Metamaterial and Plasmonic Nanocircuit Elements: Towards a New Paradigm for Optical Nanoelectronics

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For many years, the familiar notion of lumped circuit elements has been extensively and successfully used in the radio frequency (RF) and microwave electronics. This concept has allowed "modularization" of various functions at the circuit level, and thus has been proven to be a powerful tool in design, innovation, and discovery of new functionalities in those frequency domains. Can the concept of lumped circuit elements, and the mathematical machinery of circuit theory, be extended into the nanometer scale and into the optical domain? In other words, can we envision nanostructures that may act as a "module" representing a *lumped* circuit element, such as a nanoinductor, a nanocapacitor, a nanoresistor, and a nanodiode, etc., at the optical frequencies? Utilizing metamaterials and plasmonic materials with unusual values for material parameters such as negative or near-zero parameters, we have developed the theory and the notion of *lumped* circuit elements at the higher frequency regimes, such as terahertz (THz), infrared (IR), and optical domains[1,2,3,4]. With this approach, nanoelements such as nanoinductors, nanocapacitors, nanoresistors, and nanodiodes can be envisioned at optical frequencies by properly arranging plasmonic and nonplasmonic nanostructures as a tapestry of nanoparticles. This new circuit paradigm, which we coin "metamaterial nanophotonics", provides us with the possibility of tailoring optical electric fields with desired patterns in sub-wavelength regions, and thus allows the mathematical tools of circuit theory to be used in the THz, IR and optical frequencies. This will open doors to many innovations in future optical nanoelectronics and nanosystems, and may likely lead to a new paradigm for information processing, detection, and storage. In our theoretical and computational works, we have shown how more general circuits with various transfer functions can be considered by using blocks of metamaterial plasmonic nanostructures, providing new ways of designing nano-scale optical lumped components and devices such as filters, switches, etc. at optical wavelengths. Such nanoelectronics may one day be also interfaced with biological circuits, leading to the possibility of hybrid nano-bio circuits.

We have also utilized these nanocircuit concepts to suggest ideas for far-field sub-diffraction optical microscopy (FSOM)[5], Yagi-Uda-type optical nanoantennas for various potential applications, e.g., spectrum analysis of molecular spectroscopy, nanotagging and nanobarcode at optical frequencies, transparency of objects, and squeezing electromagnetic energy through tight narrow channels and bends[6].

In this talk, I will present an overview of some of our theoretical results and computational simulations on this concept of *metamaterial nanoelectronics*.

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