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Spatial Dispersion and Optical Magnetism of quasi-2D Plasmonic Nanostructures

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Contemporary techniques of material fabrication allow one to produce stoichiometrically perfect ultrathin metallic films of controlled thickness down to a few monolayers [1-3]. Such films are the major components used to create ultrathin metasurfaces for advanced applications in modern optoelectronics and quantum optics including the ultrafast information processing, microscopy, imaging, sensing, and probing the light-matter interactions at the nanoscale [4,5]. As opposed to bulk metals whose electron plasma spectrum and associated optical response are controlled by the material band structure, the plasma properties and optical response of metallic films can also be controlled by adjusting their thickness, chemical composition, and by using properly chosen substrate and superstrate materials [6]. This unique tunability makes ultrathin metallic (or plasmonic) films an attractive platform for the design of advanced multifunctional metasurfaces, metasurfaces with reduced losses that are capable of utilizing the true quantum nature of light to achieve new improved functionalities [7].

In this talk, I will briefly review the latest experiments and then enlarge on our theoretical efforts to develop a physical understanding of the properties of quasi-2D plasmonic nanostructures of finite thickness and lateral size, efforts that have uncovered their intriguing magneto-optical attributes lending themselves to new attractive device applications. More specifically, while being constant for relatively thick films, the plasma frequency of ultrathin plasmonic films is shown to acquire the spatial dispersion typical of 2D materials, gradually shifting to the red with the film thickness reduction [6]. This explains recent experiments done on ultrathin TiN films of controlled variable thickness [2,3]. The spatial dispersion and the associated dielectric response nonlocality originating from the confinement induced plasma frequency spatial dispersion can result in the new features of the dynamical magnetic response of the film [8]. Particularly, the film magnetic permeability exhibits the sharp resonance structure shifting to the red as the film aspect ratio increases. When tuned appropriately, the ultrathin films of finite lateral size and thickness can be negatively refractive in the IR frequency range [9]. These features are consistent with the general causality principle of spatially dispersive media [10]. They can be controlled by adjusting the film chemical composition, material quality and the aspect ratio of the film, as well as by choosing the deposition substrates and coating layers appropriately. We believe that our findings open up entirely new avenues for potential applications of ultrathin plasmonic films in modern optoelectronics.

Dr. Igor V. Bondarev is a tenured Professor of Physics in the Department of Mathematics & Physics at North Carolina Central University, Durham, North Carolina. Dr. Bondarev earned his MS (1989, Physics, with Honors) and PhD (1994, Theoretical Physics) degrees from the Belarusian State University in Minsk, Belarus. He earned his DSc degree (2001, Theoretical Solid State Physics) from the National Academy of Sciences of the Republic of Belarus in Minsk. (Doctor of Science in Physics and Mathematics is the Habilitation Degree awarded to less than one per cent of active former Soviet Union scientists having PhD.) In 1989-2005, Dr. Bondarev worked in the Theoretical Physics Lab of the Institute for Nuclear Problems at the Belarusian State University (last occupied position – Principal Research Associate/Group Leader). At the same time, as a visiting Professor he performed his research in Germany, France, Belgium, Italy, Poland, and Japan, supported by DAAD (Germany), OSTC (Belgium), JSPS (Japan), and other highly competitive visiting professorship fellowships. Dr. Bondarev has authored and co-authored over 180 research articles, including one US patent and five book chapters in collective monographs published by Nova Science, Taylor & Francis, CRC Press and American Scientific, USA. He presented his research at over 30 invited seminars and over 130 international conferences and symposia in Europe, China, Japan, Mexico, USA, and Canada. Dr. Bondarev is the recipient of the Presidential Young Investigator Award (Belarus, 1999-2001), NCCU College of Science & Technology Outstanding Faculty Research Award (2007, 2012), NCCU Faculty Senate Award for Scholarly Achievements (2007), NCCU Office of Sponsored Research Award for Technology Innovations (2012), and Research Grant Awards from the US National Science Foundation, the US Department of Energy, and the US Army Research Office. His current research interests are focused on the optoelectronic and sensory properties of semiconductor and carbon nanostructures, exciton/plasmon/polariton effects, efficient solar energy conversion with nanomaterials and nanobiophotonics.

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