Electrochemical plasmonics:  
(theory of electrotuneable photonic metamaterials – from fundamentals to applications)

Principle Supervisor: Prof. Alexei A. Kornyshev (Chemistry, Imperial College London)
2nd supervisor: Prof. Fernando Bresme (Chemistry, Imperial College London)
Collaborators: Prof. Joshua Edel (Chemistry, Imperial College London)
Prof. Anthony Kucernak (Chemistry, Imperial College London)

Abstract
A team at the Department of Chemistry of Imperial College (AAK, JBE and ARK) has recently achieved impressive progress in their large scale theoretical and experimental project, started by AAK 10 years ago. It is focussed on voltage controlled structure of array of plasmonic nanoparticles at electrochemical liquid/liquid and solid-liquid interfaces, and the manifestation of the controlled-variation of this structure in optical response of such interfaces. The theoretically predicted and experimentally approved effects are dramatic and they open routs for building new kind of electrotuneable optical devices. The proposed project will take the graduate student to the frontier line of research exploring novel avenues of application of plasmonic-nanoparticle-array-based systems and the orders-of-magnitude increase of their optical response switching-time. As in our previous studies in this area, this research is expected to lead to publications in high profile journals and patents. Opening a spin-off company is in perspective.

The methods to be used: model electrodynamic theory, its verification with COMSOL simulations, statistical mechanics of colloidal electrolytic solutions verified by force-field MD simulations. The project is cross-disciplinary – at the interface of photonics, solid state physics, physical chemistry and electrochemistry, nanoengineering of smart materials, theory of transport phenomena.

Several key papers:


Earlier reviews:


*See also YouTube video: https://www.youtube.com/watch?v=68J0yLrvJE

What is the multi-scale nature of the project?
The screening of electric fields in electrolytic solutions that affect the arrangement of nanoparticles, extends over 1-10 nm. The key element in this project, localized plasmon resonance will be considered in nanoparticles of 20-40 nm size. Distances between nanoparticles in the nanoparticle arrays and from the electrode are about 10 times. These nano-scale effects determine, however, macroscopic optical reflectivity of the studied 1 cm2 sample interfaces. Generally, all electrodynamic effects are pronounced at the scale of wave-length of light (between several 400-800 nm). The characteristic dimensions of the optical chips that we are going to create for miniaturized plasmonic devices are of the order of tens of microns, and that would be the characteristic scale for nanoparticle transport in the micro-electrochemical cells.

How do the expertise of the supervisors complement each other?
AAK is by background a theoretical physicist working in the area of condensed matter chemical physics. He is one of the world leaders in the theory of electrochemical systems. Among many awards and medals he had received were: (i) 1991 Humboldt Prize in Physical Electrochemistry, (ii) 2002 Wolfson Research Merit Award, (iii) 2006 RSC G.Barker Electrochemistry Medal for “his pioneering works and outstanding achievements in the application of modern theory of condensed matter to electrochemical systems”, (iv) 2010 RSC Interdisciplinary Prize for “his many outstanding contributions at the interfaces of chemistry with both physics and biology”, and (v) 2017 1st Lynden-bell Award for “his distinguished career in the field of chemical physics of ionic systems”. He will provide his expertise in formulation of theoretical models of plasmonic metamaterials and devices. He was the PI on the large nanoplasmonic EPSRC project together with JBE and ARK, leading there all the theoretical work navigating experiments. He will continue collaborating with them and will bring the students to the frontier line of nanoengineering of electrochemical photonic devices. FB is one of the internationally leading experts in molecular dynamic simulation of liquids and solutions in the bulk and at interfaces, also including nanoparticles. He was a recipient of 2008 RSC McBain medal in Colloid and Interface Science. FB will lead the parts of the project based on molecular dynamic simulations of the voltage-controlled arrangements nanoparticles at interfaces, navigating the student in performance of pertinent and fastest running codes and analysis of results. AAK and FB actively collaborate on the theory of ionic systems, including electrotuneable friction with ionic liquid lubricants and generally theory of electrochemical interfaces*.
*see WoS page: http://apps.webofknowledge.com/Search.do?product=UA&SID=D5kc6WIZJmUjrPxQha2&search_mode=GeneralSearch&prID=4e202138-1a26-4b93-9953-aa4988e43624

The role of collaborators

All recent AAK plasmonic works were in collaboration with experimentalists – JBE and ARK. FB also collaborates with JBE. ARK (experimental electrochemistry) and JBE (expert in spectroscopy and nano- and micro-fluidics) will be leading experimental parts of the project performed by other students/postdocs and building the corresponding photonic devices. The proposed theoretical project will be developed in strong feedback with the experimental research program. This will not only influence the experimental and engineering strategies, but also may affect some theoretical models and systems, to focus on, which could be modified subject to experimental findings. As it is being run now, there will be weekly project meetings, led by AAK, JBE, ARK, and FB, updating on the theoretical and experimental findings and the interplay between them.
Literature Review
See the list of publications in section 2 above.
Review title: Electrochemical nanoplasmonics for science and technology

This review will describe the role of electrochemical plasmonic metamaterials for the development of the (1) future electrically tuneable photonic devices; (2) electrochemical science, and (3) sustainable energy saving technologies, (4) sensors of hazardous molecules for security and environmental control. The review will systematically discuss the implications of these developments for minimization of energy losses and damage to the environment, with the potential effects on the climate change. It will focus specifically on how understanding of the processes at the nanoscale could affect ‘macroscopic performance’ of the devices built upon the principles of electrochemical plasmonics.

MSc Project
The MSci project will be the ticket for the student to enter this field. They will be offered to build the theoretical basis of the electrotuneable structure and its optical performance for one of the devices that we plan to build. “Due to intellectual-property-sensitive subject of the specific topic that can be offered in this area, the latter will be disclosed to the student during their personal meeting with the supervisors”. 