

# Nanotube based hybrid plasmon polariton waveguide for propagation loss reduction and enhanced field confinement inside the gap region at the subwavelength scale

Yusheng Bian<sup>a</sup>, Qihuang Gong<sup>a,b,\*</sup>

<sup>a</sup>State Key Laboratory for Mesoscopic Physics, Department of Physics, Peking University, Beijing 100871, China

<sup>b</sup>Collaborative Innovation Center of Quantum Matter, Beijing, China

Received 7 February 2014; received in revised form 26 March 2014; accepted 12 April 2014

Available online 26 April 2014

## Abstract

We present a comprehensive numerical investigation on the guiding properties of a nanotube based hybrid plasmonic waveguide, which comprises a high-index dielectric nanotube placed above a metallic substrate. It is shown that the incorporation of the nanotube offers additional freedom for tuning the optical performance of the hybrid plasmonic structure when compared to the traditional nanowire based hybrid counterparts, which enables further reduction of the propagation loss and enhanced field confinement inside the gap region, while simultaneously maintaining a subwavelength mode size at appropriate geometries. Systematic geometric parameters mapping considering the size of the nanotube and the dimension of the gap reveals that the tradeoff between the confinement and loss could be further balanced through optimizing key physical parameters. These investigations potentially lay the groundwork for the further applications of nanotube based hybrid structures.

© 2014 Elsevier B.V. All rights reserved.

**Keywords:** Surface plasmons; Optical waveguides; Nanotubes

## 1. Introduction

The miniaturization of photonic components and circuits has remained a topic of great interest during the past few decades [1]. Among various reported guiding schemes, surface plasmon polariton (SPP) based waveguides are one of the most promising candidates that exhibits the potential of breaking the fundamental

diffraction limit and providing truly nanoscale confinement along two dimensions [2,3]. Due to their unique optical properties, they have been regarded as ideal building blocks for novel miniaturized photonic components and circuits [4,5]. A number of different types of SPP waveguiding configurations have been proposed and demonstrated through the engineering of various metallic structures. Typical examples are the waveguides in the form of metal stripes [6], metallic nanowires [7–11], slots [12,13] or channels [14,15] cut into metals, metallic wedges [16], dielectric ridges on metal stripes [17–19] and hybridized waveguiding schemes [20,21]. Among them, the hybrid plasmonic

\* Corresponding author at: State Key Laboratory for Mesoscopic Physics, Department of Physics, Peking University, Beijing 100871, China.

E-mail address: [qhong@pku.edu.cn](mailto:qhong@pku.edu.cn) (Q. Gong).

waveguides (HPWs) based on the coupling between dielectric and plasmonic structures have attracted particular research interest, due to their capability of simultaneously achieving low modal loss and tight field confinement. Owing to their superior optical properties, a number of integrated photonic components based on the hybrid schemes have been proposed and demonstrated, including highly efficient nanolasers [22,23], resonators [24] and many other compact passive devices [25–33]. Moreover, several types of modified hybrid plasmonic waveguides exhibiting new features have also been intensively studied [34–50].

Most of the previously reported hybrid plasmonic waveguides are based on the hybridizations between metallic structures and solid dielectric nanowires. So far, limited attention has been paid to the hybrid structures incorporating dielectric nanotubes [39]. Here in this paper, by conducting systematic numerical studies on the guiding properties of a hybrid plasmonic configuration that consists of a high-index dielectric nanotube separated from a metallic substrate by a low-index dielectric gap, we are able to obtain a comprehensive understanding of its optical performance at the telecom wavelength. Previous studies have revealed that the introduction of air holes can be useful for the reduction of the propagation loss of long-range SPP waveguides [51], dielectric-loaded plasmonic structures [52], metal–insulator–metal waveguides [43] or silicon-based plasmonic configurations [53,54]. Yet, additional fabrication techniques are typically required in the practical implementations of the presented structures, such as electron-beam lithography, focused ion beam milling and other etching or lithography methods. In contrast to these configurations, the high-index nanotube of our proposed hybrid waveguide can be realized using chemical synthetic methods [55–57]. Moreover, by replacing the conventional dielectric nanowires with nanotubes, the loss of its supported hybrid mode can be further mitigated and the field confinement inside the low-index gap region can also be enhanced for some configurations. Meanwhile a subwavelength mode size can be maintained simultaneously by choosing appropriate geometries. These nice features of the hybrid nanotube waveguide suggest potential applications in various high-performance functional nanophotonic components.

## 2. Geometry, field distributions and modal properties of the nanotube based hybrid waveguide

The 3D geometry of the proposed hybrid nanotube waveguide is shown schematically in Fig. 1, which

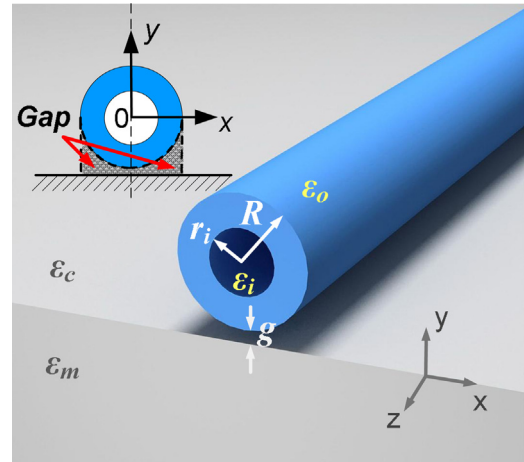


Fig. 1. Schematic of the studied nanotube based hybrid waveguide, which comprises a high-index dielectric nanotube (outer radius:  $R$ , permittivity:  $\epsilon_o$ ; inner radius:  $r_i$ , permittivity:  $\epsilon_i$ ) placed in close proximity to a metallic substrate (permittivity:  $\epsilon_m$ ) with a low-index dielectric cladding (permittivity:  $\epsilon_c$ ). The inset provides the 2D cross-sectional view of the waveguide, where the considered gap region during the following investigations is also highlighted.

consists of a high-index dielectric nanotube separated from a metallic surface by a nanometric low-index dielectric gap. The outer and inner radii of the nanotube is  $R$  and  $r_i$ , respectively. The ratio between the inner and outer radii can be obtained by  $r_i/R$ . The gap distance between the nanotube and the metal substrate is  $g$ . The considered gap region during the following calculations is highlighted in the 2D geometry of waveguide, which is shown in the inset of Fig. 1. The modal characteristics of the hybrid nanotube waveguides are investigated at the telecom wavelength,  $\lambda = 1550$  nm. The metallic substrate is assumed to be silver (Ag). The outer region and the inner core of the nanotube are made of silicon (Si) and air, whereas both the low-index dielectric gap layer and the cladding are made of silica ( $\text{SiO}_2$ ). The permittivities of air,  $\text{SiO}_2$ , Si and Ag are  $\epsilon_i = 1$ ,  $\epsilon_c = 2.25$ ,  $\epsilon_o = 12.25$  and  $\epsilon_m = -129 + 3.3i$  [58], respectively. The modal properties are investigated by means of the finite-element method (FEM) using COMSOL<sup>TM</sup>. The eigenmode solver is used with the scattering boundary condition, which is a widely employed approach to mimic the necessary open boundary.

Electric field distributions of the fundamental quasi-TM plasmonic mode supported by a typical hybrid nanotube configuration is shown in Fig. 2, where both the 2D field profiles and the 1D plots along the gray dashed-lines have been depicted. It is clearly illustrated that, the strong hybridization between the dielectric mode supported by the nanotube and the surface

Download English Version:

<https://daneshyari.com/en/article/1543289>

Download Persian Version:

<https://daneshyari.com/article/1543289>

[Daneshyari.com](https://daneshyari.com)