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**Review**

# Role of negative dielectric and optical quantum dot waveguiding methods in communication

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## ABSTRACT

While the application of optical and photonic technologies in the communications, computing, medicine and industrial manufacturing has been growing rapidly, the miniaturization of these technologies has been slow due to the limitation on the diffraction. However, the developments of nanoscale components and guiding methods are continuing with a rapid pace. Since waveguiding is a fundamental issue in communication, we briefly examine the current state of nanoscale waveguiding with their application in communication which are the building blocks of ultra-high density photonic devices. Finally, we conclude that the QD waveguide may be an effective and an alternative means to transmit light.

**Keywords:** *Nanophotonics, Negative dielectric, Quantum dot, Waveguide*

## INTRODUCTION

Any surface separating two media of distinctly different conductivities or permittivities has a guiding effect on electromagnetic waves. In general, all kinds of transmission lines, including coaxial cables and parallel wires are waveguides. A waveguide can be of any shape, but the most popular shapes are rectangular, circular or even exotic ones.Advances in the area of optical and photonic devices which is used as an other means of transferring information has made them the latest frontier in the field of communication. Meanwhile the development of nanoscale technologies and discovering ways of guiding light on the scale of nano has become the key to the development of compact optical and photonic devices. At the same time there is a growing interest for not only reducing the size but also improving the speed of transfer of information at the optical electrical interface.

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Still, limiting the optical mode width to less than that of transmitting wavelength is an obstacle. Even though the transmission lines and antennas are the most commonly used method of high-frequency transmission, the optical waveguides and fiber optics play an important role in signal transmission. However what is certain is that research advances will be brought to bear seamless integration of media, to improve the quality of life, and create efficiency in the industry. At the root of the struggles lies a need to pair the appropriate materials for specific applications to enable implementation of macroscale to nanoscale structures, the latter of which obeys the physical law of the diffraction limit. Bear in mind that the fabrication of ultra compact photonic circuits using conventional dielectric wave guiding technology is impaired by high loss and crosstalk with neighbouring structures when the transmission width falls below the size of the transmission wavelength [1]. The purpose of this paper is to highlight the latest development of nanoscale optical and photonic devices which may be used as wave guiding in communication.

## THREE TYPE OF WAVEGUIDING USING NEGATIVE DIELECTRIC MATERIALS

### *Type I. Negative dielectric optical fiber waveguide*

A metal can be served for different purposes in a communication, namely, as either the transmitting or confining medium for electromagnetic propagation. The use of negative dielectric materials, which first was proposed a little over 10 years ago, presents a way to energy propagation in a one dimensional fiber, since then several alternative metal structures have been theoretically validated to transmit photons.

As a result of this the negative metallic dielectric waveguide which removes the conventional restrains can be used as an integral part of the optical propagation. Several different types of negative two-dimensional dielectric structures are depicted in Figure 1. Considering the pin formation (Figure 1a), the transmission loss at 633nm wavelength is calculated to be 3dB/410nm or 7.3dB/µm for a silver core of 20nm diameter ($\varepsilon_{riAG}$ = -19-0.53i) clad by a dielectric ($\varepsilon r,_{dielec}$= 4). Fabrication of a one-dimensional negative dielectric waveguide is difficult because of not being able to create smooth metal films on nanometer size dielectric fibber (Figure 1b, 1c and 1d).

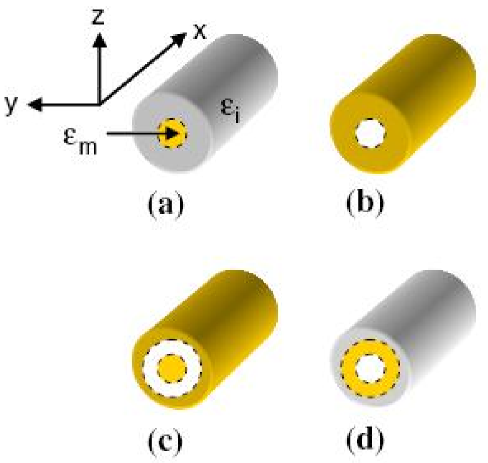


**Fig.1.** ND waveguides: (a) pin, (b) hole, (c) coaxial, and (d) tube formations

### *Type II. Metal strips/wedges and nanoparticle arrays waveguide*

The easiest case for implementing negative dielectric waveguide to transmit light relies on the principle of oscillation effect. This has a limited propagation range due to the inherent loss in the material. The principal structure of the waveguide, which is depicted in Figure 2a consists of a metal strip. A thin nanowire may be implemented on a substrate and can be left either standing alone in air or between dielectric. For a 200nm wide, 50nm thick gold strip shows guiding TM mode of 800nm wavelength light, which is clearly below the diffraction limit [2]. The propagation length or the distance at which intensity drops to 1/e of the incident value is measured to be 2.5µm. A similar device to this is another waveguide shown in Figure 2b which consists of a metallic wedge [3].

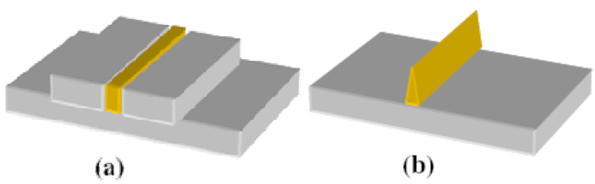


**Fig.2.** (a) Metal strip (surrounding dielectric is optional) and (b) wedge waveguides

It is worth noting that, the wedge angle determines the waveguide propagation mode. That is when the wedge angle is less than 30º, more propagation modes are possible, and for wedge angle of 40º we get a 1.5μm propagation length (2.9 dB/μm). The theoretical prediction of the propagation length provides 2.25μm (1.9 dB/μm). It is worth to mention that there are also several parameters which are important as far as propagation distance is concerned. To name a couple we mention roughness of the metal at the tip and variations between the optical propagation of metal film. Finally, the most popular negative dielectric method is the metal nanoparticle waveguide for which an evenly spaced arrays of nanoscale holes with 25nm separation in between, produces the highest electromagnetic transfer with 900nm propagation distance( 4.8 dB/μm ) Figure 3.

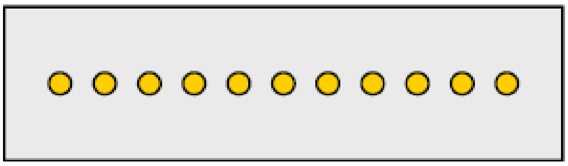

**Fig.3.** Metal nanoparticle array

### *Type III. Metal slot waveguide*

In this type of waveguide a metal-encased structure (Figure 4) instead of metal as the central part is used. The metal slot waveguides are more effective than the metal strip as far as the coupling and confinement of the transverse mode is concerned, but due to the higher loss the propagation distance is less than the metallic structures discussed above. Also some composite waveguides have been proposed and fabricated. In particular, addition of gold nanoparticles in a silica nanowire causes direct optical modulation of conductivity.In general, two-dimensional negative wave guiding is not without cost. Improving the loss figure and propagation distance causes an increase of the device width and mode confinement. The resistive component of metals, lack of effective conversion mechanisms between optical, and electric energies amongst others are still some of the biggest obstacles.

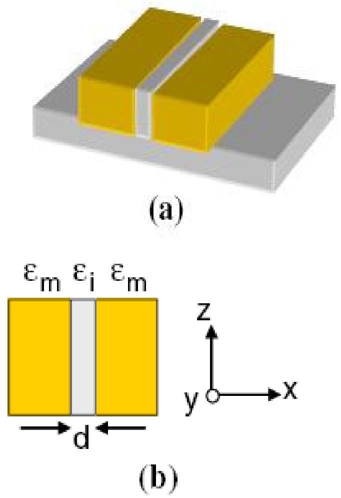


**Fig.4.** Metal slot waveguide: (a) 3D view and (b) bird's eye view

### *Type IV: The nanoribbon waveguide*

Lately, several applications of the fabrication of nanoribbon shape using semiconductor materials $SnO_2$ and ZnO have been demonstrated [4,5]. Here, the modelling of the ribbon has a cylindrical structure with the waveguide size being minimumand with propagation modes of $TE_{01}$ and $TM_{01}$. Besides propagation, this can be used in the areas of filtering, couplings, photodetectors and photonic circuitry.

### *Type V: Silicon-on-Insulator high-index-contrast waveguide*

Here, wave guiding is achieved through the controlling shape and deposition of core and surrounding medium dielectrics. The frequency or wavelength of $TE_{10}$ mode propagation for the rectangular guides can be computed through the Maxwell's equations. The lowest loss for $Si/SiO_2$ strip waveguide has been reported to be 0.8dB/cm measured at 1540nm. Experimental results show the existence of TE component guiding mode.

### *Type VI: Photonic crystal waveguide*

Photonic crystal waveguide has the advantage of reducing the radioactive loss which is common in the former type. Fabrication of 2-dimensional photonic waveguide in comparison to the3-dimensional is still under testing and development [6,7].

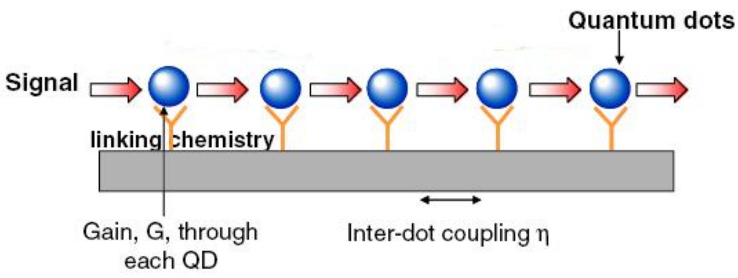


**Fig.5.** Quantum dot waveguide

***Type VII: Quantum dot array waveguide***

All of the previously stated waveguides are susceptible to the compounded loss effects. Also considering them individually, fabrication, integration, and energy conversion each for different types of applications suffer many drawbacks. To overcome some of these problems,we turn to quantum dots for reducing loss thus introducing gain.

The quantum dot waveguide can be used for coupling optical communication devices [8,9]. Therefore, due to its versality and nanometer dimension, quantum dot is an interesting candidate for nanophotonic communication devices, such as being applicable in fabrication of wave guiding Figure 5.

## RESULTS AND DISCUSSION

Discovering a low loss, sub-diffraction waveguide that can be easily fabricated and integrated with the existing circuitry is essential in communication. Among all the wave guiding methods that we have discussed, it seems that the quantum dot wave guiding for nanoscale signal transfer can have many important commercially viable applications in particular communication.

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