Segmented wave analysis of surface plasmon resonance on curved surface

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ABSTRACT

Surface plasmon resonance (SPR) has been heavily used as biosensors and studied dominantly on a flat surface. Recently, flexible sensor platforms have emerged, for example, as wearable devices. Here, we report investigation of SPR characteristics on a curved film structure. A rigorous 3D computational model requires extremely heavy calculation time and resources. Therefore, we adopted segmentation analysis in which curved surface is divided into an array of flat segments. Such analysis allows fast and efficient calculation. The results indicate that increased curvature produces broader SPR due to wider momentum-matching. The segmentation analysis is expected to play a critical role for diverse optical elements on curved surface.

Keywords: Surface plasmon, Flexible surface, Segmentation, SPR Biosensors

1. INTRODUCTION

Surface plasmon (SP) refers to an electron concentration wave that is formed at the metal and dielectric interface. SP resonance (SPR) under which SP is formed is sensitive to surface states, thus has been heavily used as biosensors in many applications. Most of the studies of SPR biosensing have attempted, based dominantly on a flat surface, to improve the detection limit [1-11] and to extend its uses in various ways including microscopy [12-15]. Recently, however, flexible sensor platforms have emerged, for example, as portable and wearable devices [16,17]. Also emerging are the possibilities of SPR biosensing in in vivo endoscopy that involve SPR measurements on curved surface [18,19].

In this study, we report investigation of SPR characteristics on a curved film structure. The analysis was simplified by decomposing the curved surface into a finite number of flat segment arrays and treating the light as an incoherent superposition of individual light reflections [20,21]. Compared to a rigorous 3D computational model that requires extremely heavy calculation time and resources, the segmentation analysis allows much faster and more efficient calculation for understanding the effects of curvature on SPR biosensing and moreover finding an optimum structure with advanced sensor characteristics under diverse environment.

2. MODEL AND METHODS

For SPR biosensing, 50-nm thick gold was assumed to be deposited on an SF10 glass substrate that is cylindrically curved. The curvature radius of the curved surface ranges from 225 μm to ∞ (flat surface). Regardless of the curvature, the surface was assumed to consist of 13 segments. SPR characteristics were calculated based on wavelength scanning detection for λ = 500 - 800 nm in two configurations of parallel and perpendicular incidence. In the parallel configuration, wave vector of incident light is contained in the cylindrical cross-section, while it is not in the perpendicular configuration. More details of the modeling appear elsewhere [21]. Material optical constants were obtained from Ref. [22].

For reference, resonance shift due to DNA hybridization was calculated after modeling it to form a homogeneous dielectric layer with 9.32 nm thickness corresponding to 24-mer DNA oligomers. The refractive indices of n_{ssDNA} = 1.449 and n_{dsDNA} = 1.517 were taken for singe-stranded (ssDNA) and double-stranded DNA (dsDNA) [23].

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3. RESULTS AND DISCUSSION

Figure 1 presents SPR characteristics in terms of resonance wavelength and width with surface curvature for parallel and perpendicular light incidence. The results indicate that increased curvature produces broader SPR due to momentum-matching between wave vectors of incident photon and SP in a wider range. Resonance width increases significantly especially for parallel polarization. After a peak, the width decreases as higher damping kicks in. The effect of surface curvature was found to be more direct and clearer in the parallel light incidence, i.e., resonance wavelength and width are maintained for much wider range of surface curvature for the perpendicular incidence.

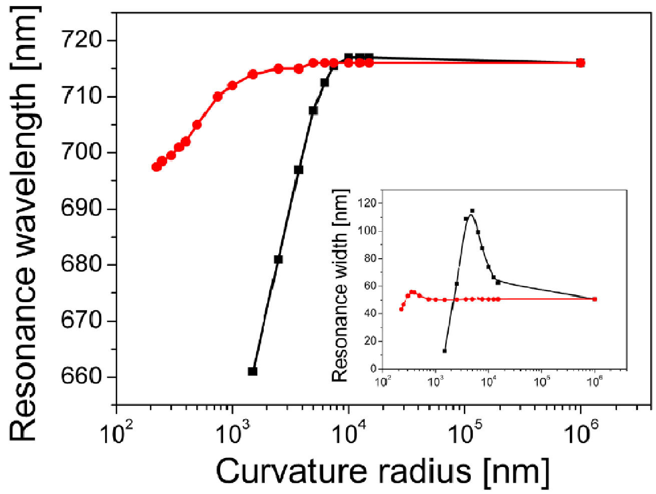

Figure 1. Resonance wavelength and width (inset) with respect to the curvature radius (r > 255 μm) for parallel (black) and perpendicular (red) light incidence. Incident light is p-polarized.

Resonant shift as a result of DNA immobilization and hybridization was also measured as shown in Figure 2, which shows that resonant shifts may decrease quite significantly because of curved surface. A threshold curvature may exist so that resonance shift below the curvature is reduced significantly. For the perpendicular light incidence, the threshold curvature covers a much wider range. Resonance shift tends to be shorter in the parallel incidence than in the perpendicular incidence.

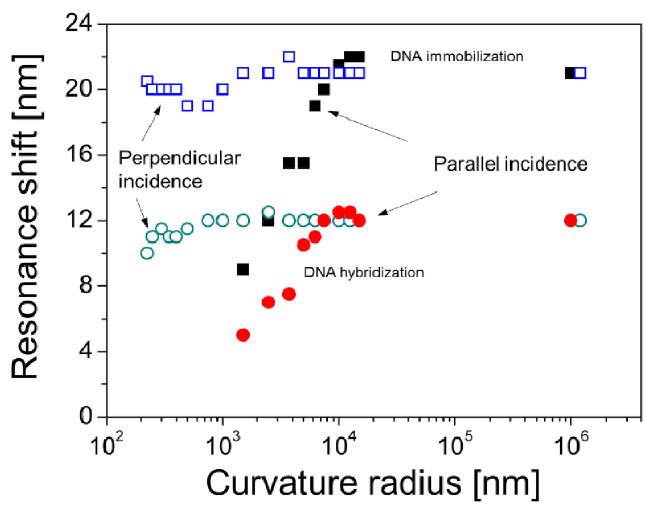

Figure 2. Resonance wavelength shift caused by DNA immobilization and hybridization with respect to the curvature radius (r > 255 μm) for parallel and perpendicular light incidence.

4. CONCLUDING REMARKS

We have applied the segmentation analysis to calculate and understand SPR shifts on a curved surface. It was shown that surface curvature deteriorates sensor properties in general by broadening resonance characteristics and reducing the shift. The adverse effect was particularly strong for the parallel light incidence. Segmentation is expected to help analyzing optical characteristics of diverse optical elements on curved surface in an efficient way.

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