Chapter 9

Metal-Dielectric-Metal stacks - The future
9.1. Road ahead for Plasmonics:

SPCE has been shown various applications so far in this thesis. Various advancements have been carried out to reduce the cost of SPCE setup and ease of working. However, one main drawback is the use of glass prism. Prism is an important part of SPCE experiments. Although reports on the use of paraboloid reflector to redirect the emission instead of using prism have been published. The cost of fabrication would amount the same. In this regard, Lakowicz et al have designed the use of a novel multi-stack format for obtaining normal emission. In other words, the emission is directed out of the plasmonic substrate at 0° on the opposite side of the incident beam. These are called as metal-dielectric-metal stacks (MDM). In this thesis, we show the use of DNA spacers for SPCE as a new spacer material. Hence we explored the use of DNA as spacer in MDM stack. This chapter shows the effect of layer thickness of DNA on single metal-dielectric stack and further extend the understanding to MDM stack. All the calculations were carried out in TFCalc by entering the respective dispersion formula, refractive index, film thickness, light source wavelength etc. The plots were exported from the standard TFCalc export menu.

9.2. Theoretical simulations with DNA spacer:

SPCE studies have been carried out with different metal thin films, aluminium, copper and gold, to name a few. Hence, to demonstrate the application of DNA thin films as dynamic plasmonic spacers, we have carried out simulation studies by replacing the conventional polymers used in SPCE platform, with DNA as the spacer layer on these metal thin films. The minimum reflectivity calculations were carried out using TFCalc. software. The surface plasmon modes appear at a particular angle of excitation, through which the plasmon-coupled radiation is emitted. Figure 9.1 a-d presents the reflectivity minimum with 30nm DNA as the spacer on silver, gold, aluminium and copper.
Lakowicz et al reported that SPCE is predominantly p-polarized, as the surface plasmons selectively couple with p-polarized light in the conventional method. However, this can be modified by changing the thickness of the PVA thin film. We found that the DNA bio-spacer also shows similar property to couple with s-polarized light (Figure 9.2). Figure 9.1 e-h depicts the reflectivity minimum for both p and s polarized light with different thickness of DNA spacer. 100nm thick DNA film suggests selective coupling of predominantly s-polarized light (Figure 9.1f) while greater thicknesses show polarization selective coupling at various angles.
9.3. DNA spacers in MDM architectures:

Recent spin-off of SPCE has been the steering of fluorescence emission with MDM structures\(^4\) where the excitation of surface plasmons and observation of fluorescence emission are normal to the metal surface. In this chapter, we explored the use of DNA thin films for symmetric and asymmetric MDM structures with different combinations of silver, gold, copper and aluminium thin films. Figure 9.3a captures the decrease in resonance wavelength of minimum reflectivity at 0° for silver-gold MDM combinations (see Figure 9.4 and 9.5 for other MDM architectures) with increase in thickness of DNA spacer and its dependence on the MDM composition. This is indicative of the DNA film thickness required to achieve normal emission angle from the fluorophore present in the MDM. Figure 9.3b presents the change in resonance wavelength with the composition of the MDM.
Figure 9.3. (a) Modulation in the beaming wavelength observed at 0° with DNA film thickness in different MDM substrates; (b) Wavelengths with reflectivity minima at 0° for different MDM substrates with 140nm DNA bio-spacer; Simulated reflectivity curves showing modes at normal incidence for MDM stacks- (c) Ag-DNA-Ag (symmetric), (d) Au-DNA-Ag (asymmetric); Calculated electric field intensities for 560nm light at 0° for MDM stacks- (e) Ag-DNA-Ag, (f) Au-DNA-Ag.

Figure 9.4. Reflectivity minima curve for s- (red) and p- polarized light (green) presenting the difference in the percentage of reflectivity at normal incidence for MDM structures: Ag-DNA-Au (left) and Au-DNA-Au (right).
Figure 9.5. Reflectivity minima curve for s- (red) and p- polarized light (green) with optimum DNA bio-spacer thick-ness for the lowest dip percentage/high coupling at normal incidence for MDM structures- [MDM stack (Optimal DNA thickness)]: (a) Ag-DNA-Al (137nm), (b) Ag-DNA-Cu (121nm), (c) Al-DNA-Ag (136nm), (d) Al-DNA-Al (146nm), (e) Al-DNA-Au (127nm), (f) Al-DNA-Cu (137nm), (g) Au-DNA-Al (137nm), (h) Au-DNA-Cu (137nm), (i) Cu-DNA-Ag (137nm), (j) Cu-DNA-Al (137nm), (k) Cu-DNA-Cu (137nm) and (l) Cu-DNA-Au (137nm).

Figure 9.6a is a compilation of the reflectivity simulations for several thicknesses of DNA bio-spacer showing the change in the reflectivity minimum of s-polarized and p-polarized cavity modes. These results demonstrate that in comparison with conventional SPCE, DNA spacer in MDM substrates could be used to couple both p- and s- polarized light with cavity modes. This enables polarization-resolved observation of emission, achieved by altering either the angle of observation or by varying the DNA spacer thickness. The variation in electric field intensities is indicative of the enhancements in s and p-polarized light when excited at appropriate resonance.
dip angles (Figure 9.6 c,d). The plasmonic properties of the DNA spacer material has been highlighted by its ability to assist the formation of cavity modes and surface plasmon modes in MDM architectures, enabling further steering of fluorescence.

Figure 9.6. (a) Angle dependence of cavity & surface plasmon modes on DNA bio-spacer thickness for Ag-DNA-Ag (symmetric) & Au-DNA-Ag (asymmetric) MDM stacks; (b) Angle-dependent reflectivity with 140nm DNA bio-spacer for Ag-DNA-Ag MDM stack showing two cavity modes and one plasmon mode; Simulated electric field intensities corresponding to (c) s- polarized and (d) p- polarized cavity modes for Ag-DNA-Ag MDM stack.

Conclusions:
We showed the use of DNA for efficient MDM stack applications. From a larger perspective, the unique DNA spacer based MDM architectures could result in various capabilities with applications in optical telecommunication systems.

References: