CHAPTER 5

ADVANCES IN OPTICAL FIBRE: PLASMONIC SENSOR FOR LEAD IONS

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5.1 INTRODUCTION

Since last decades, the optical fibre has revolutionized the modern telecommunication infrastructure and contribute towards manufacturing of wide technologically products for industry, medical, military, and fundamental science applications. The key enabler for such breakthrough is their intrinsic properties such as efficient light waveguiding, lightweight, low-cost, high sensitivity, and many more. Essentially, the simplest cross-sectional shape of optical fibre is consisting of the central core surrounded by the cladding layer, as shown in Figure 5.1. Both layers are made from Silicon Dioxide (SiO_2). Dopants such as Germanium Oxide (GeO_2) or Boron (B) are introduced to the layers to increase or decrease the Refractive Index (RI) to produce a step-index RI profile as also shown in Figure 5.1. Notably, due to this RI profile the optical fibre is also synonymy known as a step-index optical fibre.

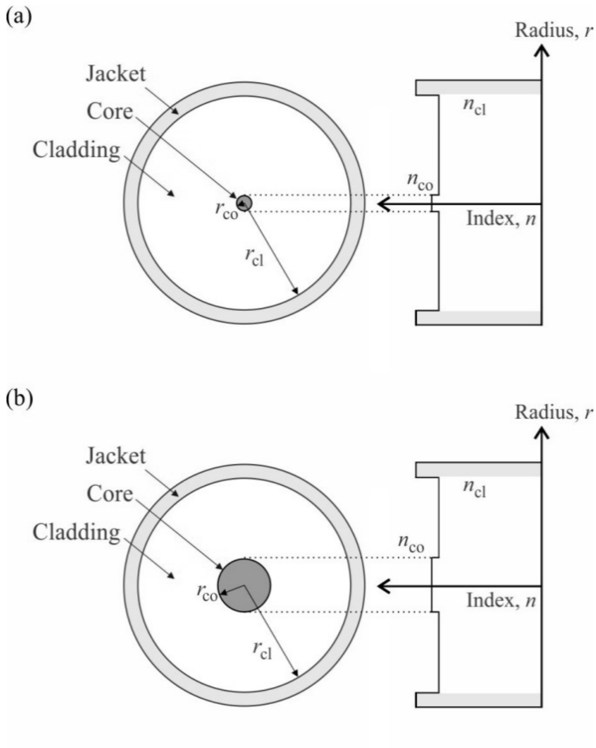

Figure 5.1 The cross-section of (a) single-mode optical fibre (SMF) and (b) multi-mode optical fibre (MMF), together with their respective step-index profile. n_{co} is RI of core, n_{cl} is RI of cladding, r_{co} is core radius and r_{cl} is cladding radius

The ray light analysis can be used as the simplest approach to understand the light wave propagation in an optical fibre. The step-index RI profile enables the waveguiding of light in the core via Total Internal Reflection (TIR). However, the more comprehensive understanding can be attained by solving the partial differential of Maxwell's equation under the specific boundary conditions imposed by the optical fibre (Agrawal, 2007; Senior, 1992). There are an infinite number of possible modal solutions in the form of vectorial components to these equations. However, those solutions of which the modes are actually guided by the core are the interest in many applications. Due to the small index differences between core (n_{co}) and cladding (n_{clad}), as given by:

$$\Delta = \frac{n_{\text{co}} - n_{\text{clad}}}{n_{\text{co}}} \ll 1 \tag{5.1}$$

A weakly guided assumption can be used in a step-index optical fibre. By considering scalar fields solutions to the core modes, the modes degenerate into Linearly Polarized (LP) modes that travel with same propagation constant, β. The transverse electric fields, E amplitude will mostly distribute in the x- and y-planes. The number of propagating core modes is given by:

$$V = \frac{2\pi r_{\text{co}}}{\lambda} \sqrt{n_{\text{co}}^2 - n_{\text{clad}}^2} \tag{5.2}$$

Eq. (5.2) is known as the V-parameter, where r_{co} is core radius and λ is the wavelength of light. The optical fibre with $V < 2.405$ will support a single mode and known as Single-Mode Fibre (SMF). For optical fibre with $V > 2.405$ multi-modes will travel in the core and the fibre is known as Multi-Modes Fibre (MMF). The main difference between these fibres is the core diameter, a is approximate 8 μm in SMF and larger than 25 μm in MMF. Figure 5.2 are the intensity distribution for the modes in SMF and MMF modelled using MATLAB at λ = 1500 nm, n_{co} =1.45 and n_{clad} =1.46. As from the figures, the light energy carried by the lower-order modes in the optical fibre is mostly confined in the core as it propagates.

Post-processing is a versatile way to tailor the physical and optical properties of optical fibre for advanced applications such as sensor development. The most common post-processing techniques are mechanical polishing, wet etching and tapering to disturb the translation symmetry of the cylindrical-shaped optical fibre to allow optical field distribution beyond the core structure, i.e., extended to the cladding or to the surrounding.