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Plasmonic nanostructures for cancer detection

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Keywords: Plasmonics, cancer detection, protein-protein interaction

Plasmonics has been used in biological context mainly to analyze protein-protein interactions. Due to the sensitivity of plasmnic resonances to the chemical environment, plasmonic nanostructures can, however, in principle also be used to analyze the interactions of living cells with their environment. In many pathological circumstances, the chemical environment of cells is altered. Cancerous cells, for example, not only have a different chemical composition from normal cells, they also modulate their environment differently and alter physicochemical properties like the pH. Hence, it is particularly appealing to monitor diseases on the cellular level using plasmonic structures. Here, we show an initial study evaluating the feasibility of measuring cells on plasmonic nanostructures. We find that in principle it should be feasible to discriminate healthy from cancerous cells.

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VolkswagenStiftung

Nanoplasmonics and Applications

WORKSHOP FOR YOUNG SCIENTISTS

Supported by the Volkswagen Foundation Grant #86933 - Experimental and Theoretical Study of Surface Plasmons in Single, Coupled and Arrays of Metallic Nanoparticles (https://www.uni-ulm.de/en/nawi/home-expphys.html)

P R O G R A M

Organizing Committee:

T. Makaryan, Yerevan State University
M. Gonçalves, Ulm University
A. Melikyan, Russian-Armenian University
H. Minassian, Yerevan Physics Institute

October 7 - 9, 2015 | Yerevan, Armenia

The workshop will take place in the Guest House of YSU located in downtown of Yerevan (52 Mashtots Avenue)

Workshop agenda

October 7

09:00 M. Gonçalves, T. Makaryan, **An Overview of the Optical Properties and Applications of Plasmonic Nanoparticles**

10:00 Q&A

10:30 Coffee break

11:00 E. Ivchenko, **Photocurrent in a planar plasmonic crystal with a 2D nanochannel**

12:00 Q&A

12:30 Lunch

14:00 O. Galstyan, **Garnet based magnetoplasmonic thin films with large Faraday rotation for imaging and spintronic applications**

15:00 – 16:00 Poster presentations and discussions

Optical Tweezers: from Light to Forces to Micro Rheology, applied to the Cytoskeleton

Othmar Marti[1]

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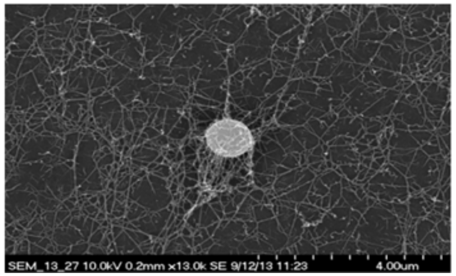
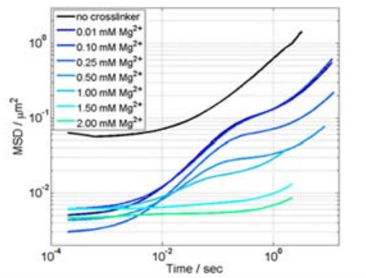
Keywords: Optical Tweezers, Cytoskeleton, Microrheology, Frequency Dependence, Dynamic Shear Modulus, Mean Squared Displacement

Optical Tweezers trap a particle using optical forces. The trapping potential of tightly focused light for a dielectric particle is to first order harmonic, hence the optical trap acts as an almost linear spring in three dimensions. The trap stiffness is up to 50 pN/µm (Malagnino et al. 2002). On the other hand, microscopic particles or sub-microscopic particles in a fluid environment are subject to stochastical forces, thus showing Brownian motion. (Uhlenbeck und Ornstein 1930; Smoluchowski 1906; Einstein 1906). The Brownian Motion is characterized by its Mean Square Displacement (MSD). A transform of this displacement gives the frequency dependent visco-elastic properties of the fluid or medium (Mason 2000). We have developed methods to improve the calculation of visco-elastic properties by using a model based approach. (Neckernuss et al. 2015b).



1 µm polystyrene bead in an extracted keratin intermediate filament network (Measurement: L. Katinka Mertens)



Mean Square Displacement of in-vitro keratin networks dependent on the concentration of divalent Mg^{2+} linker ions (Measurement: Ines Martin)

The combination of the passive microrheology with active excitation of selected beads increases the sensitivity of the method and provides directional visco-elastic data (Neckernuss et al. 2015a). We apply these techniques to the intermediate filament system of pancreatic cancer cell lines (Panc-5) and other cell lines. (Tobias Paust et al. 2013)

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Fabrication of plasmonic nanoparticles using electron beam lithography

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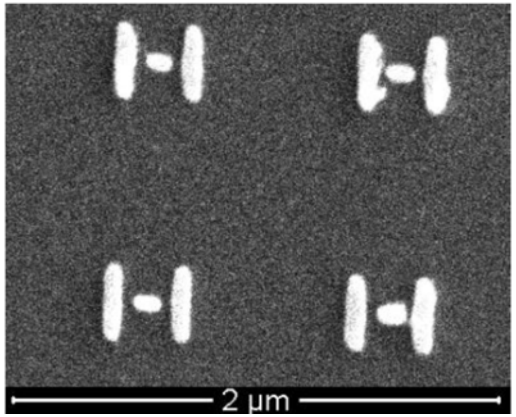
Keywords: Electron Beam Lithography, Plasmonic Nanostructures, Confocal Microscopy

We have fabricated H-shaped gold nanostructures using electron beam lithography (EBL). The structures are made up of the two vertical and one horizontal rod as shown below and are expected to show interesting plasmonic properties (Gonçalves, Melikyan et al. 2014). This includes the Fano resonance as a result of the coupling between a dark and a bright mode on the vertical and horizontal rods. The fabrication process is challenging because of the many process parameters involved. We have been investigating different choices of substrates, resist deposition conditions, CAD files of the structures, exposure doses and electron beam currents. The first structures were either completely removed during lift-off or showed no separations between rods. Recently we fabricated structures with the desired design as shown below. However, reproducing them has been challenging and we are currently trying to find out why. The scattering by the structures is currently being investigated at different wavelengths using confocal measurements by total internal reflection with a prism. The preliminary results have been in accordance with our assumptions. Spectroscopic characterization has been done with the same type of set-up, but using a white light source. These studies did not confirm the existence of any resonances, possibly because they lie outside the used wavelength range.



SEM image of H-shaped gold nanostructures fabricated by EBL. The separations between rods are about 40 nm

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October 8

09:00. A. Melikyan, H. Minassian, **Peculiarities of Fano resonance in complexes of nanoparticles**

10:00 Q&A

10:30 Coffee break

11:00 Kh. Nerkararyan, **Passage of light wave through the nanoslit**

12:00 Q&A

12:30 Lunch

14:00 M. Nilsen, **Fabrication of plasmonic nanoparticles using electron beam lithography**

15:00 – 16:00 Poster presentations and discussions

October 9

09:00 O. Marti, **Optical Tweezers: from Light to Forces to Micro Rheology, applied to the Cytoskeleton**

10:00 Q&A

10:30 Coffee break

11:00 M. Gonçalves et al., **Configurations of Rod-like Plasmonic Nanoparticles for Optical Fano Resonances**

12:00 Poster presentations and discussions 12:30 Lunch

14:00 K. Gottschalk, **Plasmonic nanostructures for cancer detection**

15:00 Concluding remarks

ABSTRACTS

Peculiarities of Fano resonance in complexes of nanoparticles

A. Melikyan[1] and H. Minassian[2]

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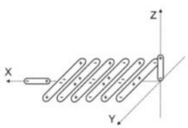
[2] *Yerevan Physics Institute*
Keywords: surface plasmon; Fano resonance; metallic nanoparticles

In 1961, during his theoretical study of the autoionization states of atoms U. Fano discovered a new type of resonance that sufficiently differed from classical Lorentzian one by pronounced asymmetric shape. The microscopic origin of the Fano resonance (FR) arises from the destructive interference of a narrow discrete resonance with a broad spectral line of continuum. While FR was first discovered in atomic systems it found the main applications in optics of metallic nanoparticles (MN) due to its exceptional spectral sensitivity to the optical properties of surrounding media and geometry of MNs.

The talk is devoted to the peculiarities and application opportunities of FR in complex nanostructures with two and more nanoparticles. Quantitative characteristics of FR – Figure of Merit $\zeta = \Delta\omega/\Delta n\cdot\gamma$, and FR Efficiency $\eta = P_d(\omega_{FR})/P_b(\omega_{FR})$ will be presented and analyzed for different configurations of complexes (Δn is the change of refractive index, $\Delta\omega$ is the shift of resonance absorption frequency, γ is the resonance linewidth, P_b and P_d are oscillation energies accumulated at FR frequency in “dark” quadrupole mode, and “bright” dipole mode). An approximate qualitative approach (analysis based on decomposition of plasmon quadrupole modes) is presented, that allows to predict easily the FR frequencies for different configurations of composite nanoparticles. This procedure significantly shortens the numerical calculation time with COMSOL Multiphysics software.
Different configurations of nanoparticles (such as chains of nanorods presented in the figure) providing high values of ζ and η will be discussed.



FR possesses huge potential for applications, especially in biomedical sensorics, photonics, and nanoantennas. The first switch was realized in 2012 (W.-S. Chang et al., A Plasmonic Fano Switch. Nano Lett. 12, 4977 (2012)).

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An Overview of the Optical Properties and Applications of Plasmonic Nanoparticles

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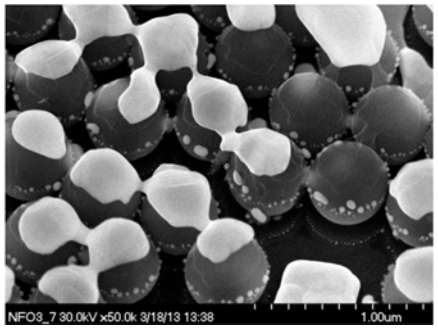
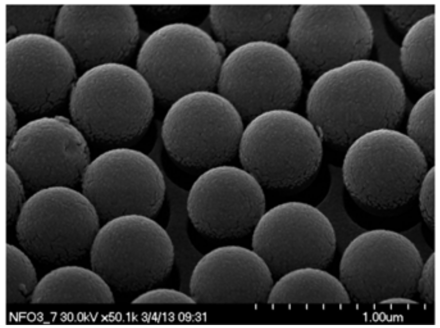
Keywords: surface plasmon, nanoantenna, Fano resonance, optical force, Purcell effect, fluorescence lifetime

Noble metal particles with dimensions of the order of the wavelength of light have very fascinating optical properties allowing for example, extreme light focusing, enhance optical absorption and scattering by surface plasmon resonance. The main reason for the unusual optical properties, comparing to other metals and dielectrica, is due to coupling of light with the free oscillating electrons of the metal. These excitations are bosonic quasiparticles but their properties can be described mostly using the Maxwell's equations. However, in the last few years the interest in the quantum effects of plasmonic particles has constantly increased.

In this talk I will give an overview of main characteristics of the surface plasmons in nanoparticles, and address several applications arising from plasmonic coupling between particles, plasmonic trapping and heating, Fano resonances, optical nanoantennas. The quantum nature of the surface plasmons will be also discussed and applications based on the spontaneous emission enhancement by Purcell effect will be presented.





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Configurations of Rod-like Plasmonic Nanoparticles for Optical Fano Resonances

M. R. Gonçalves[1], M. Nilsen[1], T. Makaryan[2], H. Minassian[3], A. Melikyan[4]

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[2] *Yerevan State University - Radiophysics Department, Armenia*
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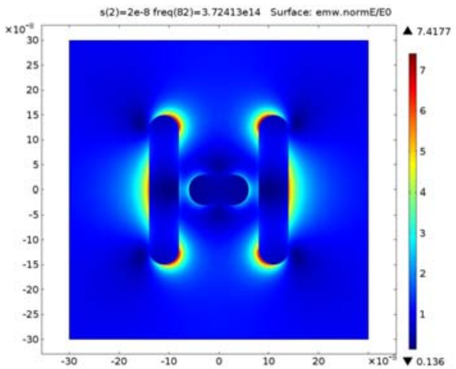
[4] *Russian-Armenian (Slavonic) University, Yerevan, Armenia*

Keywords: surface plasmon, Fano resonance, nanorod, near-field coupling

Fano resonances, also known as Fano-like resonances, in plasmonic nanoparticles were discovered in last decade [1]. Certain noble metal nanostructures under adequate illumination conditions present pronounced asymmetric resonances in the extinction spectra. In general, Fano resonances are excited when a symmetry breaking in the geometry of the structure occurs. This leads to a coupling between a radiant plasmonic mode and a dark (subradiant) plasmonic mode, which alone cannot be excited for the corresponding illumination conditions. This symmetry breaking is not absolutely required if the excitation of the dark mode is forbidden. Systems of particles constituted by rods of different lengths arranged in T-like or H-like are examples of plasmonic structures showing high efficient Fano resonances. The efficiency can be quantified by the ratio of energy absorbed in particles supporting the dark mode and the particles supporting the bright mode [2].

I will give an overview of the structures above referred, the parameters influencing the Fano resonances and present different approaches to simulate the optical properties of the particles, namely using quasi-static approximations and full electromagnetic finite-element methods.



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Photocurrent in a Planar Plasmonic Crystal with a 2D Channel

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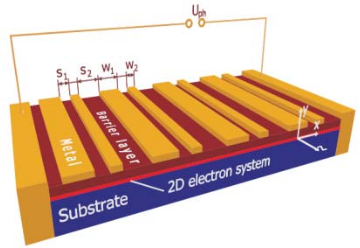
Keywords: ratchet effect, near-field optics, 2D electron gas

In condensed-matter materials lacking a center of symmetry, a dc electric photocurrent can be generated under optical illumination of an unbiased sample. If the absence of an inversion center is caused by the microscopic structure of the system, as is the case in a crystal or a semiconductor quantum well, the generation of a dc electric current under homogeneous illumination is called the photogalvanic (photovoltaic) effect. If, on the contrary, the system is an artificially prepared non-centrosymmetric periodic object, we are dealing with the electronic ratchet effect. One of the recently-realized ratchet systems is formed by depositing a periodic non-centrosymmetric grating of etched grooves or metallic fingers on the cover layer of a quantum well or graphene or creating a two-dimensional (2D) channel with a periodic asymmetric grating gate. [1–4] In my lecture I will present a theoretical study of the plasmon-photogalvanic effect in a particular ratchet system, namely, the planar non-centrosymmetric plasmonic crystal containing a homogeneous two-dimensional electron gas gated by a periodic metal grating with an asymmetric unit cell, see the figure.



The plasmon-photogalvanic dc current arises due to the two-dimensional electron drag by the non-centro-symmetric plasmon modes excited under normal incidence of terahertz radiation. We have shown that the collective plasmon modes of the planar plasmonic crystal become strongly asymmetric in the weak-coupling regime of their anticrossing. A large plasmon wave vector (which is typically by two-three orders of magnitude greater than the terahertz photon wave vector) along with strong near-field enhancement at the plasmon resonance make the plasmonic drag a much stronger effect compared to the photon drag observed in conventional 2D electron systems [5].

The Russian Science Foundation (Grant No. 14-12-01067) is gratefully acknowledged.

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Garnet based magnetoplasmonic thin films with large Faraday rotation for imaging and spintronic applications

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Keywords: Faraday rotation, magnetoplasmonics, magneto-optical imaging

When a linearly polarized electromagnetic wave passes through a magnetoactive medium rotation of polarization takes place (Faraday rotation). The rotation angle is determined by the external magnetic field as well as by the internal properties of the medium. In recent years thin films with large Faraday rotation (FR) angle attract great interest because of their numerous applications in the fields of optical isolation, magneto-optical (MO) imaging, spintronics and integrated photonics. The main technological challenge is to find easy implementation routes to prepare thin films with highest possible FR. Bismuth substituted yttrium iron garnet (Bi-YIG) thin films are recognized as materials with highest specific FR angles (almost ~10 deg/μm). By deposition of different plasmonic nanostructures on garnet thin films it is possible to further increase FR. These kinds of hybrid films (garnet+plasmonic nanostructure) are called magnetoplasmonic thin films.

We have developed a new low-cost technique based on the metal-organic decomposition method (MOD) for the fabrication of Bi-YIG thin films with high FR angles on amorphous and single crystalline substrates. MO imaging system which utilizes FR for the visualization of magnetic fields has been developed. Using our prepared indicator thin films with high FR the visualization of magnetic fields and magnetic domains becomes possible. Minimum detectable magnetic field was measured to be about 0.6 Oe and the spatial resolution can achieve 0.5 μm. We have also theoretically suggested to use several plasmonic metallic nanostructures on the garnet films for the enhancement of FR. In the visible region where we carried out most of our experiments the wavelength is much larger than the nanoscale inhomogeneities of the system. Therefore the magnetoplasmonic system can be treated as a metamaterial, where the non-diagonal term of its dielectric permittivity tensor is determined by the garnet and the diagonal term is determined by the metal.

We expect that achieved results and future research will help us on the design and fabrication of high quality magnetoplasmonic thin films. Furthermore, we expect that prepared films will find their application not only in magnetic field sensing but also in highly integrated optics and semiconductor spintronics.

Acknowledgements: We want to thank Prof. K. Lee from Sogang Univeristy, for the support on experimental issues.

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Passage of light wave through the nanoslit

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Keywords: surface wave; subwavelength slit; extraordinary transmission;

This review provides a perspective on the recent developments in the transmission of light through subwavelength apertures in metal films. The main focus is on the phenomenon of extraordinary optical transmission in periodic hole arrays, discovered over a decade ago. It is shown that surface electromagnetic modes play a key role in the emergence of the resonant transmission. These modes are also shown to be at the root of both the enhanced transmission and beaming of light found in single apertures surrounded by periodic corrugations.

In this lecture we describe both the theoretical and experimental aspects of the subject. For clarity, the physical mechanisms operating in the different structures considered are analyzed within a common theoretical framework. Several applications based on the transmission properties of subwavelength apertures are also addressed. Optical response of real materials to incident coherent radiation at petahertz frequencies leads to unexpected consequences for transmission and extinction of light through subwavelength aperture arrays.

We analytically describe light transmission through a single subwavelength slit in a thin perfect electric conductor screen for the incident polarization being perpendicular to the slit, and derive simple, yet accurate, expressions for the average electric field in the slit and the transmission efficiency. The analytic results are consistent with full-wave numerical calculations, and demonstrate that slits of widths ~100nm in real metals may feature non-resonant (i.e., broadband) field enhancements of ~100 and transmission efficiency of ~10 at infrared or terahertz frequencies, with the associated metasurface-like array of slits becoming transparent to the incident light. We believe that our findings have important implications to various fundamental and technological applications ranging from near-field THz microscopy with subwavelengths slits to surface-enhanced linear and nonlinear spectroscopy and sensing.

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