar & N. Engheta, *Phys. Rev. B*, 86, 075405 (2012)], nonlinear metatronic elements [U. Chettiar & N. Engheta, Optics Express, 23, 445 (2015)], metatronic isolators [O. Luukkonen, U. Chettiar and N. Engheta, *IEEE AWPL*, 11, 1398 (2012)], metatronic transistor amplifiers [U.Chettiar & N. Engheta, manuscript submitted], digital metamaterials [C. Della Giovampaola & N. Engheta, *Nature Materials*, 13, 1115 (2014)], and more. In this talk, I will present an overview of this field from its birth till present, and will forecast future directions and possibilities.