審 査 の 結 果 の 要 旨

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Plasmonic nanofin cavity structures for spectroscopic applications
PhD thesis defended by Ya-Lun HO

Interaction of light with metal sub-wavelength structures (hereafter nanostructures) has revealed new properties of light, such as light ability to pass through an array of nanoholes. Strong light confinement on the metal nanostructures in the form of a plasmon resonance was found to be at the origin of this far field property. Following this discovery, a wide variety of nanostructures have been studied and nanostructure functionalities reported such as detection of trace amount of molecules by spectroscopy of plasmon resonances and identification of trace amount of molecules by surface enhanced Raman spectroscopy. Two strategies have been employed to achieve strong light confinement on nanostructures, namely, isolated nanostructures (e.g., oblong particles dispersed in a solution) and periodic array of two-dimensional horizontal nanostructures on substrates (e.g., nano antenna on a substrate). Plasmonic resonances in V-groove nanostructures have also been reported, suggesting the use of a new class of vertical plasmonic resonances. This thesis focuses on the use of metal nanofins for light confinement using plasmonic resonance on the vertical plane of the nanofins. This new class of resonant nanostructures offer a wide variety of properties exploited in the design of three different structures, namely, nanofin cavity structure, U-cavity structure and hybrid channel-cavity structure.

The manuscript consists of six chapters.

The first chapter gives an introduction to the field of subwavelength nanostructures used to confine light. Localized hot spots excited at the corners and edges of nanostructures are first introduced and their limitations in terms of resonance width, resonance tunability and signal modulation are mentioned. Then, plasmonic cavities made in the form of nanofins are introduced as a possible means to obtain sharp and tunable resonances with large signal modulations. Justification for the choice of the near infrared and infrared regions for the experimental demonstrations is given.

Chapter two describes the nano-fin structure arranged in a periodic array of nano-fin cavity enabling spectral light filtering with a very narrow band pass. The narrow spectral band of reflected light at the resonance of the nanofin cavity originates in the coupling of a cavity mode and a surface plasmon mode. For non-resonant conditions, light is transmitted through the structure without being reflected, so that spectral selectivity is achieved at resonance for reflected light. The spectral selectivity is controlled by varying the period of the structure. Tunable spectral selectivity for the nanofin structure was demonstrated in the infrared region (5.5 to 7 µm) with two fabricated structures having a different period and full widths at half maximum below 200 nm were obtained. Possible applications of the proposed structure in tunable light filtering (e.g., MEMS based spectrometer) and light switching are mentioned.

Chapter three describes the hollow U-cavity structure, which is designed to exploit a resonance between the vertical nano-fins resulting in the formation of symmetric optical vortices. This symmetry is used to further enhance the optical vortex by placing a mirror at the symmetry plane, so that a stronger optical vortex pattern is obtained and complete light trapping achieved. That is, an ideal U-cavity structure has zero reflection and zero transmission at its resonance. This resonance results in a strong and sharp reflectance dip, whose position is sensitive to minute change in the refractive index in the vicinity of the cavity walls as demonstrated in the detection of biomaterials in a protein-ligand scheme.

Chapter four is a direct application of Chapter three results, making use of the property of independent light trapping in the U-cavity. A simple and low-cost design of a sensing substrate consisting of non-adjacent U-cavities is proposed and fabricated using standard lithography process. This sensing substrate demonstrates the ability of the U-cavity to independently trap light and is evaluated by determining the structure sensitivity to change in surrounding refractive index.

Chapter five describes the hybrid channel-cavity structure which is designed to absorb light selectively in the sub-wavelength vertical channel of the structure. The narrow band absorption originates in the coupling of a resonant channel mode to a surface plasmon resonance. The wavelength of the resonance is controlled by changing the period of the structure, thus readily realizing spectral selectivity by a simple variation in the structure period. Actual structures have been fabricated and exhibited characteristics in agreement with simulation. Particularly, a very narrow full width at half maximum (~20 nm) was obtained experimentally. Adding electrical detection means to the hybrid channel-cavity structure for the absorbed light should therefore realize spectral detection of light without the need for light dispersion. This idea still would require an experimental demonstration.

The conclusions of the manuscript are given in Chapter six.

Ya-Lun HO has delivered five publications in per-reviewed international scientific journals and one proceeding as a first author.

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