Theoretical Study Of Role Of Ag Film Thickness On Surface Plasmon Resonance In P3HT: PCBM/Ag Film

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Abstract. Surface Plasmon resonance (SPR) technique is used to characterize the thickness of nanometer range metallic films. The poly (3-hexylthiophene) (P3HT) and phenyl-C61-butyric acid methyl ester (PCBM) is used as the most efficient solar cell. In this paper, we have theoretically studied the variation of reflectance of medium with the thickness of Ag film on P3HT-PCBM: Ag composite film, which is deposited on prism surface. He-Ne laser at exciting wavelength of 632.8 nm is used for theoretical investigation for SPR study. The reflectance of P3HT-PCBM: Ag film becomes zero at 51 nm thickness of nano silver film and 23 nm thickness of P3HT-PCBM film. The result shows strong dependence of reflectance on thickness of P3HT-PCBM: Ag film. Surface Plasmon resonance in nanostructure silver film is responsible for this unusual effect.

INTRODUCTION

T Surface Plasmon resonance [SPR] is used to monitor the binding events between molecules ranging from ions to viruses. It is a label free detection technique that enables us to monitor the binding, kinetics, affinity, specificity and concentration. Surface Plasmon resonance (SPR) effect depends on excitation wavelength of radiation source, thickness and refractive index of metallic film as well as dielectric material [1]. The recent applications of surface Plasmon's are in Solar cells, biomedical sensing devices [2, 3] and sub wavelength optical devices and components [4]. We can detect a change in refractive index of the medium signifying the existence or nonexistence of target molecule in this technique. Because of the sensing technique involves physical interaction and not chemical, the properties of target molecule remains unchanged. Any changes in the refractive index, SPR react very sensitive. Using SPR phenomenon it is possible to measure small changes in refractive index of a thin metallic film.

The poly(3-hexylthiophene)(P3HT) and [5]-phenyl C61-butyric acid methyl ester (PCBM) blends is one of the promising organic solar cell materials. It is the most efficient fullerene derivate-based donor-acceptor polymer so far [6]. P3HT: PCBM has reported efficiency as high as 5%, which is unusual in the organic cell material. Their structures are as shown (Fig 1). It is the excitation of the π-orbit electron in P3HT that gives the photovoltaic effect in the blend [7].

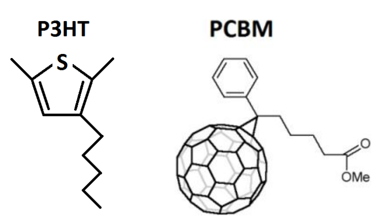

FIGURE 1: Chemical structure of PH3T and PCBM

Organic polymers have wider gap than semiconductors. Thus, they give an efficient absorption at near UV part. So is PH3T: PCBM blends. The gap of the blend is approximately 1.8eV. Now plasmonics researchers are turning their attention to photovoltaic, where design approaches based on plasmonics can be used to improve absorption in photovoltaic devices, permitting a considerable reduction in the physical thickness of solar photovoltaic absorber layers, and yielding new options for solar-cell design.

THEORTEICAL MODELLING

Consider a three layer sensing structure which forms the basis of surface Plasmon resonance sensing device as shown in the Figure 2. For the purpose of this derivation, Kretschmann-Raether Configuration is utilized, as it is easy to verify experimentally.

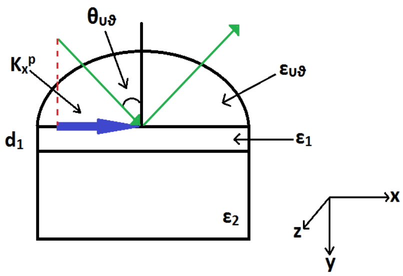

Figure 2. Three layer model

The equations of reflectivity for 3 layer model given as

$$R = |r_{Pr12}|^2 = \left|\frac{r_{Pr1}+r_{12}e^{2iK_{z1}d_1}}{1+r_{Pr1}.r_{12}e^{2iK_{z1}d_1}}\right|^2 \quad (1)$$

$$r_{ab} = \frac{\tilde{n}_b\cos\theta_a - \tilde{n}_a\cos\theta_b}{\tilde{n}_b\cos\theta_a + \tilde{n}_a\cos\theta_b} = \frac{\left(\frac{\cos\theta_a}{\tilde{n}_a}\right)-\left(\frac{\cos\theta_b}{\tilde{n}_b}\right)}{\left(\frac{\cos\theta_a}{\tilde{n}_a}\right)+\left(\frac{\cos\theta_b}{\tilde{n}_b}\right)} \quad (2)$$

$$n_{Pr}\sin\theta_{Pr} = \tilde{n}_1\sin\theta_1 = \tilde{n}_2\sin\theta_2$$

$$\tilde{n}_a\cos\theta_a = \tilde{n}_a(1-\sin^2\theta_2)^{1/2} = \tilde{n}_a\left[1-\left(\frac{n_{Pr}}{\tilde{n}_a}\right)^2\sin^2\theta_{Pr}\right]^{1/2} = \left[\tilde{n}_a{}^2 - n_{Pr}{}^2\sin^2\theta_{Pr}\right]^{1/2} \quad (3)$$

Using medium a as prism and medium b as Metal, we get

$$r_{Pr1} = \frac{\left(\frac{\cos\theta_{Pr}}{n_{Pr}}\right) - \frac{(\tilde{\varepsilon}_1 - n_{Pr}{}^2\sin^2\theta_{Pr})^{1/2}}{\tilde{\varepsilon}_1}}{\left(\frac{\cos\theta_{Pr}}{n_{Pr}}\right) + \frac{(\tilde{\varepsilon}_1 - n_{Pr}{}^2\sin^2\theta_{Pr})^{1/2}}{\tilde{\varepsilon}_1}} \quad (4)$$

$$r_{Pr12} = \frac{r_{Pr1}+r_{12}e^{2iK_{z1}d_1}}{1+r_{Pr1}.r_{12}e^{2iK_{z1}d_1}} \quad (5)$$

Using binomial expansion in above equation, and expanding result, we get

$$r_{Pr12} = r_{Pr1} + r_{12}(1-r_{Pr1}{}^2)e^{2iK_{z1}d_1} + r_{12}{}^2(-r_{Pr1})(1-r_{Pr1}{}^2)e^{4iK_{z1}d_1} + \cdots$$

$$r_{Pr12} = r_{Pr1} + t_{Pr1}\cdot r_{12}\cdot t_{1Pr}e^{2iK_{z1}d_1} + t_{Pr1}\cdot r_{12}\cdot r_{Pr1}\cdot r_{21}\cdot t_{1Pr}e^{4iK_{z1}d_1} + \cdots$$

SILVER FILM THICKNESS DEPENDENCE

The thickness dependence of Silver film on surface Plasmon resonance (SPR) curve for prism-silver-air three layer arrangements is shown in Figure 3. A BK7 prism with a refractive index of 1.7225 was chosen for simulation. The thickness of P3HT: PCBM film is 23 nm. The wavelength of the laser beam was selected to be 632.8 nm. Later the silver film thickness was varied between 36 nm to 57 nm with a step size of 2 nm. It is apparent from the figure 3 that a broad curve is obtained for 36 nm film thickness and the SPR curve becomes narrower with increase in film thickness. Narrow dip can produce improved resolution with a better detection of refractive index variation. But beyond 51 nm film thickness, the reflectivity increases showing a decrease in the dip. The dip of the surface Plasmon resonance curve corresponds to the absorption of energy from evanescent wave to surface Plasmon's [8]. So it indicates that greater the depth of the dip, better the efficiency of resonance and thus the reflectance at SPR angle is found to have the minimum value at optimum metal film thickness[9]. Thus, it can be concluded that a silver film thickness of 51 ± 2 nm, can be considered as suitable for performing surface Plasmon resonance experiments.

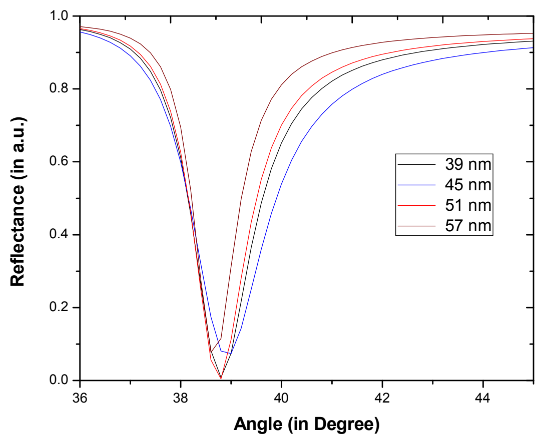

FIGURE 3. Dependence of SPR curve on the thickness of metal (silver) film. The parameters used in simulation are Prism BK7 (RI: 1.7225), wavelength – 632.8 nm. The thickness of P3HT: PCBM film is 23 nm.

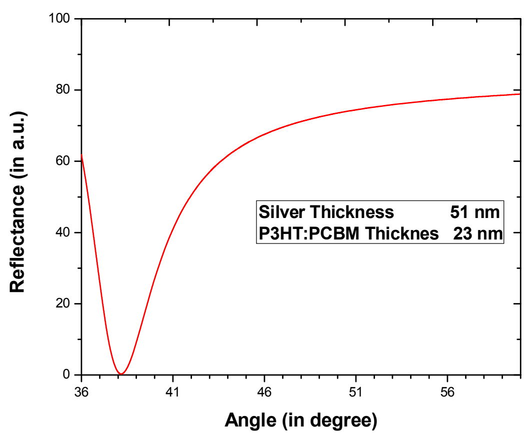

FIGURE 4. The reflectance of P3HT-PCBM: Ag film becomes zero at 51 nm thickness of nano Ag film and 23 nm of P3HT-PCBM film.

CONCLUSIONS

The reflectance becomes zero at 51 nm thickness of nano silver film and 23 nm thickness of P3HT-PCBM film. The result shows strong dependence of reflectance on thickness of P3HT-PCBM: Au film. The localized surface Plasmon resonance in nanostructure silver film is responsible for this unusual effect. The importance of developing efficient solar cells is well known. The sun supplies us a clean and unlimited resource of energy, helping us relieve the energy crises and world pollution. Ever since 1954, when the first modern Si p-n junction solar cell is invented at bell lab, many attempts have been done looking for a high-efficiency low-cost solar cells, leaving several significant milestones.

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