Chapter

4

Method of Lines computation of surface plasmon modes on metal-dielectric interface in Otto and Kretschmann-Raether configurations
4.1 Introduction

Two notable excitation schemes for surface plasmon modes at a single M-D interface are the Otto and Kretschmann-Raether (K-R) configurations. Both utilize total internal reflection (TIR) at the base of a prism to generate an evanescent field. While the former uses a thin air-gap, the latter uses a thin metal film as the buffer layer. The basic excitation scheme of Otto and K-R configuration are shown in figure 4.1 and figure 4.2 respectively.

![Figure 4.1 SPP excitation in Otto configuration](image)

In Otto configuration the dielectric constant of the buffer layer (ε₁) is required to be lower than that of the prism (ε₂) to ensure total internal reflection at the prism-buffer layer interface. In figure 4.1 when θ > θ_{critical}, there will be total internal reflection of the free light at the prism base with an evanescent tail into the buffer layer. The excitation of SPP mode is only possible if the real part of the plasmonic β at the metal – buffer layer interface is equal to $k_0 \sqrt{\varepsilon_2} \sin \theta$ where $k_0$ is free space wave number and $\varepsilon_2$ is the dielectric constant of the prism. The well known expression for surface plasmon β is $k_0 \sqrt{\varepsilon_1 \varepsilon_M} / \sqrt{\varepsilon_1 + \varepsilon_M}$, for a dielectric (ε₁) half space above a metal (ε₉) half space. As such it
cannot be applied readily to a practical configuration as in figure 4.1. The precise computation of $\beta$ for a finite buffer layer thickness and its dispersion with the buffer layer thickness are important to study particularly for the quality and nature of the surface plasmon mode being excited at the metal-dielectric interface. In this chapter we model the waveguide configuration in figure 4.1 as a three layer structure as shown in figure 4.3 and study the dispersion of the plasmonic $\beta$ and evolution of SPP modes with the thickness of the buffer layer using a Method of Lines (MOL) modeling scheme.

![Diagram of a prism with a buffer layer and propagation](image)

**Figure 4.2 SPP excitation in K-R configuration**

The similar study for K-R configuration in figure 4.2 is also carried out using a three layer model shown in figure 4.4.
Figure 4.3 Three layer modeling of Otto configuration and the coordinate system

Figure 4.4 Three layer modeling of K-R configuration and the coordinate system
4.2 Formulation of the problem

The three layer structures in figure 4.3 and figure 4.4 can be considered as representative models of the excitation configurations shown in figure 4.1 and figure 4.2 respectively where the prism is replaced by the bulk dielectric having permittivity $\varepsilon_2$ filling the half space above the buffer layer of finite thickness $b_1$. The shape of the prism is not so important as long as the surface plasmon modes are excited due to total internal reflection at the prism base. In case of Otto configuration the buffer layer is a dielectric having permittivity $\varepsilon_1$ whereas for K-R configuration it is a metal of permittivity $\varepsilon_M$. The dispersion equations of the three layer structures in figure 4.3 and figure 4.4 can be derived solving the Helmholtz equation and following the general guidelines in [1]. However for the cases in study, the dispersion relations involve complex terms because of complex nature of $\varepsilon_M$ and the intended solutions for $\beta$ are also complex numbers. Handling such transcendental equations for locating complex roots is usually not straightforward. Generally, the presence of singularity in the equations of multilayer structures and existence of trivial solutions for the equations further complicate the problem. It is also observed that different forms of the dispersion equation are possible depending upon the choice of forms of the trial solutions (exponential, trigonometric or hyperbolic) at different layers. Different forms of the plasmonic dispersion relation do not always produce results in the entire range of computation. The semi-analytical MOL technique, used in this chapter, can overcome these difficulties of mode computation.

4.2.1 Outline of the formulation using MOL

The non-zero field components of the TM type SPP mode in the three layer structure in figure 4.3 and figure 4.4 are $\{E_x, H_y, E_z\}$ and the guiding equation is:

$$\frac{\partial^2 \psi(x,z)}{\partial x^2} + \frac{\partial^2 \psi(x,z)}{\partial z^2} + k_0^2 \varepsilon(x) \psi(x,z) = 0 \tag{1}$$

In MOL computation we start with $\psi(x,z)=H_y$ and then proceed with discretizing the equation (1) along X-axis on a set of parallel lines perpendicular to the X-axis with interval $\Delta x$ [2]. The parallel lines need not be equidistant and are generally referred as computation gridlines. Incorporating the interface conditions to take care the boundary
conditions at the layer to layer index discontinuities and using 3-point central difference
approximation for the term $\frac{\partial^2 \psi(x,z)}{\partial x^2}$ on each gridline $i$, we finally arrive at a set of
equations that can be expressed in matrix form:

$$ \tilde{Q} \tilde{\psi} + \frac{d^2}{dz^2} \tilde{\psi} = \tilde{0} $$

(2)

where $\tilde{Q}$ is an $M \times M$ square matrix, $M$ is the total number of gridlines in the
geometrical domain of computation and $\tilde{\psi}$ is the column vector containing the
discretized field values on the gridlines. The $M \times M$ matrix $\tilde{Q}$ is expressed as:

$$ \tilde{Q} = -\frac{1}{(\Delta x)^2} \tilde{C} + k_z^2 \tilde{N} $$

(3)

Where $\tilde{C}$ is a tri-diagonal central-difference matrix with interface conditions incorporated
therein [2] and $\tilde{N}$ is a diagonal matrix containing the discretized values of $\varepsilon(x)$ on the
gridlines. Following [2] the derivation of equations (2) and (3) has been presented in
Appendix-A1. For a particular modal solution of the problem, the $z$-dependence of $\tilde{\psi}$
can be expressed as $\exp(-j \beta z)$, $\beta$ being the propagation constant for the mode.
Therefore equation (2) can be further written as:

$$ \tilde{Q} \tilde{\psi} = \beta^2 \tilde{\psi} $$

(4)

Equation (4) can be solved for the eigenvalues and the corresponding eigenvectors. The
square root of the eigenvalue of the square matrix $\tilde{Q}$ gives the propagation constant and
the eigenvector corresponds to the associated discretized field pattern on the gridlines.
While solving the characteristic equation (4) we get a large number of eigenvalues and
their associated eigenvectors depending upon the number of gridlines in the computation
domain. In the present problem we are interested in computing $\beta$ for the surface
plasmon modes at the Dielectric($\varepsilon_i$) - Metal($\varepsilon_M$) interface. The correct $\beta$ from the
large set of computed eigenvalues is identified by inspection of the plot of the associated
normalized eigenvectors. For each computation only one eigenvector having sharp
features of a surface plasmon mode can be identified and the corresponding eigenvalue is considered for computing the effective index for the mode.

### 4.2.2 Use of perfectly matched layer absorbing boundary condition to restrict the size of computation domain

The problem space under consideration is extended from $x = -\infty$ to $x = +\infty$ and therefore the computation domain needs to be restricted to a finite size. Since we have started with $H_y$ field, the most appropriate termination of the computation window would be to place magnetic walls (MW) at some grid lines on both -ve and +ve X-axis within the Dielectric ($\varepsilon_2$) and Metal ($\varepsilon_M$) respectively for Otto configuration. Since we are interested in SPP modes, the $H_y$ field within the metal quickly dies down and therefore a MW at a suitably located grid line in the metal can be safely placed to restrict the domain of computation along +ve X-axis. The situation is not that simple along -ve X-axis. The field pattern in Dielectric ($\varepsilon_2$) can have a general characteristic of free propagating wave with no confinement or decay along the -ve X-direction. Therefore placement of a MW on a gridline may generally produce backward reflection resulting in error in computation. To address this issue we have terminated the computation window along -ve X-axis by placing a finite width perfectly matched layer (PML) having absorbing boundary conditions (ABC) [3]. The computation widow for Otto configuration using PML and MW is shown in figure 4.5. There is no material discontinuity between the PML and the Dielectric ($\varepsilon_2$). However the formulation enforces the wave to travel through a complex distance within the PML by a method of co-ordinate transformation $x \rightarrow x + j\alpha x$, ($\alpha > 0$) which causes attenuation of the field inside the PML so that at a suitable grid line $X = -b_1 - b_2 - b_3$, a MW can be safely placed. The criteria for deciding the width of the PML, the number of gridlines within the PML and the value of $\alpha$ have been discussed in details in [3] and the same is applied in the present work. The computation widow for K-R configuration is shown in figure 4.6. As in Otto configuration, in this case also we have not considered any PML termination.
for bottom most layer in the computation widow and an adequate layer thickness would be enough for computing correct eigenvalues for the desired Surface Plasmon modes.

Magnetic Wall

PML \((\varepsilon_2)\)

Dielectric \((\varepsilon_2)\)

Dielectric \((\varepsilon_1)\)

Metal \((\varepsilon_M)\)

Magnetic Wall

\[ X = -b_1 - b_2 - b_3 \]

\[ X = -b_1 - b_2 \]

\[ X = -b_1 \]

\[ X = 0 \]

\[ X = b_0 \]

**Figure 4.5** Computation widow using PML and MW in Otto configuration

Magnetic Wall

PML \((\varepsilon_2)\)

Dielectric \((\varepsilon_2)\)

Dielectric \((\varepsilon_1)\)

Metal \((\varepsilon_M)\)

Magnetic Wall

\[ X = -b_1 - b_2 - b_3 \]

\[ X = -b_1 - b_2 \]

\[ X = -b_1 \]

\[ X = 0 \]

\[ X = b_0 \]

**Figure 4.6** Computation widow using PML and MW in K-R configuration
4.3 Results and discussion

The numerical modeling using MOL with PML ABC involves (i) proper choice of discretization scheme of the problem space, (ii) selection of parameters for the PML and (iii) proper identification of the surface plasmon modes from a large set of computed eigenvectors. It is therefore necessary to have a validation scheme before applying the MOL technique to the problems under consideration. For the purpose of validation we have considered the data published in [4], where the properties of the surface plasmon wave (SPW) in the modified Otto configuration have been investigated. In the modified Otto configuration for SPW excitation, there is a multilayer dielectric system between the prism and the buffer layer of the conventional Otto configuration (figure 4.7).

![Diagram of the modified Otto configuration](image)

**Figure 4.7** The modified Otto configuration of a multilayer system with N+1 layers used to couple incident light to SPW at the air-metal interface. N, prism; layers (N-1) to 2, dielectrics; 1, air gap; 0, metal.

The 4 (or 5) layer modified Otto configuration system is modeled as D3-D2-D1-M (or D4-D3-D2-D1-M) layered configuration where D, M stand for dielectric and metal respectively. $b_k$, $\varepsilon_k$ are the thickness and permittivity of the k-th layer. The 0th and the N-
th layers are assumed to be of infinite extent (half space). In [4] the authors derived an approximate reflectivity formula from Fresnel formulae and also a series of approximate expressions for the damping rate of SPW, the resonant angle, the optimum air gap thickness of the system and the half-width of resonance were proposed. The resonant angle of SPW excitation and the corresponding optimum air gap thickness for different combinations of dielectrics and metals are available in [4]. The resonant angles of SPW excitation corresponding to the parameters used in [4] are calculated here using MOL with PML and ABC from the computed plasmonic $\beta$. For SPW excitation in $N+1$ layer system, the Resonant Angle is given by 
$$\sin^{-1}\left(\frac{\beta}{k_0\sqrt{\varepsilon_N}}\right).$$

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Metal</th>
<th>$\varepsilon_M$ [Air data from [4]]</th>
<th>$\varepsilon_1$ (in $\mu$m):</th>
<th>$b_1 = t_{4o}$</th>
<th>$\varepsilon_2$ (Prism from [4])</th>
<th>$\varepsilon_3$ (D2)</th>
<th>$b_2$ (Prism from [4])</th>
<th>Resonant angle in degree $\theta_{4o}$, calculated using MOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silver</td>
<td>1.00</td>
<td>0.952</td>
<td>2.25</td>
<td>0.2</td>
<td>8.27</td>
<td>20.95</td>
<td>20.88</td>
</tr>
<tr>
<td>2</td>
<td>Silver</td>
<td>-18+0.47i</td>
<td>1.00</td>
<td>0.941</td>
<td>1.96</td>
<td>2.28</td>
<td>42.92</td>
<td>43.07</td>
</tr>
<tr>
<td>3</td>
<td>Gold</td>
<td>1.00</td>
<td>0.529</td>
<td>2.25</td>
<td>0.2</td>
<td>8.27</td>
<td>21.19</td>
<td>21.58</td>
</tr>
<tr>
<td>4</td>
<td>Gold</td>
<td>-12+1.26i</td>
<td>1.00</td>
<td>0.549</td>
<td>1.96</td>
<td>2.28</td>
<td>43.55</td>
<td>43.95</td>
</tr>
<tr>
<td>5</td>
<td>Copper</td>
<td>1.00</td>
<td>0.475</td>
<td>2.25</td>
<td>0.2</td>
<td>8.27</td>
<td>21.13</td>
<td>21.63</td>
</tr>
<tr>
<td>6</td>
<td>Copper</td>
<td>-12+1.84i</td>
<td>1.00</td>
<td>0.500</td>
<td>1.96</td>
<td>2.28</td>
<td>43.43</td>
<td>43.98</td>
</tr>
</tbody>
</table>
Table 2. Optimum air gap thickness \((t_{so})\) and resonant angle \((\theta_{so})\) for silver, gold and copper metals used in modified Otto configuration of the five-layer system. Comparison of computed results using MOL at \(\lambda = 0.6328\mu m\).

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Metal</th>
<th>(\varepsilon_M) ([\text{Air gap}])</th>
<th>(\varepsilon_1) data from</th>
<th>(\varepsilon_2) ([\mu m])</th>
<th>(\varepsilon_3) ([\mu m])</th>
<th>(\varepsilon_4)</th>
<th>(b_1)</th>
<th>(t_{so})</th>
<th>SPW resonant angle in degree calculated</th>
<th>Resonant angle in degree from [4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silver</td>
<td>1.00</td>
<td>0.997</td>
<td>2.19</td>
<td>0.5</td>
<td>2.25</td>
<td>0.4</td>
<td>8.27</td>
<td>20.96</td>
<td>20.95</td>
</tr>
<tr>
<td>2</td>
<td>Silver</td>
<td>0.47</td>
<td>1.00</td>
<td>0.959</td>
<td>1.86</td>
<td>0.5</td>
<td>1.96</td>
<td>0.4</td>
<td>2.28</td>
<td>42.92</td>
</tr>
<tr>
<td>3</td>
<td>Gold</td>
<td>1.26</td>
<td>1.00</td>
<td>0.619</td>
<td>2.19</td>
<td>0.5</td>
<td>2.25</td>
<td>0.4</td>
<td>8.27</td>
<td>21.24</td>
</tr>
<tr>
<td>4</td>
<td>Gold</td>
<td>1.26</td>
<td>1.00</td>
<td>0.533</td>
<td>1.86</td>
<td>0.5</td>
<td>1.96</td>
<td>0.4</td>
<td>2.28</td>
<td>43.54</td>
</tr>
<tr>
<td>5</td>
<td>Copper</td>
<td>1.84</td>
<td>1.00</td>
<td>0.575</td>
<td>2.19</td>
<td>0.5</td>
<td>2.25</td>
<td>0.4</td>
<td>8.27</td>
<td>21.20</td>
</tr>
<tr>
<td>6</td>
<td>Copper</td>
<td>1.84</td>
<td>1.00</td>
<td>0.488</td>
<td>1.86</td>
<td>0.5</td>
<td>1.96</td>
<td>0.4</td>
<td>2.28</td>
<td>43.42</td>
</tr>
</tbody>
</table>

The computed values for four-layer and five-layer systems are presented in Table 1 and Table 2 together with the corresponding data in [4]. The degree of agreement between the MOL data and the data published in [4] is fairly good for different values of layer thicknesses, dielectric constants and also for the three different metals. The same modeling scheme is then applied to the excitation configurations under consideration in figure 4.1 and figure 4.2. The wavelength of operation, metal and the dielectric material of the prism are taken the same as those used in [5]. The value of \(\varepsilon_1\) is taken 1.5 times less than \(\varepsilon_2\).

### 4.3.1 Results and discussion: Otto Configuration

The basic Otto configuration for excitation of SPP modes in metal-dielectric interface and the corresponding multilayer model for MOL computation are shown in figure 4.1 and figure 4.5 respectively. The effective index \((N_{\text{eff}})\) of the SPW in such a configuration is defined as \(N_{\text{eff}} = \frac{\beta}{k_0}\), which is a complex number for SPP mode. The dispersions of real
and imaginary parts of $N_{\text{eff}} (= N_{\text{eff},r} + jN_{\text{eff},i})$ with the buffer layer thickness ($b_i$) are plotted in figure 4.8 and figure 4.9 respectively for the Otto configuration. The ideal value of $N_{\text{eff}}$ for the isolated Dielectric ($\varepsilon_i$)-Metal ($\varepsilon_M$) interface is given as

$$N_{\text{eff,ideal}} = \sqrt{\frac{\varepsilon_i \varepsilon_M}{\varepsilon_i + \varepsilon_M}}$$

and for the chosen parameters its numerical value is $2.9553 + j0.0026$. The computed $\beta$ is related to the angle of incidence ($\theta$) by the relation:

$$\text{Real part of } \beta = k_0 \sqrt{\varepsilon_2} \sin \theta.$$

To excite SPP at the metal-buffer layer interface, we are therefore interested in finding $\beta$ in the range:

$$k_0 \sqrt{\varepsilon_2} \sin \theta_{\text{max}} \geq \beta_{\text{real}} \geq k_0 \sqrt{\varepsilon_2} \sin \theta_{\text{min}}.$$

The angles $\theta_{\text{max}}, \theta_{\text{min}}$ correspond to grazing incidence ($\theta = 90^0$) and $\theta_{\text{critical}}$ respectively. Therefore the desired range of $\beta_{\text{real}}$ would be $[k_0 \sqrt{\varepsilon_1}, k_0 \sqrt{\varepsilon_2}]$. For the parameters under consideration the range of $\beta_{\text{real}}$ is $[2.8577k_0, 3.5k_0]$. The angle $\phi$ in the Otto configuration (figure 4.1) can be calculated from the value of computed $\theta$ applying Snell’s law. In figures 4.8 and 4.9, the departure from the ideal $N_{\text{effective}}$ and the increase in loss component for smaller buffer layer thicknesses in the modal effective index are interesting to note. For smaller buffer layer thickness the loss component of the modal effective index increases while the real part decreases. The dispersion curves indicate that below a certain buffer layer thickness (about $0.2 \mu m$ for the present parameters) in Otto configuration, the computed $\beta$ corresponds to an angle $\theta$, which is less than the critical angle at the prism base and the characteristics of the excited mode deviate to a great extent from an ideal surface plasmon mode. We may therefore conclude that to excite SPP at the metal-buffer layer interface in Otto configuration, we cannot arbitrarily reduce the gap between the prism and metal. For larger gap, the computed $N_{\text{effective}}$, as expected, approaches that of the isolated Metal - Dielectric (of the buffer layer) interface. But, one cannot in practice make the gap arbitrarily large also as it would lead to weaker coupling of SPP through the tunneled evanescent tail generated at prism-buffer layer interface. This statement is made intuitively though MOL modeling does not yield quantitative estimate of coupling. In
both the Otto and K-R excitation schemes, the SPP mode is inherently leaky, but with suitable adjustment of the buffer layer thickness we can realize quasi-bound Plasmon mode in the metal-dielectric interface.

**Figure 4.8** Dispersion of real part of surface plasmon mode effective index with dielectric buffer layer thickness in the three-layer Otto configuration (Fig. 4.3) with $\varepsilon_M = -125.735 + j3.233$, $\varepsilon_1 = 8.1667$, $\varepsilon_2 = 12.25$. Wavelength $\lambda = 1.55 \mu m$. 
To see how the surface plasmon mode in Otto configuration evolves as the buffer thickness $b_1$ is varied from a very small value of 0.1 $\mu$m to much larger value of 2.0 $\mu$m, the normalized eigenvector ($H_y$) is plotted in figures 4.10 to 4.14 for $b_1=0.1$ $\mu$m, 0.2 $\mu$m, 0.5 $\mu$m, 1.00 $\mu$m and 2.00 $\mu$m. For the large buffer thickness of 2 $\mu$m, the mode looks like a true surface electromagnetic wave with its distinct modal features (figure 4.14). With decreasing buffer thickness the characteristic modal feature of the SPP gradually diminishes and the SPP mode becomes lossy and less tightly bound to the interface (figure 4.11). The plot in figure 4.10 corresponds to a mode which is excited at an angle less than the critical angle at the prism base and cannot be looked upon as a surface plasmon mode.
Figure 4.10 Plot of normalized eigen vector \( (H_y) \) for the surface plasmon mode in the Otto configuration (Fig. 4.3) for a buffer layer thickness of 0.10 \( \mu m \) with \( \epsilon_\mu = -125.735 \) + j3.233, \( \epsilon_1 = 8.1667 \), \( \epsilon_2 = 12.25 \) and \( \lambda = 1.55 \mu m \).

Figure 4.11 Plot of normalized eigen vector \( (H_y) \) for the surface plasmon mode in the Otto configuration (Fig. 4.3) for a buffer layer thickness of 0.20 \( \mu m \) with \( \epsilon_\mu = -125.735 \) + j3.233, \( \epsilon_1 = 8.1667 \), \( \epsilon_2 = 12.25 \) and \( \lambda = 1.55 \mu m \).
Figure 4.12 Plot of normalized eigen vector \((H_y)\) for the surface plasmon mode in the Otto configuration (Fig. 4.3) for a buffer layer thickness of 0.50 \(\mu m\) with \(\varepsilon_M = -125.735 + j3.233\), \(\varepsilon_1 = 8.1667\), \(\varepsilon_2 = 12.25\) and \(\lambda = 1.55 \mu m\).

Figure 4.13 Plot of normalized eigen vector \((H_y)\) for the surface plasmon mode in the Otto configuration (Fig. 4.3) for a buffer layer thickness of 1.00 \(\mu m\) with \(\varepsilon_M = -125.735 + j3.233\), \(\varepsilon_1 = 8.1667\), \(\varepsilon_2 = 12.25\) and \(\lambda = 1.55 \mu m\).
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Figure 4.14 Plot of normalized eigen vector \( (H_y) \) for the surface plasmon mode in the Otto configuration (Fig. 4.3) for a buffer layer thickness of 2.00 \( \mu m \) with \( \varepsilon_M = -125.735 + j3.233, \varepsilon_1 = 8.1667, \varepsilon_2 = 12.25 \) and \( \lambda = 1.55 \mu m \).

4.3.2 Results and discussion: Kretschmann - Raether Configuration

The basic Kretschmann-Raether (K-R) configuration for excitation of SPP modes in metal-dielectric interface and the corresponding multilayer model for MOL computation are shown in figure 4.2 and figure 4.6 respectively. The dispersion characteristics for K-R configuration are shown in figure 4.15 and figure 4.16. It is seen that for smaller buffer layer (a metal in this case) thickness, the loss component as well as the real part of the modal effective index increase. In both Otto and K-R configurations, the SPP mode becomes lossy (leaky) for very thin buffer thicknesses because of enhanced coupling of the surface wave with the free electromagnetic wave inside the prism. However such transition from a quasi-bound to leaky mode takes place at much larger buffer thickness in case of Otto configuration, when compared with K-R configuration.
Figure 4.15 Dispersion of real part of surface plasmon mode effective index with metal layer thickness in the three-layer K-R configuration (Fig. 4.4) with \( \epsilon_\mu = -125.735 + j3.233, \epsilon_1 = 8.1667, \epsilon_2 = 12.25 \). Wavelength \( \lambda = 1.55 \mu m \).

Figure 4.16 Dispersion of imaginary part of surface plasmon mode effective index with metal layer thickness in the three-layer K-R configuration (Fig. 4.4) with \( \epsilon_\mu = -125.735 + j3.233, \epsilon_1 = 8.1667, \epsilon_2 = 12.25 \). Wavelength \( \lambda = 1.55 \mu m \).
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Figure 4.17 Plot of normalized eigen vector \((H_y)\) for the surface plasmon mode in the K-R configuration (Fig. 4.4) for a buffer layer thickness of 2.00 \(\mu m\) with \(\varepsilon_M = -125.735 + j3.233, \varepsilon_1 = 8.1667, \varepsilon_2 = 12.25\) and \(\lambda = 1.55 \mu m\).

Figure 4.18 Plot of normalized eigen vector \((H_y)\) for the surface plasmon mode in the K-R configuration (Fig. 4.4) for a buffer layer thickness of 0.02 \(\mu m\) with \(\varepsilon_M = -125.735 + j3.233, \varepsilon_1 = 8.1667, \varepsilon_2 = 12.25\) and \(\lambda = 1.55 \mu m\).
For two widely separated buffer thicknesses of 0.02 µm and 2.00 µm the normalized eigenvector (H_y) in K-R configuration is plotted in figures 4.17 and 4.18 to show the modal evolution. It is interesting to note that the nature of dispersion of real part of modal effective index in K-R scheme is characteristically opposite to that in Otto configuration (figures 4.8 and 4.15). The modal feature of SPP in K-R configuration resembles that of the dominant asymmetric slow surface plasmon wave in a three layer D-M-D slab waveguide where the phase velocity decreases with decreasing metal thickness.

4.4 Conclusions

Prism excitation of SPP on a metal–dielectric interface in Otto and Kretshmann-Raether configurations has been modeled using Method of Lines. PML absorbing boundary condition is applied for computing the dispersion of plasmonic β with thickness of buffer layer. The model has been validated by comparing with the published results obtained by approximate theoretical formulas for modified Otto configuration with multi-layered dielectric buffer. The results computed from the MOL models for both configurations bring out the following features. (i) For small buffer thickness, both the real and imaginary parts of the effective index of the SP mode deviate significantly from the corresponding values for an isolated interface. (ii) In particular, the loss component of the effective index increases with the decreasing buffer thickness. (iii) Both the real and imaginary parts of the computed effective index approach the isolated-interface values for large buffer thickness. (iv) When the buffer thickness is smaller than a certain value, the mode loses the distinct SPP features. The mode is still SPP-like but is weakly bound to the interface. These features should be useful in designing a prism-excitation scheme for SPP on a metal–dielectric interface.

References

