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Characterization of Nanorod Structure Using Spectroscopic Ellipsometry

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Abstract

We investigate the resonance modes of gold nanorods on an Indium tin oxide (ITO) coated glass substrate using spectroscopic ellipsometry. The unit cell of the structure investigated is composed of two gold nanorods with differing lengths. In such a structure, we can excite the bright resoance and the dark resonance modes. Numerical simulation of the gold nanorod on substrate was performed with the bright resonance mode at 825.0 nm and the dark resonance mode at 1107.1 nm respectively. Using spectroscopic ellipsometry we optically characterize the fabricated gold nanostructure, with the bright resonance mode at 700.0 nm and the dark resonance mode at 1350.0 nm respectively. The experimental results from ellipsometry show a good agreement with the results from simulation.

Keywords

Spectroscopy, Ellipsometry, Nanorod, Resonance Modes

1. Introduction

The advances in nanofabrication procedures have led to an evolution in the experimental study of nanostructures. The use of techniques such as the electron beam lithography [1]-[5] and nanoimprint lithography [6]-[8] has enabled the fabrication of structures with dimensions in the nanometer range, thereby enhancing further research in nanofabricated structures. In a structure with asymmetry, the dark or subradiant mode is shown to be excited [9]-[13]. In our study, our focus is mainly on the optical characterization of the fabricated structure. With advances in nano fabrication techniques also comes with it improved methods for optical characterization of the fabricated nanostructures. A common technique for the optical characterization of nanostructures involves normal incidence transmission and reflection measurements [14].

Another technique which can be employed is the method of ellipsometry, a method dependent on the changes

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in amplitude and phase of polarized light due to their interaction with matter. Measurements with ellipsometer are non contact thereby making it a suitable tool for the investigation of nanostructures. In ellipsometry the changes in the polarization state of light after reflection on a sample or after transmission through a sample can be measured and from these different properties of materials can be established. The ellipsometer is able to measure the amplitude ratio and also the phase difference between the p-polarized and the s-polarized light. The ellipsometer offers the added advantage of obtaining phase information, thereby making it a powerful optical characterization technique [15] [16]. Different nanostructures such as split ring resonators [7], fishnet metamaterial [17] [18] etc. have been characterized using the method of ellipsometry. The method of ellipsometry has also been shown to be very useful in determining the thickness and properties of thin films [19] [20]. In this work, I employ the method of spectroscopic ellipsometry to optically characterize a fabricated gold nanorod structure. The structure whose unit cell is composed of two gold nanorods of unequal lengths is simulated and the bright and dark resonances for electromagnetic wave incident normally on the structure are obtained. Using the method of ellipsometer we then optically characterized the fabricated gold nanorod on glass substrate. Our experimental results from ellipsometry are found to be in agreement with the results from simulation. Also, aside from the identifying the resonances from the ellipsometric experimental measurements, by using the method of ellipsometry we have obtained the phase information of the fabricated structure.

2. Design and Fabrication

The gold rod on substrate under investigation is presented here. The structure is composed of gold nanorods deposited on an Indium Tin Oxide (ITO) coated glass substrate. A schematic of the unit cell of the structure is shown in **Figure 1**, which is composed of two gold nanorod of unequal lengths deposited on a substrate. The lengths of the gold nanorods are L1 and L2 respectively. The gold nanorods L1 and L2 are separated by a distance d of 50nm as shown in **Figure 1**. One of the gold nanorods of the unit cell has a length L1 of 170 nm while the other gold nanorod of the unit cell has a length L2 of 200 nm respectively. The gold nanorods L1 and L2 both have equal width w of 70 nm each and an equal thickness of 30 nm. The unit cell is such that its periodicity is 300 nm along the x direction and 300 nm along y direction respectively. The index of the glass substrate is taken to be 1.5. The permittivity of the ITO is 3.8 while its thickness is 25 nm.

We performed the electromagnetic simulation of the gold nanorod on ITO coated glass substrate structure of **Figure 1** using finite difference time domain (FDTD). With the incident wave normal to the plane containing the gold nanorods of **Figure 1**, and with the electric field component along the length of the gold nanorods or x-direction, we obtain the transmission spectrum for the gold nanorod on ITO coated glass substrate. The transmission spectrum from simulation for the structure of **Figure 1** is depicted in **Figure 2**. From the transmission spectrum, two resonance dips can be observed. The first resonance dip is at the shorter wavelength of 825.0 nm and has a broad profile. The second resonance dip is at the longer wavelength of 1107.1 nm and has a narrow profile compared to the first resonance. The first resonance at 825.0 nm is bright resonant mode with symmetric electric field distribution while the second resonance at 1107.1 nm is a dark resonant mode with a characteristic

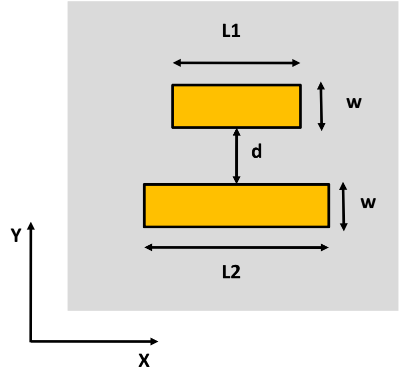

Figure 1. Gold nanorods on an Indium tin oxide (ITO) coated glass substrate. The gold has a thickness of 30 nm with lengths L1 of 170 nm and L2 of 200 nm respectively. The gold nanorods have equal widths of 70 nm.

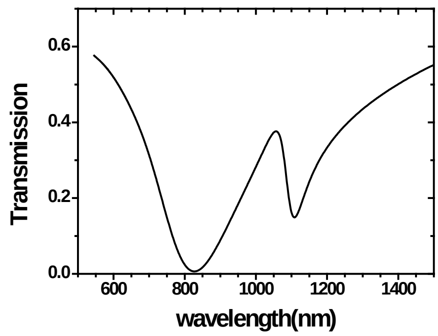

Figure 2. Transmission spectra versus wavelength for the gold nanorod on ITO coated glass substrate with resonances at 825.0 nm and 1107.1 nm.

anti-symmetric electric field distribution [9]-[13]. It is worth mentioning that for the case where the length L1 is equal to L2 in **Figure 1**, only the shorter wavelength resonance having a broad spectrum is obtained (not shown). However, for lengths L1 not equal to L2 we can excite the dark resonance at the longer wavelength as shown in **Figure 2**.

The gold nanorod on ITO coated glass substrate shown in **Figure 1** was fabricated and the basic fabrication processes are outlined. After cleaning the ITO-coated glass substrate it was spin coated with polymethyl metacrylate (PMMA) which is a positive photoresist [21]. Afterwards, the sample is then exposed to electron beam lithography (EBL) for the nano structure pattern writing on the PMMA with an exposure dose of 500 mJ/cm^2. After the pattern writing, the sample is then developed using a developer solution of methyl isobutyl ketonebonds (MIBK). Following this, the sample is then rinsed in a solution of Isopropyl alcohol (IPA) and then dried using nitrogen flow. A scanning electron microscope (SEM) image of the fabricated structure of **Figure 1** is shown **Figure 3**.

3. Optical Characterization

The optical characterization of the fabricated gold nanorod on ITO coated glass substrate (**Figure 3**), was carried out using the Variable Angle Spectroscopic Ellipsometer (VASE). Using the method of ellipsometry, the polarization ratios for oblique incident reflected and transmitted beams can be obtained. Ellipsometry uses the ratio of polarized reflection coefficients ρ which can be expressed in terms of the ellipsometric angles Ψ and Δ, given by

$$\rho = \frac{R_p}{R_s} = \tan \Psi e^{i\Delta}$$

where Ψ is the amplitude ratio of reflection coefficient and Δ is the phase difference of the reflection coefficient for the p and s directions respectively [7] [15] [16]. R_p is the complex-valued reflection coefficient for light polarized parallel (p-polarized) to the plane of incidence and R_s is the complex-valued reflection coefficient for light polarized perpendicular (s-polarized) to the plane of incidence [15]. The fabricated sample shown in **Figure 3** is characterized under variable angle spectroscopic ellipsometry (VASE) for angles of incidence (AOI) ranging from 0˚ to 35˚ at increments of 5˚. In our measurements, the incidence plane is the xz plane of **Figure 1** and the electric field is along the length of the gold nanorod or along the x-axis as shown in **Figure 1**. The measured representative VASE data (Ψ and Δ) of the ellipsometric angles for the sample for angles of incidence (AOI) from 0˚ to 35˚ are shown in **Figure 4** and **Figure 5** respectively.

4. Results and Discussion

The VASE Ψ spectrum in **Figure 4** is the p-polarized spectra of the fabricated nanostructure (**Figure 4**) in transmission, which depicts the measured Ψ versus the wavelength. As can be seen from **Figure 4**, a first resonance dip is observed at the shorter wavelength of about 700 nm and a second dip observed at the longer wavelength of about 1350 nm. The first dip at about 700 nm corresponds to the bright resonance mode. This resonant

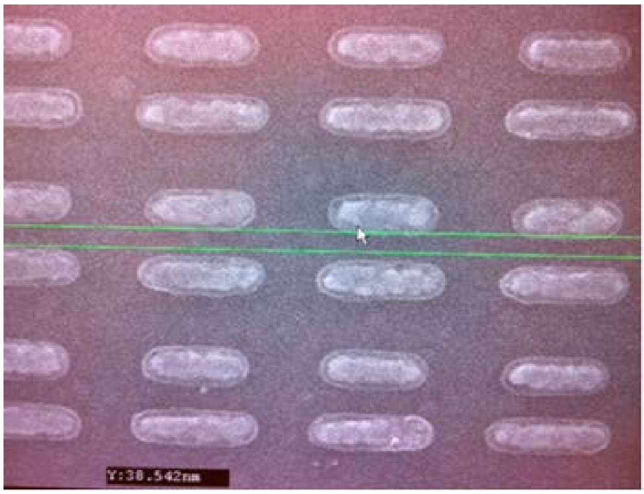

Figure 3. Scanning electron microscope (SEM) image of the fabricated gold nanorods on an Indium tin oxide (ITO) coated glass substrate.

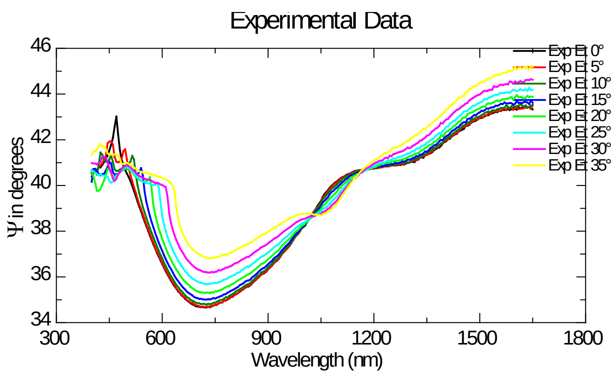

Figure 4. Representative VASE Ψ spectra for the transmission ellipsometry of the gold nanostructure. Ψ in degrees versus wavelength in nanometers for angles of incidence (AOI) from 0˚ to 35˚ at intervals of 5˚. The incidence plane is perpendicular to the gold nanorods (p-polarization).

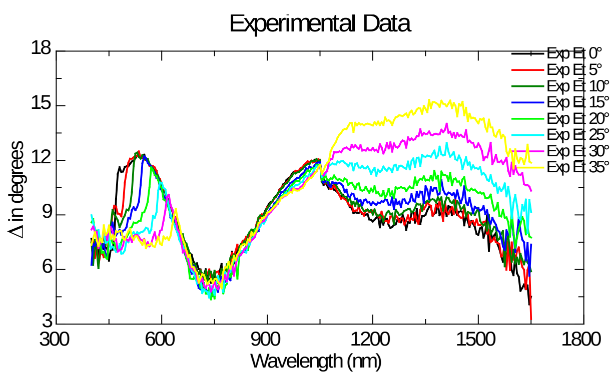

Figure 5. Representative VASE Δ spectra for the transmission ellipsometry of the gold nanostructure. The Δ in degrees versus wavelength in nanometers for angles of incidence from 0˚ to 35˚. The incidence plane is perpendicular to the gold nanorods (p-polarization).

mode at about 700 nm is the electric resonance with a characteristic broad resonance profile, having low quality factor owing to the low loss nature of the mode. These dips correspond to the resonance modes of the gold nanostructure as depicted in **Figure 2**.

In **Figure 4** of the representative VASE Ψ spectra, a second dip can be observed at the longer wavelength of 1350 nm. This second resonance mode at the longer wavelength of about 1350 nm has a characteristic narrow profile and consequently a high quality factor, unlike the first resonance at 700 nm.

Likewise, **Figure 5** shows the measured VASE Δ spectra for the gold nanostructure (**Figure 3**) against wavelength for incidence angles (AOI) from 0˚ to 35˚, at intervals of 5˚. From the experimental measurement (**Figure 5**), a first resonance at the shorter wavelength of about 700 nm is observed, which corresponds to the resonance mode observed from the VASE Ψ spectra of **Figure 4**. Also from the VASE Δ spectra of **Figure 4**, a second resonance mode at the longer wavelength of about 1350 nm is observed, similar to the observed second resonance in the VASE Ψ spectra of **Figure 5**, consistent with experimental results. It is worth noting that the variance of the resonance position in **Figure 2** with the experimentally obtained spectrum of **Figure 4** and **Figure 5** can be attributed to imperfections in the fabrication procedures.

5. Conclusion

In this work the spectroscopic ellipsometry has been used in investigating a gold nanorod on an ITO coated glass substrate. The optical spectrum of the fabricated gold nanorod was experimentally obtained using ellipsometry. From the experimental results in **Figure 4** and **Figure 5** the observed resonance of the gold nanorod is in agreement with that from the simulated results in **Figure 2**. The discrepancy in the positions of resonance of the experimental measurements and simulation results is attributed to fabrication imperfections. The sensitive nature of ellipsometry measurements to polarization changes has enabled the clear identification of the resonant modes of the fabricated gold nanorod on Indium tin oxide (ITO) coated glass substrate.

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