MITMECHE

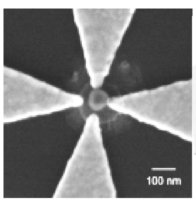
Fang Group Research Forum

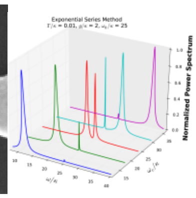
Date: 9/13/2014, Saturday
Room: 3-333, MIT
Advisor: Professor Nicholas X. Fang
(http://web.mit.edu/nanophotonics)

Our research efforts concentrate on focusing photon and sound into sub-wavelength scales. While we emphasize on new insights of material and device design from fundamental approaches, we also actively pursue the applications of our technology in the areas of nanofabrication, energy conversion, communication, and biomedical imaging.

Acoustic Metamaterials

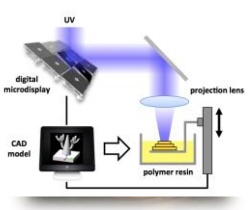
Acoustic metamaterials promise new applications for steering and focusing sound waves, and reducing the ultrasound signature of the underwater objects. Our recent effort on acoustic metamaterials has been expanded to tailoring the wavefront and energy flow of elastic waves, with emerging applications such as shock wave propagation and energy dissipation.

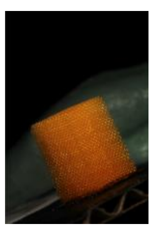




Nano-Photonics

Our research in nanophotonics focuses on breaking the diffraction limit by optical metamaterials, with potential application in nanoscale imaging and energy conversion. Recently we have begun to investigate optics in a few atom layered materials as potential compact and power efficient integrated optical switches and modulators.





Soft Materials

We study soft active materials such as stimuli-responsive hydrogels and shape memory polymers. We are interested in developing new micro 3D printing techniques as well as fundamental studies such as mechanics, elastic instabilities, and diffusion kinetics. Various emerging fields including soft robotics, tunable metamaterials, and tissue engineering are explored.

Schedule

Time	Event	Speaker
8:00 am – 8:30 am	**Setup / Breakfast / Opening**	
8:30 am – 10:30 am	**Session I – Acoustic Metamaterials** (Chair: Qi Ge)	
	Manipulating the Acoustic Wave by Acoustic Metamaterials	Jun Xu
	Nonlocal description of sound propagation in an array of Helmholtz resonators	Navid Nemati
	Nonlinear acoustic in heterogeneous materials	Nicolas Viard
	Broadband acoustic wave phase manipulation	Chu Ma
10:30 am - 10:45 am	**Discussion/Break**	
10:45 am – 11:45 am	**Session II – Soft Materials: 3D Manufacturing and Mechanics** (Chair: Dafei Jin)	
	3D Printing of Active Structures and Devices with Multiple Soft Materials	Qi Ge
	Cephalopod-inspired Design of Electro-mechano-chemically Responsive Elastomers for On-demand Fluorescent Patterning	Qiming Wang
11:45 am - 12:00 pm	**Brief Introduction to Posters**	Qing Hu, Sang Hoon Nam, Matt Klug, Narges Kaynia, Mo Chen, Tian Gan
12:00 pm – 2:00 pm	**Lunch Break and Poster Session**	
2:00 am – 4:30 pm	**Session III – Nano-Photonics** (Chair: Jun Xu)	
	Quantum Manipulation of surface Plasmons via Extraordinary Photonic and Excitonic Materials	Dafei Jin
	Making plasmons live longer	Anshuman Kumar
	Mechanical effects of nanoparticle vector beam scattering	Yoonkyung Lee
	Controlling spontaneous emission of monolayer MoS2 with plasmonic optical antennas	Yingyi Yang
	Ultrafast femtosecond pulse shaping using preset spatial modulators	Zheng Jie Tan

Session I – Acoustic Metamaterials

<table>
<tr><td>08:30 am -
9:00 am</td><td>Manipulating the Acoustic Wave by Acoustic Metamaterials</td><td>Jun Xu,
PhD</td></tr>
<tr><td colspan="3">The explosion of interest in metamaterials is due to the dramatically increased manipulation ability over light as well as sound waves. These novel materials promise a host of exciting applications such as super-resolution imaging, high directional beam steering, and invisible cloaks. For instance, an invisible cloak device is proposed to render the hidden object undetectable under the flow of light or sound, by guiding and controlling the wave path through an engineered space surrounding the object. In the presentation, I will introduce the transformation acoustics method for designing acoustic metamaterials for manipulating the acoustic waves. In addition, I will show the recent progresses in acoustic wave collimation, acoustic complementary metamaterials, etc. In summary, the area of the acoustic metamaterials shows the greatest promise for new materials, new physics, and new applications.</td></tr>
<tr><td>9:00 am –
9:30 am</td><td>Nonlocal description of sound propagation in an array of Helmholtz resonators</td><td>Navid Nemati,
PhD</td></tr>
<tr><td colspan="3">A generalized macroscopic nonlocal theory of sound propagation in rigid-framed porous media saturated with a viscothermal fluid has been recently proposed. This theory allows to go beyond the limits of the classical local theory and within the limits of the linear theory, to take not only temporal dispersion, but also spatial dispersion into account. In the framework of the new approach, a homogenization procedure is developed, through solving two independent microscopic action-response problems each of which determines the effective density and effective bulk modulus of the material. Contrary to the classical asymptotic method of homogenization, there is no length-constraint or scale separation to be considered alongside of the development of the new method, thus, there would be no frequency limit for the medium effective properties to be valid. Moreover, the effects due to material local resonances can be described taking into account the spatial dispersion. These features of the nonlocal approach give the possibility to predict precisely metamaterial macroscopic properties. Here, employing this effective medium theory, we present the description of sound propagation through a metamaterial made by an array of Helmholtz resonators, whose unusual properties, such as negative bulk modulus, have been experimentally demonstrated. Three different calculations have been performed validating the results relating to the frequency dependent Bloch wavenumber and bulk modulus, for 2D as well as 3D structures.</td></tr>
<tr><td>9:30 am -
10:00 am</td><td>Nonlinear acoustic in heterogeneous materials</td><td>Nicolas Viard,
PhD</td></tr>
<tr><td colspan="3">Acoustic wave propagation is inherently nonlinear. In a homogeneous fluid, the non linearity originates from the convection and the nonlinear thermodynamic response of the medium, which are modeled through the nonlinear terms of conservation and state equations. This non linearity -so called classical non linearity- has already been exploited in various applications such as acoustic parametric antenna or second harmonic imaging. These applications usually take place in homogeneous or weekly heterogeneous media, where the elastic mean free path is larger than the characteristic dimension of the medium. Here we are interested in the nonlinear propagation of acoustic wave in highly heterogeneous media. We present the results of an experiment where an acoustic shock wave is formed in water before it interacts with a highly heterogeneous synthetic medium. Although it is not without interest, we show that this configuration is not in favor of non linearity, as multiple scattering dominates. These findings invite us to think of other means or configurations to promote non linearity. Some leads are presented.</td></tr>
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10:00am – 10:30am	Broadband acoustic wave phase manipulation	Chu Ma, G2

Acoustic wave phase manipulation can be achieved by generating phase inhomogeneity in the wave path of elementary beams. In this presentation, I will first present some background of this relatively new research topic, discussing the advantages and limitations of some published designs. Then I will introduce my simulation work about a set of phase manipulation unit cells that can realize discrete phase discontinuity ranges from 0 to 2π in a step of π /4. One remarkable property of this design is that both the amplitude and the phase shift of unit cells are broadband, which enables an arbitrary phase front with no dispersion in the working frequency range.

Session II – Soft Materials: 3D Manufacturing and Mechanics

10:45am - 11:15am	3D Printing of Active Structures and Devices with Multiple Soft Materials	Qi Ge, PhD

Soft active materials such as hydrogels and shape memory polymers have recently gained great attention due to their abilities of switching configurations in response to various environmental stimuli. Unique properties and advantages of these materials, however, have not been fully exploited because manufacturing and material processing for this new class of materials still rely on conventional methods. The rapid advanced 3D printing technique provides unprecedented freedom of design and manufacturing and allows us to fabricate complex 3D structures and devices with soft active materials. The technique of printing 3D structures with active materials that change configurations over time sometimes also refers to as "4D printing".

In this talk, I will first introduce a new paradigm of *printed active composites* (PACs) that is realized by printing composites with complex and controllable anisotropic thermomechanical behavior *via* prescribing the architecture, shape, size, orientation and even spatial variation of the fibers with shape memory effects. By deliberately varying fiber volume fractions, orientations and positions, the printed laminates in thin plate form that can then be thermomechanically programmed to assume complex three-dimensional configurations including bent, coiled, and twisted strips, folded shapes, and complex contoured shapes with nonuniform, spatially-varying curvature.

The main limitations of using commercial 3D printer to fabricating active structures and devices are the material selections and costs. To overcome these limitations, I will introduce a new multi-material micro 3D printing technique developed in our lab for soft active materials - projection micro-stereolithography (PμSL). PμSL is a 3D micro-stereolithography technology capable of rapidly building highly complex microstructures by converting photocurable resin into solid layer-upon-layer. PμSL allows us to freely tune the thermomechanical properties for shape memory polymers such as glass transition temperature, entropic elasticity, and stretchability with inexpensive commercial available materials. Using PμSL, we are able to create freely tunable shape memory composites with multi-shape memory effects and fabricate highly deformable complex 3D shape memorable devices with refined features.

11:15am – 11:45am	Cephalopod-inspired Design of Electro-mechano-chemically Responsive Elastomers for On-demand Fluorescent Patterning	Qiming Wang, PhD

Cephalopods can display dazzling patterns of colors by selectively contracting muscles to reversibly activate chromatophores – pigment-containing cells under their skins. Inspired by this novel coloring strategy found in nature, we design an electro-mechano-chemically responsive elastomer system that can exhibit a wide variety of fluorescent patterns under the control of electric fields. We covalently couple a stretchable elastomer with mechanochromic molecules, which emit strong fluorescent signals if sufficiently deformed. We then use electric fields to induce various patterns of large deformation on the elastomer surface, which displays versatile fluorescent patterns including lines, circles and letters on demand. Theoretical models are further constructed to predict the electrically-induced fluorescent patterns and to guide the design of this class of elastomers and devices. The material and method open promising avenues for creating flexible devices in soft/wet environments that combine deformation, colorimetric and fluorescent response with topological and chemical changes in response to a single remote signal.

Session III – Nano-Photonics

<table>
<tr><td>2:00pm -
2:30pm</td><td>Quantum Manipulation of surface Plasmons via Extraordinary Photonic and Excitonic Materials</td><td>Dafei Jin,
PhD</td></tr>
<tr><td colspan="3">In this talk, I will first present our theoretical prediction and experimental verification of the existence of quantum multipole-surface-plasmon modes at the interfaces between silver and a number of high-index dielectrics. These modes result from the broadened interfacial density profile of the conduction electrons in silver, under the strong polarization and lowered surface potential from the dielectrics. In contrast with the classical monopole-surface-plasmon modes, they couple efficiently with propagating photons, and exhibit minimal momentum dependence and higher energy confinement. I will also present our recent progress on the active control of surface plasmons through organic semiconductors. We have designed and tested a novel organic field-effect transistor device, through which we intend to employ the strong coupling between surface plasmons at the silver-air interface and the exitons in molecular aggregates to produce a switch on plasmonic waveguides.</td></tr>
<tr><td>2:30pm –
3:00pm</td><td>Making plasmons live longer</td><td>Anshuman Kumar,
G5</td></tr>
<tr><td colspan="3">One of the major problems with plasmonics is loss. Though graphene provides a better alternative to metal plasmonics, yet for realistic experimental parameters, the improvement is only marginal. In this talk, I will describing some of my recent progress regarding enhancing the plasmon lifetime in graphene by coupling it with other less lossy excitations.</td></tr>
<tr><td>3:00pm –
3:30pm</td><td>Mechanical effects of nanoparticle vector beam scattering</td><td>Yoonkyung Lee,
G4</td></tr>
<tr><td colspan="3">Even the most intricate structures in the world are often made from small building blocks. While we can assemble bricks or Lego blocks with our own hands, we have very limited control over the tiny building blocks on the nanoscale that comprise both natural and man-made wonders. Now chemists and engineers have made it possible to synthesize nanoscale building-blocks inside a laboratory. The particles are right here but still far away from our reach, especially if they absorb, scatter, or emit light in uncontrolled manners. In this talk, the mechanical interaction between an electromagnetic vector field and a sub-micron particle will be discussed, with a focus on the exchange of force and torque.</td></tr>
<tr><td>3:30pm –
4:00pm</td><td>Controlling spontaneous emission of monolayer MoS2 with plasmonic optical antennas</td><td>Yingyi Yang, G2</td></tr>
<tr><td colspan="3">Two-dimensional material MoS2 is an emerging direct gap semiconductor, which exhibits novel optical properties such as valley polarization. For practical device performance, one challenge is to improve the light-matter interaction, because this interaction is inherently weak due to the atomically thin nature of monolayer MoS2. Here, we explore the possibility of enhancing the spontaneous emission of monolayer MoS2, by coupling it with plasmonic antennas. These antennas are plasmonic nanostructures which can confine the electromagnetic field on sub-wavelength scale. Some preliminary phenomena show that the photoluminescence of MoS2 is enhanced because of the local strong field. This demonstrates the potential of plasmonic antennas in improving the quantum yield of monolayer MoS2.</td></tr>
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4:00pm – 4:30pm	Ultrafast femtosecond pulse shaping using preset spatial modulators	Zheng Jie Tan, G2

Spatially-structured light has led to many uses in the area of imaging, e.g, in super-resolution imaging or 3D imaging. A temporally-structured pulse could have similar potential in probing materials for diagnosis, but the existing schemes for shaping optical pulses are limited in speed and resolution. In this talk, I will propose the use of digital micromirror devices (DMD) over the traditional liquid crystal display (LCD) chips to shape optical pulses. Both methods will share the basic principle of using spatial light modulators to modulate the pulse in its Fourier spatial domain to obtain features in the temporal domain, since no electro-optical modulators can be fast enough to directly modulate a pulse on the femtosecond scale.

Poster Session

12:00 PM-2:00PM	Waveguide Structures: Towards Confining and Tailoring Light on Subwavelength Scale	Qing Hu, PhD

Two-dimensional optoelectronic materials, like monolayer of MoS_2 (and its analogues MoSe2, WS2, WSe2, *et al*.) and thin film of organic molecule aggregates, are of great interests due to their novel properties. Firstly, the electronic structures undergo remarkable changes when the number of the layers is lowered, e.g. change from indirect-band gap bulk semiconductors to direct-band gap monolayer semiconductors occurs in MoS_2 and two-level band gap forms in the cyanine dyes (e.g. TDBC) molecules after they get aggregated. Secondly, the 2D geometry generates highly confined optoelectronic modes, and then leads to the application like ultra-compact optoelectronic device.
In most of the emitting materials, the emission of light is induced by recombination of bound electron-hole pairs (excitons) via the absorption of light. The process exhibits coherent coupling between light modes and electronic excitations in matter. When a strong coupling occurs, the electromagnetic modes and the localized electronic excitations mix and create an exciton-polariton state. The strong coupled light-matter state shows great potential in new device applications, such as the generation of low-threshold coherent emission at room temperature without the need for population inversion, modulator and low-threshold all-optical switches based on exciton-polariton scattering.
In order to further explore the coupling mechanism and related applications, we build up a charge modulate spectroscopy system for the measurement and develop a layer-by-layer self-assembly method for the fabrication. Our preliminary experimental results show many interesting aspects. The strong polariton-exciton coupling occurs in monolayer molecular aggregates on metal surface and the Rabi splitting is enhanced due to the oriented dipolar molecules in the self-assembled monolayer. The interference between exciton and photon states leads to strong Fano resonant and the coupling coefficient is extremely high comparing with the other semiconductor cavity system. The similar nonlinearity behaviors, such as saturation phenomenon in two-level material and the shift of photoluminescence in the molecular thin film with different layers, are observed. Meanwhile, the molecular aggregates are mixed with monolayer MoS_2 to study the interaction between different types of excitons. The measurement shows the intrinsic PL peak of MoS_2 has red shift after doping with the molecular aggregates. It means the exciton in molecular aggregates has interaction with the trion in monolayer MoS_2. In the next, we will build a systematic theoretical model to investigate these phenomena and find an efficient way to actively tune the exciton-polariton coupling behavior.

12:00 PM-2:00PM	Broadband Light Absorption of Titanium Oxide with Metal Reflector for Solar Energy Devices	Sang Hoon Nam, PhD

Titanium oxide (TiO_2) remains one of the most promising because of its low cost, chemical inertness and photostability. However, the limitation coming from the large band gap of TiO_2 becomes severe, which limits its optical absorption only within UV light region (only ~4% of the entire solar spectrum). Various approaches, such as doping and band gap engineering, have been explored to expand TiO_2 optical absorption spectrum into the visible and infrared region. However, those kind of researches are still unsatisfactory. For this reason, adding metal films as a reflector have been explored for enhancement of solar absorption of TiO_2. We could enhance light absorption efficiency amazingly by ultrathin film of TiO_2 on the metal reflector. Since these metallic films support localized surface plasmons or surface plasmon polaritons. We found powerful to fold light into an ultrathin film, which can contributes to the rational design of the visible light responsive plasmonic photocatalytic material based on wide band gap metal oxides for solar energy devices.

12:00 PM-2:00PM	Optical Sensing in Nanoporous Bacteriophage-Based Networks via Localized Surface Plasmon Resonance	Matt Klug, G5

Photoactive nanoporous films are assembled by cross-linking M13 bacteriophages using a layer-by-layer process. By genetically engineering the bacteriophage to display peptides with an affinity for noble metals, plasmonic nanoparticles can be dispersed throughout the thin film in a manner that avoids aggregation, enabling them to act as reliable probes for sensing the effective refractive index inside the film. Furthermore, the resulting plasmonic bacteriophage scaffold can act as a template to build crystalline titania nanoporous networks via biomineralization, allowing sensing to proceed in both biomolecular and inorganic films. This is possible because the localized surface plasmon resonance (LSPR) frequency of sub-wavelength gold nanospheres is very sensitive to the complex dielectric function of its surrounding medium. By combining Mie theory with effective medium theory, the absorption peak position of well-dispersed gold nanoparticles in the bacteriophage-film was predicted and found to be in excellent agreement with experimental measurements. Moreover, the analytical model developed herein allows the porosity of both the biological and semiconducting networks to be determined by simply measuring the absorption peak position of the gold nanoparticles with a spectrophotometer. It is expected that both the organic and inorganic nanoporous networks will find further use in biomedical and energy applications as slight changes in the local environment within the pores of the nanoparticle-loaded film can be detected by monitoring the LSPR peak position in the absorption spectrum

12:00 PM-2:00PM	Multifunctional applications of instability-induced transformation in composites	Narges Kaynia, G4

The microstructure of a composite structure has an essential influence on the effective properties and behavior of the structure, and can be used to regulate mechanical, chemical, acoustic, adhesive, thermal, electrical and optical functions of the structure. In this research, we purposely deploy the principles and mechanics of instabilities to achieve sudden pattern transformations in the composite structure. Instability principles such as buckling and wrinkling are favorable mechanisms as they are elastic and consequently also reversible. Furthermore, the ability to actively alter the microstructure can enable on-demand tunability of the structure’s attributes and functions to provide, for example, active control of wave propagation phenomenon (e.g., phononic and photonic), mechanical stiffness and deformation, energy absorption properties, and material swelling and growth.

12:00 PM-2:00PM	Adaptive Optofluidic Encoding of Particles	Mo Chen, G3

Colloids of a few to tens of microns have shown great promise in various applications. For practical purposes, colloidal building blocks which self-assemble into operational device is sometimes desired. This preprogrammed assembly requires large quantities of colloidal building blocks with well-defined shape, size and composition, which cannot be provided with existing techniques.

A new fabrication technique is presented combining Stop-Flow Lithography (SFL) and a spatial light modulator (SLM). With this technique, geometrically anisotropic colloid particles are generated at high throughput (~10^6 particles/h). Fabrication of functional materials such as hydrogel and shape memory polymer is proven compatible. All candidate materials can be combined to form chemically anisotropic colloid particles like Janus particles. Further, the feedback mechanism of our system allows adaptive fabrication according to detected suspensions. On the one hand, this extends our material selection pool for the building blocks, as materials incompatible with direct SFL fabrication are incorporated by encapsulation; on the other hand, this capability applies to single cell encapsulation and graphical encoding. This powerful tool facilitates fabrication of complex building blocks and potentially promotes self-assembly and application of colloids.

12:00 PM-2:00PM	Design and Fabrication of Granular Materials for Surface Acoustic Wave	Tian Gan, G3

Granular materials with structural discreteness and periodicity can lead to novel propagation behaviors of mechanical waves. A type of granular materials consisting of close-packed, ordered arrays of elastic particles in contact has been shown to support a wide range of unconventional linear and nonlinear wave phenomena. However, most studies on granular materials involve only macroscopic particles and correspondingly the wave is limited within the low frequency range. We will employ the self-assembly technique to fabricate granular materials composed of microspheres/nanospheres in order to explore the wave propagation in microscale system at higher frequencies ~100MHz. The microscopic system is not a simply scaled-down version of the macroscopic system, so qualitatively different dynamics and novel wave phenomenon in the microscale system are also expected.