Session 2A2
Plasmonic Nanophotonics

Optical Response of Metal Nanoparticle Chains

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The excitation of surface plasmon on metal nanoparticles is interesting to many researchers because of its variety of applications. By arranging nanoparticles in different ways, many interesting properties can be observed [1]. For metal nanoparticle chains, there is a red (blue) shift on the plasmon resonant frequency for longitudinal (transverse) excitation. Numerical and experimental results on this splitting of plasmon resonant frequency for Ag nanoparticle chains with diameters around 10 nm are compared by Sweatlock et al. recently [2]. They used finite integration techniques (which may contains artifacts) for the numerical calculations [2]. Here, we present the results calculated by the multiple scattering theory (MST) and the ways to understand the results using simple models.

MST calculations are performed on the extinction of finite silver nanosphere chains embedded in glass matrix. The transmission and reflection of an infinite 2D arrays of silver nanospheres are also calculated to understand the interaction between nanoparticle chains. The results are in agreement with recent experiments. The splitting of plasmon-resonance modes associated with different polarizations of the incident light is further understood by employing simple models. Results on the effect of order and disorder in nanoparticle chains are also presented.

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Focusing Using Single-negative Medium

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A thin slab of single negative material, such as a silver slab, is known as the poorman's version of the perfect lens proposed by Pendry. It can also act as a super lens in the sense that it can break the classical diffraction limit for the TM wave in the near field. In this work, we analyze the condition for image formation for a thin (nanoscale) slab and show that there exists quantized conditions for the optical path in order for a slab to behave like a lens, and both the silver (single negative) thin slab and the perfect (double negative) lens become special cases of such condition. This quantization serves to be an extension of the focusing criteria. Moreover, by employing an additional resonance configuration, high transmittance of light can be induced and the lens functions like the perfect lens, and yet it is much simpler in structure. This improvement follows directly from the established quantization rule.

Fabrication and Characterization of High Sensitivity Visible Light Photonic Crystal Biosensors

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We report the fabrication and characterization of improved Photonic Crystal (PC) biosensors operating in the visible region of the electromagnetic spectrum (instead of infrared) and based on a nanoporous low refractive index surface structure. These devices display a high degree of sensitivity to surface-specific bimolecular interactions and very low sensitivity to nonspecific bulk refractive index variations. Such properties are extremely attractive in a biosensor, as the Signal to Noise Ratio (SNR) is improved and consequently the detection resolution of the bio-assay is enhanced. Rigorous Coupled Wave Analysis (RCWA) is used to model the device and show that its superior characteristics arise from stronger confinement of evanescent electric fields close to its surface (Figure 1). Electron Beam Lithography (EBL) is used to fabricate a nano-structure 'mold' (Figure 2) from which nano-replicas are created using PDMS stamps at high throughput and low cost. The replicated nanostructures are coated with a high refractive index dielectric (TiO_2) to form the final device (Figure 3). Results of the Bulk Sensitivity and Surface Sensitivity of the device are reported and compared to devices operating in the same manner but in longer wavelength regimes.

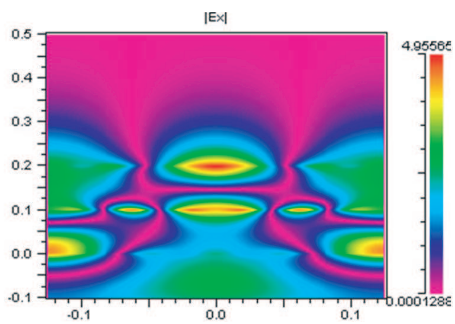

Figure 1: RCWA modeling results showing strongly confined electric fields at resonance.

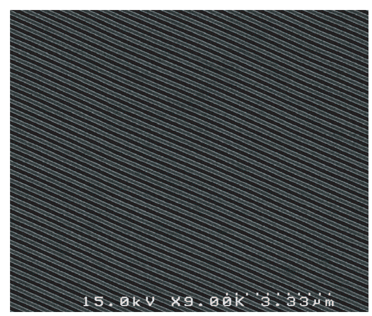

Figure 2: SEM micrograph of the surface structure of the 'mold' from which devices are made. The structure is comprised of linear features, with a period of 250 nm.

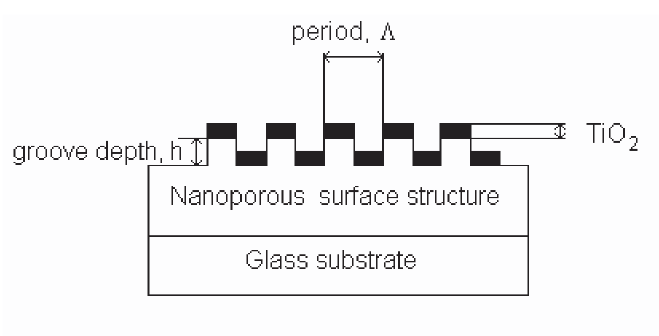

Figure 3: Cross section structure of the photonic crystal device. The resonance wavelength depends on the values of h, Λ and thickness of the TiO_2 layer.

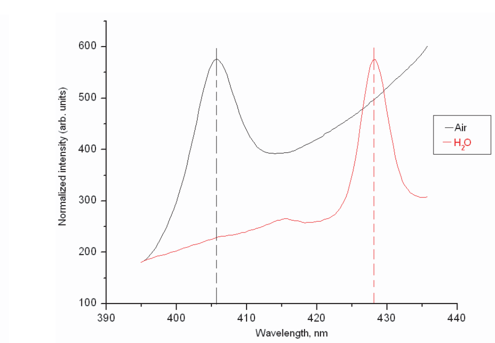

Figure 4: Normalized reflectance spectra shift of the PC device in air (black) and water (red) corresponding to a bulk refractive index change.

Thermal Emission by Photonic Micro-textured Surfaces

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Ordinary metallic photonic crystals (PCS) have photonic band gaps in which the density of states is suppressed. Thermal emission of photons is suppressed in those frequencies, and is enhanced in other frequencies. We considered the thermal emission property of a photonic crystal and compared it with that of a simple micro-textured surface. The proposed micro-textured surface exhibits a similar optical thermal emission spectrum with that of a photonic crystal. In addition, the present proposed topology also suppress emission in low frequencies. This simple and yet effective surface structure inspires new directions in fabricating thermal emitting materials.

Calculation of Scattering from Polyethylene Particles Compared with Terahertz Measurements

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The Terahertz (THz) portion of the electromagnetic (EM) spectrum that lies between the microwave and infra-red spectrums ($1\,\mathrm{THz} = 10^{12}\,\mathrm{Hz}$) and has remained almost entirely unexplored due to difficulties in the generation and detection of energy at these frequencies. With the advent of ultrafast optical laser technologies, the ability to generate and detect energy is enabling the exploration within this so-called THz-gap. One potentially promising application of THz spectroscopy is the detection of explosive materials, and initial measurements indicate that explosives may have unique spectral characteristics in this region. However, the scattering physics that gives rise to these signatures is only beginning to be explored, and may be critically effected by the granular composition of most explosive materials.

In this paper, formulations for the EM scattering from collections of spherical scatterers are developed and applied to granular materials representative of explosive materials. Calculations are presented for pellets comprised of polyethylene (PE) powder. This spectrophotometric grade powder is manufactured by Sigma-Aldrich and has been used as a pellet binder in experiments focused on the detection of RDX explosive. In this paper, the transmission characteristics of PE itself are computed using a random media model consisting of uniformly distributed Mie spheres with a log-normal size distribution. The result of the Monte Carlo computation is compared with FTIR spectroscopy acquired from PE samples obtained from two different manufactured bins, and the two bins were observed to have markedly different grain size distributions. As expected, the observed scattering is strongly grain-size dependent. Implications and future research on this topic are discussed in the context of evaluating the ability to use THz spectroscopy for explosives detection.

Slow Electromagnetic Waves and Resonance Phenomena in Photonic Crystals

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The problem of slowing down electromagnetic (EM) waves has been extensively discussed in the literature. Such a possibility can be useful in a variety of microwave and optical applications. Our objective is to compare different ways to achieve this effect in linear dispersive media such as photonic crystals. A very low group velocity $v_g = \partial\omega/\partial k$ corresponds to stationary points of the dispersion relation $\omega(k)$. In periodic layered media, the dispersion relations can develop only three kinds of stationary points. Assuming that the values ω_s and k_s correspond to a stationary point, the above three possibilities can be defined as follows

1. The vicinity of a band edge, where $\omega - \omega_s \sim (k - k_s)^2$
2. The vicinity of a stationary inflection point, where $\omega - \omega_s \sim (k - k_s)^3$.
3. The vicinity of a degenerate band edge, where $\omega - \omega_s \sim (k - k_s)^4$.

The case 1 relates to a common EM band edge, it can be found in any periodic array. By contrast, the cases 2 and 3 can only occur in periodic arrays with special geometry [1-6]. In all three cases the group velocity v_g vanishes as ω approaches ω_s. But when the efficiency of conversion of incident light into the slow mode is concerned, the three cases are fundamentally different from one other. Consider plane EM wave incident on semi-infinite photonic crystal with dispersion relation having a stationary point at $\omega = \omega_s$. What happens if the wave frequency ω approaches ω_s? Let S be the energy flux associated with the slow wave transmitted inside the crystal. It turns out that in the vicinity of photonic band edge (case 1), the energy flux S of the transmitted wave vanishes along with the group velocity $v_g = \partial\omega/\partial k$. This implies total reflection of the incident wave as $\omega \to \omega_s$.

By contrast, in the vicinity of stationary inflection point (case 2), the energy flux $\boldsymbol{S}$ remains finite even at $\omega = \omega_s$, contrary to the fact that the wave group velocity vanishes. The latter implies that the wave amplitude inside the photonic crystal increases dramatically. In steady-state regime, the incident wave with $\omega = \omega_s$, after entering the periodic structure, gets almost 100% converted into a non-Bloch frozen mode with the energy density growing quadratically with the distance from the photonic crystal boundary. Thus, the case 2 provides ideal conditions for slowing down the EM wave by a semi-infinite photonic crystal.

Finally, in the vicinity of degenerate band edge (case 3), the energy flux $\boldsymbol{S}$ vanishes, similarly to what we had in the vicinity of a regular band edge (case 1). At the same time, the electromagnetic energy density inside the periodic structure now becomes enormous, similarly to what takes place in the vicinity of stationary inflection point (case 2).

Finite bounded periodic structures supporting the frozen mode regime, can also display a giant Fabry-Perot cavity resonance associated with the degenerate photonic band edge [6]. In contrast to the regular transmission band edge resonance, in the case of degenerate band edge the field intensity enhancement is proportional to the forth degree of the number of layers in the stack. This allows to drastically reduce the dimensions of the resonant cavity without compromising on performance. This effect can be realized not only in bounded photonic crystals, but also in a waveguide environment, as well as in a finite array of coupled resonators.

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The Dispersion Relations of the Sub-skin-depth Metal Particles

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According to Maxwell's equations, if sizes of conductors are much larger than the incident wavelength, the electromagnetic fields are forbidden inside the conductor, only a very thin layer is penetrated by electromagnetic fields, this thin layer is the so-called "skin depth". Under optical waves, the skin depth is about 20 nanometers for noble metals, thus, if the size of the metal particle is less than the skin depth, the particle will be possible to be full of the electromagnetic fields. Based on such point of view, it is easy to understand why the absorption of optical waves only happened in sub-micro particles [1].

There are some interesting phenomena should be further studied in the sub-skin-depth optics. For example, the internal electric field of the optical wave can excite volume plasmons, for classical electromagnetic theories, volume plasmons can be excited only when the incident frequency is higher than the plasma frequency [2]. It means that both the surface plasmon and volume plasmon are able to coexist in sub-skin-depth space, the coupling of these two type plasmons suggests that the dispersion relation of the sub-skin-depth particle should be quite different from the classical one. We will try to derive the novel dispersion relation from fundamental theories and verify it by experiments and numerical simulations.

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Photonic Crystal Made of Dichroic Filters

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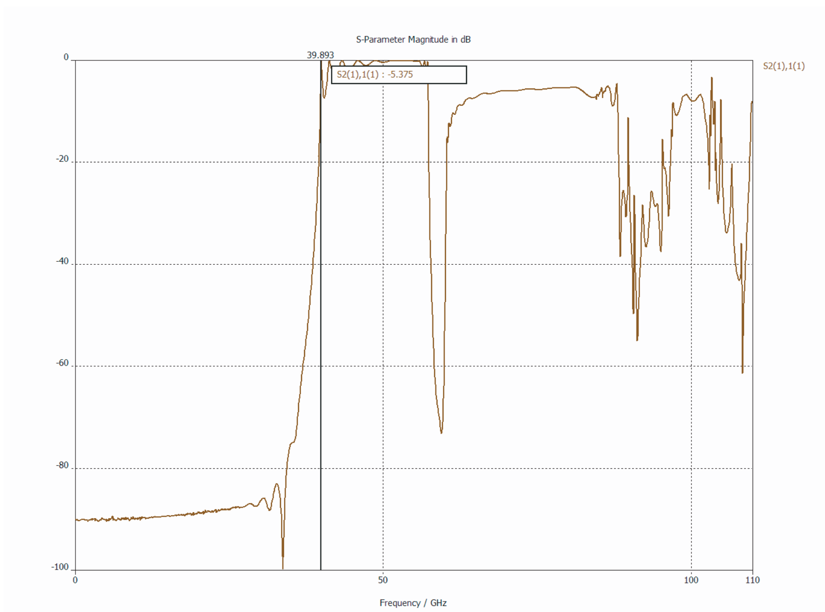
By using a convencional dichroic filter operating in the Millimeter Waves, made of a metallic plate of 0.5 mm thickness drilled with a two dimensional hole array with 4 mm hole diameter and 5 mm geometrical period in both transversal dimensions, we have designed a Photonic Crystal consisting of stacking several plates separated by air with a longitudinal geometrical period of 2 mm. In spite of the fact that the longitudinal periodicity predicts a bandgap around 85 GHz, a lower bandgap is also present at 57 GHz due to transversal periodicity. Possible applications as frequency selective surfaces are discussed.



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Magnonic-photonic Crystals with Application to Tunable Microwave Devices

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Magnonic and magneto-photonic crystals based on magnetic materials have become a field of increasing interest in recent years. One- and two-dimensional (1-D and 2-D) periodic layer structures can be engineered by varying the magnetic properties such as magnetization and anisotropy using magnetic-non-magnetic, all-magnetic, ferro- and anti-ferromagnetic lattices. A variety of tunable microwave and magnetooptic devices based on propagation of magnetostatic (or spin) waves in such magnonic and magneto-photonic crystals can be envisaged.

In this work, the dispersion and bandgap characteristics of magnetostatic waves propagating in 1- and 2-D magnonic and magneto-photonic crystals are first formulated using Maxwell's and Landau-Lifshitz equations. Specifically, the 2-D periodic structure with magnetization inhomogeneity facilitated by creating 2-D array of holes in yttrium iron garnet (YIG) ferromagnetic thin films are analyzed in detail. The resulting dispersion characteristics depend on the periodicity and depth of the holes as well as the bias magnetic field. The corresponding experimental studies were carried out at the frequencny range of 2.0 to 6.0 GHz. The measured dispersion characteristics of the magnetostatic waves show magnetic field-dependent bandgaps. Such magnetically-tunable frequency bandgaps should facilitate control and processing of microwaves. The findings of both theoretical and experimental studies will be presented.

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