مجلة جامعة طرطوس للبحوث والدراسات العلمية _ سلسلة العلوم الهندسية المجلد (8) العدد(3) 2024
Tartous University Journal for Research and Scientific Studies - engineering Sciences Series Vol. (8) No. (3) 2024

Design of Polarization Filter based on Sierpiński Photonic Crystal Fiber and Surface Plasmons

Dr. Eng. Alsamawal Saleh*
Dr. Eng. Hadeel Issa**
Eng. Ralda Jaafar***

(Received 9/8/2023 . Accepted 24/2/2024)

□ ABSTRACT □

The proposed structures in this study are Sierpiński Plasmonic Photonic Crystal Fibers (PPCF) with tringle air holes filled by Plasmonic material (gold or silver). We studied the confinement loss and effective refractive index, by varying the position of the Plasmonic material and holes size. The (Comsol Multiphysics) and (Matlab) have been used to calculate the refractive index, confinement loss and optical properties for the preposed polarization filter fiber within the range of wavelengths [0.4≤λ≤2] μm. The confinement loss reaches $(3.35 * 10^{12} dB/cm)$ and $(8.64 * 10^{11} dB/cm)$at the wavelength of $0.74\mu m$ for the second fiber and $1.8\mu m$ for the first fiber respectively for the y-polarized direction.

Key Words: Photonic Crystal Fiber, Plasmonic Materials, Surface Plasmon, Polarization Filter, Resonance Wavelength, Confinement Loss.

*Professor، Department of communication Engineering- Faculty of Mechanical and Electrical Engineering-Tishreen University- Lattakia-Syria.
**Associate Professor-Department of communication Engineering- Faculty of Mechanical and Electrical Engineering-Tishreen University –Lattakia-Syria.
***Phd Student- Department of communication Engineering- Faculty of Mechanical and Electrical Engineering- Tishreen University ,Lattakia- Syria.

مجلة جامعة طرطوس للبحوث والدراسات العلمية _ سلسلة العلوم الهندسية المجلد (8) العدد(3) 2024
Tartous University Journal for Research and Scientific Studies - engineering Sciences Series Vol. (8) No. (3) 2024

تصميم ليف بلوري فوتوني يعمل كمرشح استقطاب باستخدام توزيع سيربرنسكي وبلازمونات السطح

د.م السموءل صالح*
د.م هديل عيسى**
م.رالدا جعفر***

(تاريخ الإيداع 2023/8/9 . قُبِل للنشر في 2024/2/24)

□ ملخّص □

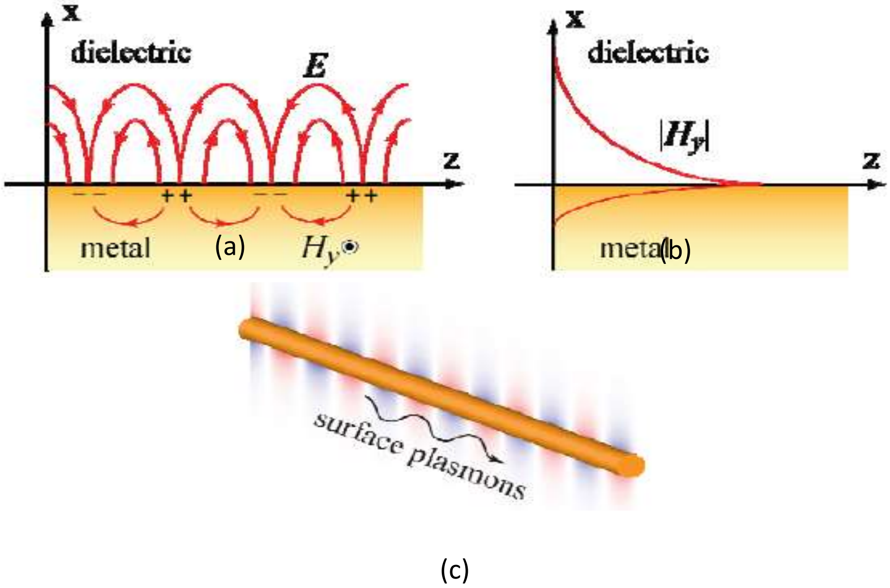
تقدم هذه الدراسة اقتراح لبنى ألياف بلورية فوتونية بلازمونية Plasmonic Photonic Crystal Fiber) ((PPCF) تتوزع فيه الثقوب تجزيئياً على شكل سجادة سبرينسكي، مع اضافة المواد البلازمونية مثل (الذهب والفضة)، وتم تغيير مواقع المواد البلازمونية ومساحة ثقبين مثلثين، واستخدام برنامجي (Comsol Multiphysics) و(Matlab) لتحديد خواص التوجيه الجديدة وحساب قرينة الانكسار الفعالة وخسارة الحصر واستخدام الليف المقترح كمرشح استقطاب ضمن مجالا الطوال الموجية .μm [0.4≤λ≤2]. وكانت نتائج قيم خسارة الحصر $(3.35 * 10^{12} dB/cm)$ و$(8.64 * 10^{11} dB/cm)$ عند الاطوال الموجية $0.74\mu m$ و $1.8\mu m$ لليف الثاني والأول على الترتيب من اجل الاستقطاب بالاتجاه y.

الكلمات المفتاحية: الليف الضوئي الفوتوني، المواد البلازمونية، بلازمونات السطح، مرشح استقطاب, طول موجة الرنين، ضياع الحصر.

* أستاذ– قسم هندسة الاتصالات والالكترونيات– كلية الهندسة الميكانيكية والكهربائية–جامعة تشرين– اللاذقية –سورية.
** مدرس– قسم هندسة الاتصالات والالكترونيات– كلية الهندسة الميكانيكية والكهربائية– جامعة تشرين–اللاذقية–سورية.
***طالبة دكتوراه– قسم هندسة الاتصالات والالكترونيات– كلية الهندسة الميكانيكية والكهربائية–جامعة تشرين– اللاذقية–سورية

1. Introduction:

Plasmonics has drawn a lot of interest because of its exceptional ability to control the flow of light at the interface between metal/dielectric. Metamaterials and active plasmonic materials allow the mass manufacture of low-cost, high-performance, and effective nanosized optical components for imaging, sensing, and communications. Plasmonics research focuses on the unique properties and applications of surface plasmon polaritons (SPPs), quasiparticles arising from the strong interaction between light and free electrons in metals. At the interface between a semi-infinite metal and a semi-infinite dielectric, SPPs behave as a surface wave that propagates along the interface while exponentially decays into both the dielectric and metal (Figures 1(a,b)).Surface plasmon polaritons (SPPs) are collective electron density oscillations bounded at metal-dielectric interfaces, which propagate in a wave-like along the interface as we can see in figure(1(c))[1-2].



Figure(1):(a) Illustration of SPPs and oscillation of surface charges at the interface between a dielectric and a metal. (b) The electromagnetic field is maximum at the interface and exponentially decays in the direction perpendicular to the interface, reflecting the bound, non-radiant nature of SPPs. (c) Schematics of SPPs supported by a metallic nanowire which are confined to metal–dielectric interfaces, The false color indicates the electric field of SPPs.

Effective and efficient integration of new metamaterials with unique surface plasmonic resonance behaviors, for example, could create a full basket of "newconception" THz photonic components bearing new operation mechanisms including negative refraction, lossless transmission, dynamic tunability, and so forth.

Previously many techniques were used to excite the SPP modes, one of them was the prism which is used for passing the light to the metal surface interface, the prism based SPR waveguide is bulky and its limit the remote applications. To overcome those problems, photonic crystal fiber (PCF) based SPR is introduced. PCF-based plasmonic devices have gained popularity because of their small size, versatility and controllability [1-2]. Sensors [3], polarization filters [4], and polarization splitters [5] are few examples of PCF-based plasmonic devices applications. In communication systems, a polarization filter is an essential element and PCF- Plasmonic Polarization Filters have gained a lot of interest in recent years which are based on the leaky modes (or the high levels of confinement losses), that interacts with the interface between the metal and dielectric so, when the core-guided mode is phase matched with the plasmon mode at a specific wavelength, SPR occurs. It will also absorb the power of one polarized mode while allowing the other one to pass[6-9].

The using of fractal geometries, on the other hand, has been successfully exploited during the last decades for the realization of multiband (or broadband) compact and high-performance antennas [10-12]. More recently, these self-similar geometries have also enabled multispectral compatibility and multiple applications when used for patterning one- and two-dimensional Plasmonic superlattices. In contrast, self-similar plasmonic properties in SPR-PCFs remain unexplored. In recent years, many researchers have proposed novel PCF-based polarization filters. In[13] reported an RI sensor using an annular core photonic crystal fiber. This work exhibits high sensitivity over a large dynamic range. In particular, in the RI range from 1.31 to 1.39, this proposed fiber displays more propagation loss to sense the biochemicals. In [14] suggested a single polarization bimetal-coated (Au/Ag) PCF filter with liquid-filled air holes. Confinement losses for the Y-polarized mode were 544.3 dB/cm and 147.3 dB/cm for a wavelength of $1.31\mu m$ and $1.55\mu m$, respectively. In the same wavelength, the X-polarized losses were 12.3 dB/cm and 24.0 dB/cm. At a wavelength of $1.31\mu m$ and $1.55\mu m$ also in[15] published a new gold-plated PCF polarization filter. There were two big air holes in the filter, which was selectively coated with gold after being filled with water. At 1310 nm, the confinement loss in the Y-polarized mode was 1209.57 dB/cm, but the confinement loss in the X-polarized mode was almost non-existent while in [16] reported a combined silver–graphene layered pentagonal PCF filter. The filter renders an X-polarized mode with losses of 0.12 dB/cm and 0.59 dB/cm at wavelengths of $1.31\mu m$ and$1.55\mu m$, respectively. It also rejects a Y-polarized mode with a loss of 361.26 dB/cm and 1508.37 dB/cm, respectively. At $1.31\mu m$ and$1.55\mu m$, respectively.In [17] proposed a bimetallic coated D-shaped PCF-based single-polarization filter. A Y-polarized mode's confinement loss reached 950.68 dB/cm at a wavelength of $1.55\mu m$.

Herein, we demonstrate the excitation of multiple SPRs by using plasmonic materials (gold and silver) in PCFs Polarization Filters with fractal cross-section designs, we utilized a Sierpinski-like geometry [18] of the fiber, where tow of the holes in the fractal geometry were considered with metallic inclusions in the communication windows within the range of wavelengths $[0.4\leq\lambda\leq2]$ μm.

2. Research Importance:

The plasmonic materials and surface plasmons play major role in developing optical communications systems and obtain new features and properties through the possibility of converting the lost energy (leaky modes) into plasmonic waves inPCF_s On the other hand using The Fractal geometry which is Self-similar fractals provides a degree of freedom for varying the resonance frequency by arranging the holes, due to the multiscale geometric features involved to obtain new structures suitable for optical applications, filters, and optical sensors.

Research Tools:

Calculations in this work were made using the finite element method (FEM), through the commercial software COMSOL Multiphysics, and the analytical method is made by matlab program.

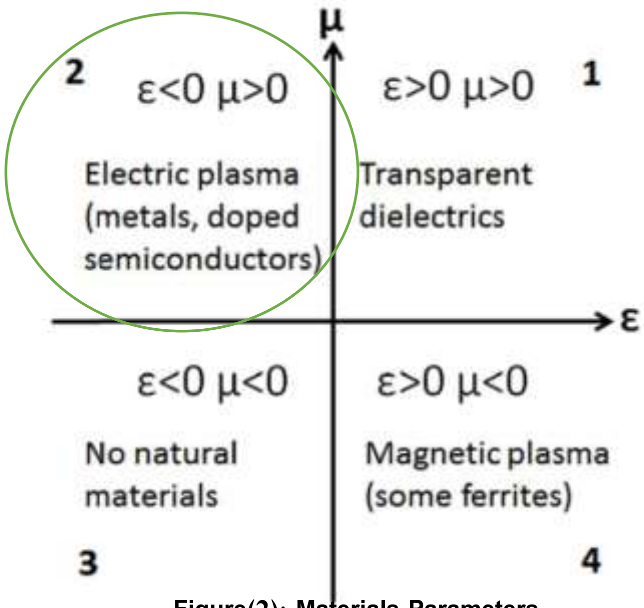
3. Structural Design & Numerical Analysis:

3.1 Optical metamaterials:

Metamaterials can be defined as artificial structures composed of units with dimensions

smaller than the wavelength of interest. The subwavelength feature size allows one to apply the effective medium approximation and homogenize the response [19]. As a result, the assembly of individual units can be assigned effective material properties at a macroscopic level. The individual units can be considered as artificial "atoms" or "molecules" interacting with electromagnetic waves. The effective material properties arising from the interaction is determined be the shape of subwavelength units rather than intrinsic properties of the constituting materials. Particularly, at optical frequencies, the units are metal/dielectric composites in order to excite plasmons.

It is well known that the electric permittivity and magnetic permeability are useful optical constants that describe light-matter interaction. Maxwell equations govern the response of the electromagnetic field in a medium. Physically, one can understand that the permittivity (ε) relates the material response to the electric field and the permeability (μ) relates the response to the magnetic field. The materials parameters are shown in figure (2) is informative to grasp the set of all materials possible. The first quadrant (region (1)) represents most common dielectric materials where (ε) and (μ) are both positive. For region (2), (μ) is positive but (ε) is negative thus the refractive index is also negative and this part is our of interest. Metals and doped semiconductors are fall in this region. Region (3) is when both (ε) and (μ) are negative. No natural material is known to exist in this region. Finally, region (4) includes several ferrites but only microwave frequencies [20-22].



Figure(2): Materials Parameters

4.2 Fractal Geometry:

First, we demonstrate the fractal geometry, Despite the prominent role that Euclidean geometry plays in mathematics, science, and engineering, there are very few objects in nature that it accurately describes. Many naturally occurring structures are composed of features with numerous length scales, where each length scale appears similar to the others when magnified by an appropriate factor. Common examples include a snowflake, a tree and a coastline. A mathematical abstraction of Euclidean geometry which acts as a much better descriptor of these self-similar objects is fractal geometry [23]. Rather than being described by elementary shapes such as polygons and arcs, a fractal is defined by a basis shape and an operator that acts iteratively on that shape. Applying the operator to the basis shape produces the first-iteration shape; applying it again to the first-stage of growth shape produces the second-stage of growth shape; and so, on as in figure (3). When carried out an infinite number of times, the resulting shape may exhibit interesting properties, such as zero area and infinite perimeter simultaneously [24-26].

Figure (3): Sierpinski tringle fractal shape steps

Notably, fractals exist in a space that is characterized by a non-integer, or fractional, dimension [27]. In electromagnetic theory, the manner in which an object scatters an incident photon is strongly dependent on the size of that object relative to the wavelength spectrum that composes the photon. The presence of numerous length scales in fractal structures makes their interaction with electromagnetic radiation intriguing and suggests that the object may act preferentially in multiple bands of wavelengths[28]. There are three operators in Fractal design which add some we degree of freedom:

1. Fractal Dimension (D): which is a non-integer value that suggests the fractal has a dimension not equal to the space it resides in given by:

$$D = \frac{log(N)}{log\left(\frac{1}{\rho}\right)} \qquad (1)$$

Where (N) stands for number of measurement units, (ρ) is the scaling factor.

2. The stage of growth: which is repeating pattern process starting by (s=0)

3. Lacunarity: is referring to a measure of how patterns fill space, where patterns having more or larger gaps generally having higher lacunarity[28-30].

4.3 Filter Design:

Surface plasmon polaritons (SPP) are the electromagnetic waves propagating along the interface between metal and dielectric medium which can influence the light propagation characteristics in PCF. Therefore, exciting surface plasmon resonance (SPR) i.e., matching the core mode with SPP modes at a desired wavelength, one particular polarized ray can be absorbed in the metal ensuring filtering capabilities. This has encouraged researchers to analyze the prospect of partially filling or completely filling the hollow channels of PCF with the plasmonic materials like silver [19] and gold [20] to create plasmonic devices.

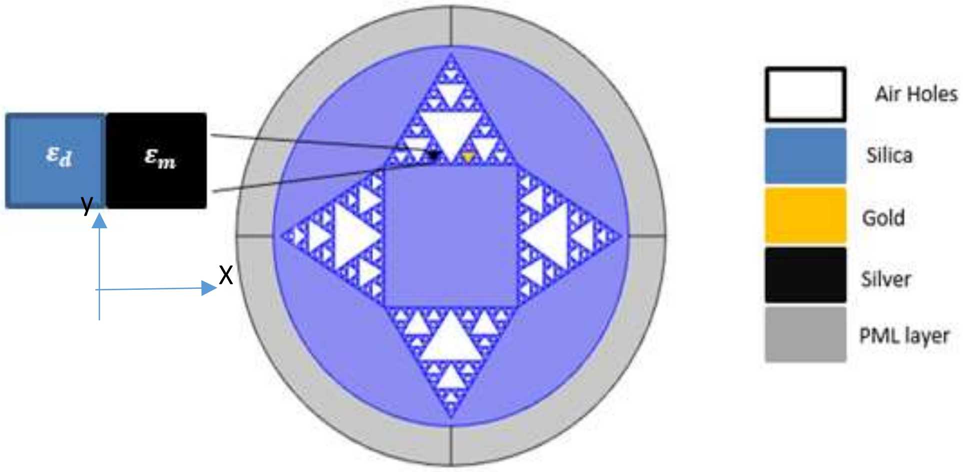
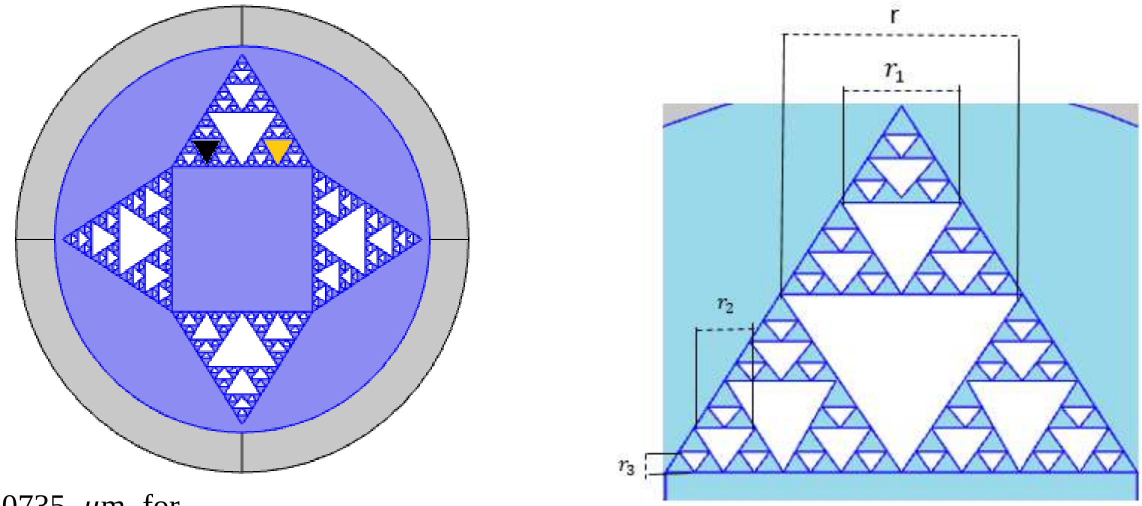


Fig (4): First FPCF with small holes

Fig. 4 shows the structure of the proposed fibers. It is composed of a number of air holes of varying diameters for guiding the light. Investigation of key performance parameters are the confinement loss and dispersion that were achieved using a full-vectorial Finite Element Method (FEM), with anisotropic (PML) Perfectly Matched Layers [21].

We schematized the design of the fractal cross-section of the optical Plasmonic fiber In Figure (4), which provides a degree of freedom for varying the resonance frequency by arranging the four Sierpiński tringle air holes, For each Sierpiński triangle, doubling its side creates 3 copies of itself. Thus the Sierpinski triangle has Hausdorff dimension D=log2/log3=1.585, which follows from solving as 2^D = 3[22].

A solid tringle of diameter r is used as the starting point, i.e., as the 0-th iteration step and equals to $0.92\mu m$. The solid tringle is then divided into tow identical lines with fractional diameter r_1 =r/2. More specifically, these sub-lines are distributed as a central tringle surrounded by identical tringles. The same generator is recursively applied to the remaining solid sub-tringles and so on until the third iteration step. So $r_2 = r_1/2$, $r_3 = r_2/2$ as in figure (5b). We use this geometry to build our fractal PCF so we have a square core (fiber core), the side length of the square equals ($1.84\mu m$) where light is guided along the fiber. Plasmonic effects are introduced in the system considering tow of these fractal subsets have metallic components. In particular, we considered a fractal subsets consisting of a gold and silver holes, the size of the metal hole is also varied from 0.0187 μm for the first fiber in figure (4) to 0.0735 μm for the second fiber in figure (5a) .



(a) (b)

The air holes have the permittivity value equal ($\varepsilon_a = 1$)[22],while the background material is pure silica, has the value ($\varepsilon_d = 2.09$) [22] its material dispersion is given by Sellmeier's formula [23]. Similarly, the plasmonic materials permittivity is derived using the Drude–Lorentz model [24]:

Figure(5): (a) second FPCF with large holes,(b) the dimensions of the tringle in Sierpiński fractal shape

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_D^2}{\omega(\omega + j\gamma_D)} - \frac{\Delta\varepsilon . \Omega_L^2}{(\omega^2 - \Omega_L^2) - j\Gamma_L \omega} \qquad (2)$$

The specification of these variables is reported in table (1) [19-20]

Table (1)

$\Gamma_L/2\pi$	$\Omega_L/2\pi$	$\gamma_D/2\pi$	$\omega_D/2\pi$	ε_∞	
104.86 THz	650.07 THz	15.92 THz.	2113.6 THz,	5.9673	Gold
64.2944[THz]	1010.72[THz]	5.0778[THz]	241.7991[THz]	9.75	Silver

where the high frequency dielectric constant is ε_∞, ω_D and γ_D represents plasma frequency and damping frequency, respectively. The frequency and spectrum width of the Lorentz oscillator are denoted by Ω_L and Γ_L.

Furthermore, the mode's confinement loss can be derived using the following formula [25]:

$$L = 8.686 \times \frac{2\pi}{\lambda} Im(neff) \times 10^7 \ (\frac{dB}{cm}) \qquad (3)$$

where λ is the wavelength and $Im(neff)$is the imaginary part of the effective refractive index. Here the PML and scattering boundary condition are used, so the waves could pass through domain boundary without reflection.

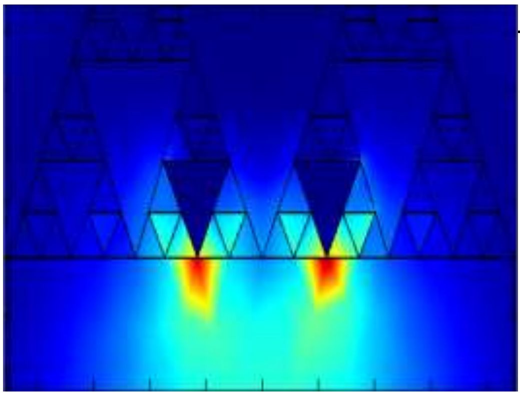
We studied varying the positions and sizes of the metallic Plasmonic materials (gold and silver) and their effects on the confinement loss and dispersion. Taking advantage of the freedom in arranging air holes in the cladding region provided by PCF, polarization fiber can be created by destroying structure geometry or using Plasmonic materials in hollow channels. In this investigation, we study the Plasmonic materials(gold and silver) in the fractal photonic crystal fiber then dispersion and confinement loss properties were calculated using (Matlab) and (Comsol) programs, within the range of wavelengths [$0.4 \leq \lambda \leq 2$] μm.

4. Simulation results and analysis

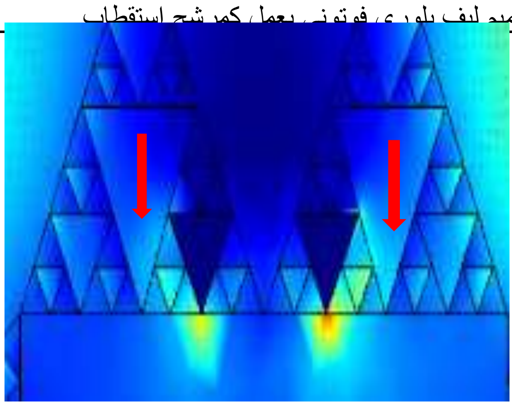
Fractal Plasmonic PCF work based on the evanescent fields. Efficient excitation of the metal surface is a key factor of plasmonic phenomenon while at a certain wavelength; incident field can excite the surface and generate the resonance. Plasmonic PCFs have a potential use in realizing single-polarization single-mode (SPSM) fibers which guide only one polarization mode of the fundamental mode in the fiber core. With ability to eliminate polarization coupling and polarization mode dispersion. The key point of designing SPSM fibers is to attenuate one polarization while keep the orthogonal polarization propagating with low loss the particularly desirable polarized mode can be chosen by the correct direction of the Plasmonic material, so if the desired mode is the x-polarized mode, the Plasmonic material should be in the y-direction, and vera versa.

One of the approaches to achieve SPSM is utilizes the principle of resonant coupling. With proper design, the effective refractive index of one polarization can be matched to that of the leaky defect mode in cladding. Thus, energy of the matched polarization is transferred to the defect mode. The leaky defect modes can be formed by reducing the diameter of certain air holes and selectively filling air holes with liquid or metal [35].

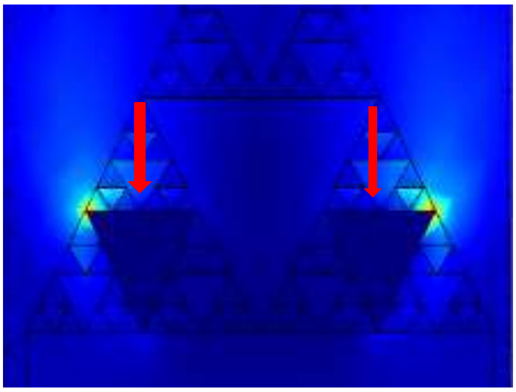
There are two kinds of SPP mode in the structure holes filled with metals (gold and silver): One is the SPP stimulated at the gold/silica interface. Second is the SPP stimulated at the silver/silica interface. Once the basic structure parameters of PCF are designed, such as the hole-filling fraction, the effective propagation constant of this SPP is affected by the RI change of the metal. The RI change of the metals would change the phase matching condition with the fiber core mode. Thus, the resonant wavelength varies with the RI value of the metals. As two metals (gold and silver) are utilized in the structure, the degenerated SPP modes which possess similar modal refractive index will affect each other and finally form SPP mode. Figure(6) shows the optical field distribution of the fundamental mode and plasmonic modes of the PCF SPR. Gold and silver are used as Plasmonic materials to excite spp modes.



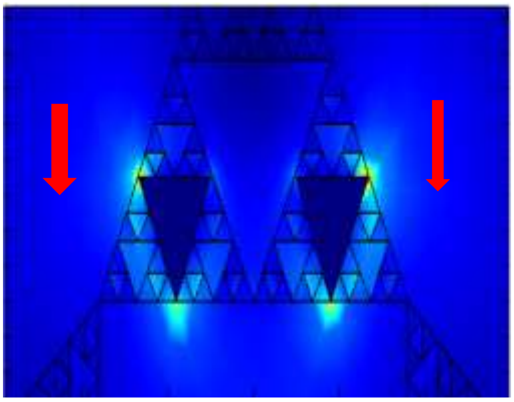
(a)



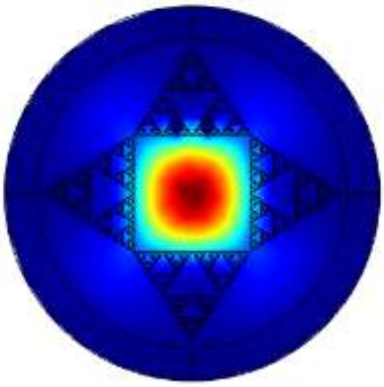
(b)



(c)



(d)



(e)

Fig(6): field profiles of the first fiber in y polarization:(a) spp mode first order,(b) spp mode second order, field profiles of the second fiber in y polarization:(c) spp mode first order,(d) spp mode second order,(e) field profile of the fundamental mode in y

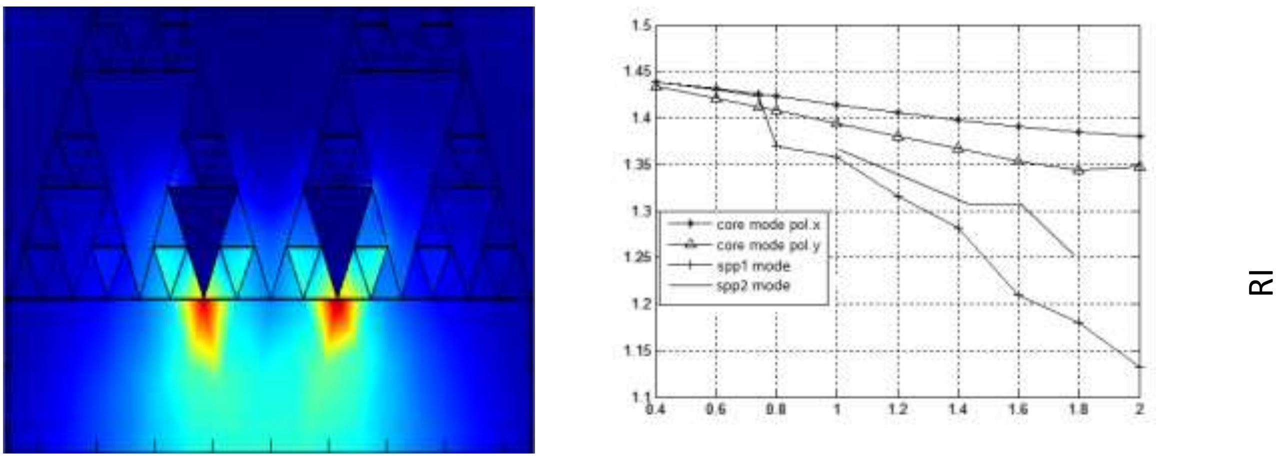
We notice that the lower effective refractive index of the core-guided mode could match with the plasmon mode well. The holes in the first-layer acting as a low effective refractive index cladding restrict the core-guided mode from propagating in the fiber core. Only small energy can infiltrate the plasmonic holes in the second layer through the aperture between the first-layer holes.

The energy coupling between the plasmon and core-guided mode is more efficient as the holes are close to the fiber core, and most of the energy is confined in the fiber core by the cladding holes and only a part of energy penetrates into the Plasmonic filled holes in the second layer to excite the plasmon mode. The first and second-order SPP modes have the highest influence on the filtering performance because they coupled with the *y*-polarized or x-polarized core modes at certain wavelengths [26-28].

5. Results and Discussion

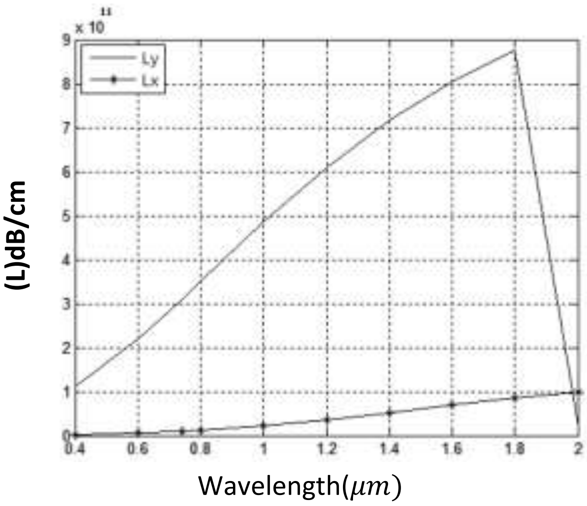
The fractional sizes of different nearby scatters, the positions of the Plasmonic materials and the size of the element i.e., the fractal-like geometry, also introduce a broadening of the frequency range for SPR excitation. Figure 7 shows the results of Re(neff) for the core-guided modes and SPP modes while the coupling is shown by the arrows. The confinement loss values are shown for x-pol and y-pol in figure 6, for λ ranging from [$0.4 \leq \lambda \leq 2$] μm. From the phase-matching condition, we identified the SPR modes in the structure, as it can be seen from Figure 7. For small λ values we can note that as the elements of the Plasmonic materials are larger as the refractive index became smaller due to the negative ε of the metals. The RI of the core and SPP modes are analyzed through the FEM-based commercial COMSOL software 5.2.Using the COMSOL Multiphysics program, the RI values were evaluated via FEM We notice that the values of the RI fundamental modes are much higher than the RI spp modes because the negative refractive index for the metals at some frequencies.

Now, we investigate the shifts in the Plasmonic loss peak spectra Therefore, SPR occurs at the desired wavelengths and the confinement loss of *y*-polarized light gets much higher than the *x*-polarized light.



(a) (b)

Figure(7): Refractive Index for :(a) first fractal fiber with small holes, (b) second fractal fiber with large holes.



(a)

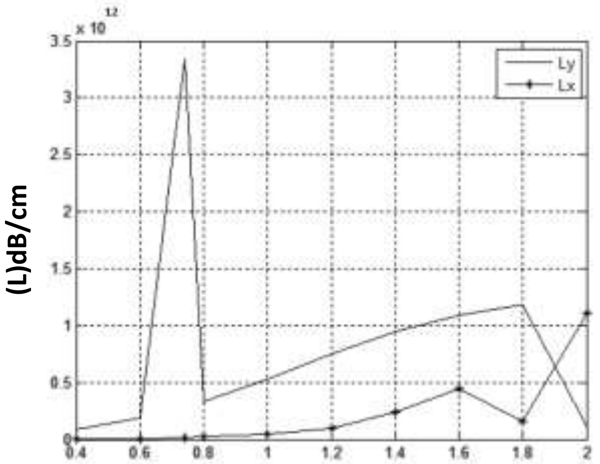


Figure (8): Loss spectra for (a): first fractal fiber with small holes, (b) second fractal fiber with large holes.

It can be seen from Fig. 6 that when the modal refractive index in the core of the fiber and the SPP modes on the metal match, strong coupling occurs. The loss at the wavelength of $0.74\mu m$ and $1.8\mu m$ can nearly reach to $(3.35 * 10^{12}) dB/cm$ and $(8.64 * 10^{11}) dB/cm$. The resonance strength in y-polarized direction is much stronger than that in x-polarized direction as Fig. 8 shows. So, when the size of the metal holes is varied from 0.0187 μm to 0.0735 μm in order to get desired output, these Increasing results a blue shifting for the resonance wavelength around 0.74 μm with increasing trend of loss strength. This is happening because surface plasmonic waves (SPWs) are very sensitive to the thickness of the gold layer and the electric field has difficulty penetrating through as the layer becomes wider. Hence, it is very important to carefully choose the appropriate size of the metal so that the desired filtering performance of the device can be achieved.

6. Effects of tringle holes location and size of plasmonic materials (Ag and Au) on the polarizer performance in y-polarized direction:

In this section, we will discuss the importance of the holes in y-polarized direction. Fig. 6. Shows impact of different structures of PCF with different sizes of tringle holes on the loss. As we can see in Fig. 6, when we use different sizes of tringle holes in y-polarized direction, the y-polarized peak experiences a shift towards the longer wavelength and decreases for small holes, while for larger holes the y-polarized peak experiences a shift towards the shorter wavelength and the amplitude of x-polarized peak also decreases by a large amount but there is no shift for both of them. Therefore, the resonance peaks of x-polarized and y-polarized directions are separated. Using these sizes of the holes can actually help separating the 1st order SPP mode and improving the performance such PCF based polarization filters. These features are all very beneficial for the single polarized filter to filter light in one direction.

7. Conclusion:

The comparison of the proposed work with contemporary literature works is as depicted in Table 2. It shows a good Confinement loss values over the wavelength range[0.4≤λ≤2] μm by using the fractal geometry in the proposed work.

Table (2)

Reference	wavelength	Confinement loss
34	1.378 µm	450.8 dB/cm
35	1.55 µm	1375.94 dB/cm
36	1.63 µm	2953 dB/cm
37	1550 nm	445.10 dB/cm
38	1.55 μm	736.30 dB/cm
39	1.31 μm	736.30 dB/cm
40	1.56 µm,	1013.2 dB/cm

In summary, the plasmonic photonic crystal fibers using tow metals (gold and silver) is designed for polarization filtering applications with Sierpinski-like geometry, have been numerically demonstrated. We varied the holes size by 74% between the first and second fibers and the sizes of the metallic holes are very small so the cost of using the metals is low. The fractal fiber exhibited broadband capabilities, with a set of plasmonic resonances within the range of wavelengths [0.4≤λ≤2] μm. The loss at the wavelength of $0.74\mu m$ for the second fiber and $1.8\mu m$ for the first fiber can nearly reach to $(3.35 * 10^{12}) dB/cm$ and $(8.64 * 10^{11}) dB/cm$ respectively. The resonance strength in y-polarized direction is much stronger than that in x-polarized direction. Based on our results, we can't use the fibers in this work in the optical transmission because of the high levels of confinement loss but they are suitable for optical applications, filters, and sensors. We expect that further improvements can be made using other geometries like higher Sierpinski-steps, other fractal sequences, or different geometrical sizes of the holes in order to tune the corresponding frequency ranges.

8. References:

[1] K. Yao, L. Yongmin, ***"Plasmonic Metamaterials"*** ,Department of Mechanical and Industrial Engineering, Northeastern University,USA.2020.

[2]Z. AL-Kinani, K. Hussain,' ***Analysis of circular plasmonic photonic crystal fiber for filter applications'***, AIP Conference Proceedings, 2020.

[3] A. Davina Tjandra, R. Chandrawati, ***"Optical sensors"*** , Bioengineering Innovative Solutions for Cancer, 2020

[4] D. muthana, A. Abd Algaffar,"***Design and Evaluation of a Polarizer Filter"*** 2018.

[5] D. Kwon, H. Werner, ***"Polarization splitter and polarization rotator designs based on transformation Optics"*** Department of Electrical and Computer Engineering University of Massachusetts, Opt. Express *USA* 2008.

[6] V.K. Sharma, A. Kapoor, ' ***Analysis of surface and guided wave plasmon polariton modes in insulator–metal– insulator planar plasmonic waveguides'***, Elsevier,2012.

[7] A. Khaleque, G. Mironov , T. Hattori***, ' Analysis of the properties of a dual-core plasmonic photonic crystal fiber polarization splitter',*** Springer-Verlag Berlin Heidelberg ,2015**.**

[8] I. Haddouche, L Cherbi,' ***Comparison of finite element and transfer matrix methods for numerical investigation of surface plasmon waveguides'***, Elsevier,2017.

[9] A. Paul, A. Krishno Sarkar,' ***Dual Core Photonic Crystal Fiber based Surface Plasmon Resonance Biosensor'***, optics *Australia* ,2018.

[10] Sh. Sederberg , A.Y. Elezzabi***,'Sierpiński fractal plasmonic antenna: a fractal abstraction of the plasmonic bowtie antenna' .*** Optical Society of America. *University of Alberta, Edmonton, Canada .2011*

[11] U.Yoshihide, Y.Hiroaki, SH. Masayoshi, F. Masahiko, Y. Toshiki, ***"Compact and High-performance Millimeter-wave Antennas***", FUJITSU TEN TECHNICAL JOURNAL,2011.

[12] Y. Wanlan , Ma. Kaixue , ***'A Compact High-Performance Patch Antenna Array for 60-GHz Applications'***. IEEE Antennas and Wireless Propagation Letters, 2016.

[13] Sharma, M.; Mishra, S.K.; Ung, B. **Ultra-sensitive and large dynamic range refractive index sensor utilizing annular core photonic crystal fiber**. Spie 2019

[14] Liu, C.;Wang, L.;Wang, F.; Xu, C.; Liu, Q.; Liu, W.; Yang, L.; Li, X.; Sun, T.; Chu, P.K. **Tunable single-polarization bimetal-coated and liquid-filled photonic crystal fiber filter based on surface plasmon resonance**. Appl. Opt. 2019.

[15] Yan, X.; Guo, Z.; Cheng, T.; Li, S. **A novel gold-coated PCF polarization filter based on surface plasmon resonance.** Opt. Laser Technol. 2020,

[16] Lavanya, A.; Geetha, G. **Broadband polarization filter based on hybrid silver-graphene coated pentagonal photonic crystal fiber**. Opt. Quantum Electron. **2021**.

[17] Shima, R.A.; Mollah, A.; Ali, Y. **Au-ITO deposited D-shaped photonic crystal fiber polarizer with a micro-opening based on surface plasmon resonance**. Optik **2020**.

[18] Lu. Yalin, W. Zhang, **Metamaterials, Plasmonics, and THz Frequency Photonic Components**, Hindawi Publishing Corporation, University of Colorado, USA, 2008

[19] P. CHATURVEDI, ***"OPTICAL METAMATERIALS: DESIGN, CHARACTERIZATION AND APPLICATIONS***" Indian Institute of Technology Bombay, University of Illinois at Urbana-Champaign, 2009.

[20] C. Ropers, G. Stibenz, G. Steinmeyer, ***"Ultrafast dynamics of surface plasmon polaritons in plasmonic Metamaterials"*** School of Physics, Seoul National University, Korea Phys. B manuscript, 2010.

[21] M. McClure, ***"Fractal Geometry".*** University of North Carolina, Yale University 2022.

[22] Sh. Sederberg , A.Y. Elezzabi***,'Sierpiński fractal plasmonic antenna: a fractal abstraction of the plasmonic bowtie antenna' .*** Optical Society of America. *University of Alberta, Edmonton, Canada .2011*

[23] B.Danielle, M. McRae, A. Denis, B. Therien, ***"Sierpirski Fractals as Plasmonic Metastructures for Second-Harmonic Generation"***, ACS Applied Nano Materials Department of Chemistry and the Centre for Advanced Materials and Biomaterials, Canada, 2020.

[24] U.Honghua, D. Jeffrey***," Optical dielectric function of silver"*** Department of Physics, Department of Chemistry, University of Colorado, PHYSICAL REVIEW, USA 2015.

[25] A. Kheirandish, N. Sepehri Javan, ***"Modified Drude model for small gold nanoparticles surface plasmon resonance based on the role of classical confinement"***, *Scientific Reports* Department of Physics, University of Mohaghegh Ardabili, Iran 2020.

[26] Y. Xin, G. Ziheng, T. Cheng, Li. Shuguang, ***'A novel gold-coated PCF polarization filter based on surface plasmon resonance',*** Optics and Laser Technology china,2020.

[27] D. Mart, A. Ortiz-Mora, ***"A new Sierpinski-based fractal photonic crystal fiber design with low dispersion and confinement loss"*** Department of Chemistry University of Crdoba, , Spain 2021.

[28] V. Brückner, "**To the use of Sellmeier formula**", Bonn and HfT Leipzig, Germany, 2014.

[29] M. G. Blaber, M. D. Arnold, and M. J. Ford, *"**Search for the Ideal Plasmonic Nanoshell: The Effects of Surface Scattering and Alternatives to Gold and Silver",*** J. Phys Hindawi Publishing Corporation, University of Colorado, USA, 2009.

[30] M. Hossain, ***" Study of Confinement Loss in Photonic Crystal Fiber",***
Conference: International Conference on Materials, Electronics & Information Engineering At: Faculty of Engineering, Rajshahi University, Bangladesh
2015.

[31] S. Selvendran, J. Divya, A. Sivanantha Raja. "***A Reconfigurable Surface-Plasmon-Based Filter/Sensor Using D-Shaped Photonic Crystal Fiber"***, School of Electronics Engineering (SENSE), Vellore Institute of Technology, India; 2022.

[32] M. Rahman, A. Khaleque,F Rabbi," ***Gold-coated photonic crystal fiber based polarization filter for dual communication windows'***, Elsevier, Bangladesh.,2019.

[33] Qu.Yuwei, J. Yuan, X. Zhou,' ***Mid-infrared silicon photonic crystal fiber polarization filter based on surface plasmon resonance effect',*** Optics Communications,china,2020.

[34] D. Kumar; S. Kumar, ***"SPR-Assisted Photonic Crystal Fiber-Based Dual-Wavelength Single Polarizing Filter With Improved Performance"***, IEEE Transactions on Plasma Science Shandong Key Laboratory of Optical Communication, Liaocheng University,China,2021.

[35] D. Yang, W.Zhulin, ***"Design of an asymmetric gold-coated photonic crystal fiber (PCF) polarization filter based on surface plasmon resonance (SPR)"***
Taylor and Francis online Instrumentation Science & Technology a School of Information Science & Engineering, Northeastern University, Shenyang, China,2022
[36] D. Kumar, S. Kumar, ***"SPR-Assisted Photonic Crystal Fiber-Based Dual-Wavelength Single Polarizing Filter With Improved Performance"*** International Conference on Computer, Communication, Chemical, Materials and Electronic Engineering (IC4ME2),University of Technology Gorakhpur, India, 2022
[37] G. Zhigang, X. Jing, Li Shuguang, H. Chen,"***Analysis of filtering and refractive index sensing characteristics based on gold-coated photonic crystal fiber"*** Journal of the Optical Society of America B, University, Shenyang, China,2022
[38] T.PANDEY, A. ISLAM,"***Surface plasmon resonance based tunable D-shaped single polarization filter at the communication band***",Department of Electrical & Electronic Engineering, Rajshahi University of Engineering & Technology, Bangladesh 2022.
[39] T. Pandey,A. Islam,"***Surface plasmon resonance based tunable D-shaped single polarization filter at the communication band***",Optical Materials Express, University of Mohaghegh Ardabili, Iran 2022.
[40]H. RAHMAN, A. KHALEQUE, ***"Dual-function plasmonic device on photonic crystal fiber for near to mid-infrared regions",***Department of Electrical & Electronic Engineering, Rajshahi University of Engineering & Technology,Bangladesh
Optical Materials Express 2023.