行政院國家科學委員會專題研究計畫 成果報告

二維微型小孔對光子晶體光纖光學特性的影響
研究成果報告(精簡版)

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碩士班研究生-兼任助理人員：張宏榮

處 理 方 式 ： 本計畫涉及專利或其他智慧財產權，2 年後可公開查詢

中 華 民 國 99 年 10 月 28 日

計畫成果:

1. Jin-Jei Wu, Daru Chen, Kun-Lin Liao, Tzong-Jer Yang, and Linfang Shen, "Highly birefringent Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal structure" , Progress In Electromagnetics Research Letters, Vol. 10, 87-95, 2009.
2. Kun-Lin Liao, Daru Chen, Jin-Jei Wu, Tzong-Jer Yang, and Linfang Shen, "Highly birefringent Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal structure" Progress in electromagnetics research symposium 2009(PIERS).
3. Kun-Lin Liao, Jin-Jei Wu, Tzong-Jer Yang, Daru Chen, and Linfang Shen, "A novel fiber sensor based on a Bragg fiber with a defect layer", Progress in electromagnetics research symposium 2009(PIERS).
4. X. F. Zhang, L. F. Shen, J. J. Wu and Tzong-Jer Yang, "The guiding properties of periodic dielectric waveguides (PDWGs) are investigated theoretically at erahertz frequencies for", J. of Electromagn. Waves and Appl., Vol. 24, 57–564, 2010.
5. X. F. Zhang, L. F. Shen, J. J. Wu and Tzong-Jer Yang, "Terahertz surface plasmon polaritons on a periodically structured metal film with high confinement and low loss", J. of Electromagn. Waves and Appl., Vol. 23, 2451–2460, 2009.
6. J. J. Wu, "Subwavelength microwave guiding by periodically corrugated strip line", Progress In Electromagnetics Research, PIER 104, 113-123, 2010.

Highly birefringent Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal structure

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Abstract- A novel highly birefringent Bragg fiber with a fiber core of 2-dimension (2D) elliptical-hole photonic crystal structure is proposed. Elliptical air holes are introduced into the fiber core to form a normal 2D photonic crystal structure with a hole pitch (center-to-center distance between the air holes) much smaller that the

operation wavelength of the Bragg fiber. The elliptical-hole photonic crystal structure acts as an anisotropic medium with different effective indices for transmission light of differently polarization, which inevitably results to high birefringence (up to the order of magnitude of0.01) of the Bragg fiber. The proposed Bragg fiber possesses different band-gaps for differently polarized mode. Besides the periodic alternating layers of high/low refractive indices, the bandwidth of the band-gap is also dependent on the effective index of the fiber core, which can be controlled by the area of the elliptical air holes.

INTRODUCTION

Photonic crystal fibers (PCFs) [1-3] which also include Bragg fibers have attracted increasing interest over the past decade because of their unique property, such as high birefringence, high nonlinearity, endlessly single-mode operation, single-polarization single-mode operation, and tailorable chromatic dispersion. Highly birefringent PCFs are one kind of extemely important PCFs which have promising applications in e.g. fiber sensors, fiber lasers, and fiber filters [4-5]. So far, various highly birefringent PCFs have been proposed [6-8]. Meanwhile, Bragg fibers have recently received much attention for their interesting dispersion and modal properties and for advances in fabrication techniques [9]. However, so far there is no report about birefringent Bragg fibers. In this letter, we propose a highly birefringent Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal (2D-EH-PhC) structure surrounded by a multilayer cladding with the suitable designed alternating layers of high/low refractive indices. High birefringence (up to the order of magnitude of 0.01) has been achieved and other characteristics of the proposed Bragg fiber have also been investigated.

SIMULATION RESULTS AND ANALYSIS

Figure 1 shows a quarter of the cross section of the proposed Bragg fiber with a fiber core of 2D-EH-PhC structure. In the fiber core, the hole pitch Γ (the center-to-center distance between the two adjacent air holes) is 200 nm, which is much smaller than the operating wavelength of the Bragg fibers in this letter. The elliptical air holes are characterized by the normalized area $S = \pi ab / \Gamma^2$ and ellipticity $\eta = b/a$, where *a,b* are the radius in x, y direction, respectively. The fiber core is encompassed by fifty periodic structures of alternating layers of high and low refractive indices in the fiber cladding. The thickness of the periodic structure formed by one high and one low refractive index layer is $\Lambda = 387.5nm$. In this paper, we choose high/low refractive index of 4.6/1.6, with thicknesses of $d_1 = 0.2176\Lambda$ and $d_2 = 0.7824\Lambda$ (forming a quarter wavelength waveguide stack for the wavelength within the optical fiber comminication window). The refractive index of the fiber core is set to be 1.45 (considering the silica materials). A full-vector finite-element method (FEM) and anisotropic perfectly matched layers [17] are employed to simulate the guided modes of the proposed Bragg fibers. The calculated results are expressed in terms of the normalized frequency $\nu = \Lambda / \lambda$, where λ is the operation wavelength in free space.

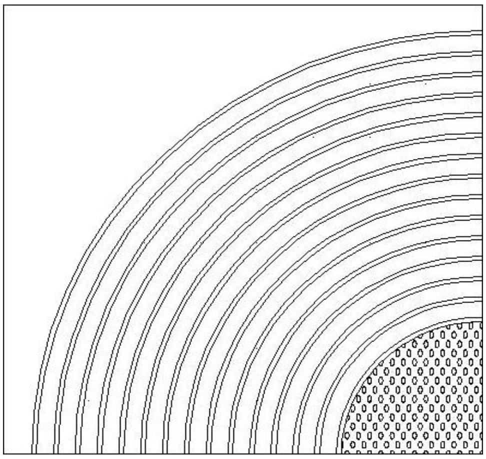

Fig. 1. Cross section of the proposed Bragg fiber.

To understand the characteristics of the Bragg fiber, band structure of the planar dielectric mirror which consists of suitable designed alternating layers of high and low refractive indices with the same parameters as those of the periodic structures of the Bragg fiber mentioned above is shown in Fig. 2. The surface-parallel wave-vector component β and the frequency ω are expressed in the unit of $2\pi c / \Lambda$ and $2\pi / \Lambda$, respectively. The heavy gray regions correspond to the situations where light can propagate in the planar dielectric mirror. Hence, for the Bragg fiber with a fiber cladding of the periodic structures, guided modes appear in the white regions in Fig. 2 which are so called bang gap regions. The dashed curve represents the light line ($\omega = c\beta$). The solid curve and red dotted curve in Fig. 2 show the dispersion characteristics of x-polarized and y-polarized modes for the Bragg fiber with 15 periodic two-layer structures and a fiber core of 2D-EH-PhC structure, respectively. The gap between the two curves indicates the high birefringence of the proposed Bragg fiber.

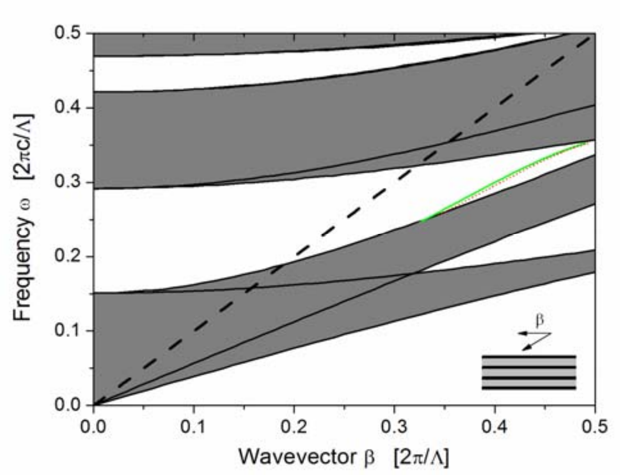

Fig. 2. Band structure of the planar dielectric mirror and disperion property for y-polarized (dotted curve) and x-polarized (solid curve) modes of the Bragg fiber.

It is well known that the Bragg fiber with a hollow fiber core (or filled with uniform media) will not be birefringent because of the symmetry. The fiber core of 2D-EH-PhC structure results in the high birefringence. To understand the birefringence induced by elliptical air holes in the fiber, the effective indices of the 2D-EH-PhC material should be investigated carefully. The parameters of the 2D-EH-PhC structure we consider here are $e = 2$ and $s = 0.2$, as illustrated in the inset of Fig. 3(a). The refractive index of the fused silica is set to be 1.45. A plane-wave expansion method [19] is used to calculate the effective indices for the wave propagation along the z direction in the photonic crystal material, and the results are shown as a function of the normalized frequency $\nu = \Lambda / \lambda$ in Fig. 3(a), where the solid curve and dotted curve represent the effective indices for the y-polarized and x-polarized light waves, respectively. Large difference between the effective indices for differently polarized light waves is observed. Insets of Fig. 3(a) shows the cross section of the array of elliptical-hole in fused silica. Figure 3(b) shows the index differences when the normalized areas of the elliptical air holes are 0.1 (short dashed curve), 0.2 (solid curve) and 0.3 (dotted curve), respectively. For the photonic crystal material with a normalized area of 0.2, the birefringence reaches its maximum of about 0.0277 as the normalized frequency approaches zero (namely, Λ tends to zero for a given wavelength). This indicates the photonic crystal material can act as an (dispersive) anisotropic medium.

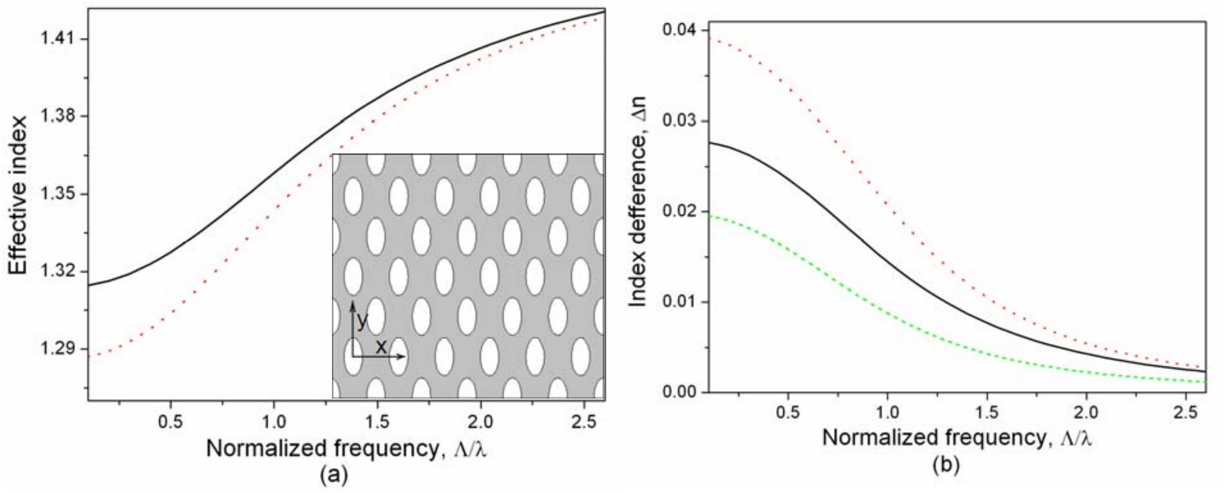

Fig. 3. (a) Effective index of the 2D-EH-PhC structure for the y-polarized (solid curve) and x-polarized (dotted curve) light waves (propagating in the z direction). (b) Effective index difference of the 2D-EH-PhC for the y-polarized and x-polarized light waves. Insets of (a) shows the cross section of the array of elliptical-hole in fused silica.

Figure 4(a) shows the birefringence of the proposed Bragg fibers when the ellipticity of the elliptical air holes is 2 and the normalized areas of the elliptical air holes are 0.1 (dashed curve), 0.2 (dotted curve) and 0.3 (solid curve), respectively. Figure 4(b) shows the birefringence of the proposed Bragg fibers when the normalized area of the elliptical air holes is 0.3 and the ellipticities of the elliptical air holes are 1.5 (dashed curve), 2 (solid curve) and 3 (dotted curve), respectively. Note that the different lengths of the curves in Fig. 4 are due to the fact that different Bragg fibers have different band gap regions.

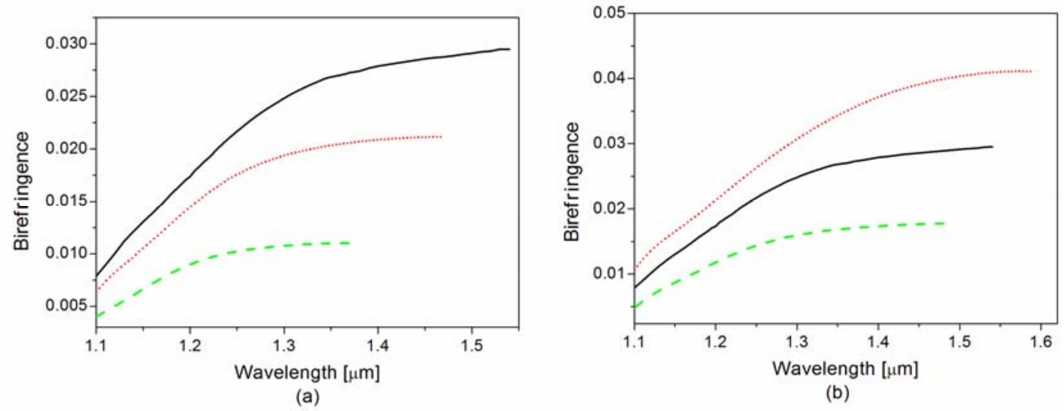

Fig. 4. (a) Birefringence of the Bragg fibers when the normalized areas are 0.1, 0.2 and 0.3, respectively. (b) Birefringence of the Bragg fibers when the ellipticities are 1.5, 2 and 3, respectively.

4. CONCLUSIONS

In conclusion, 2D-EH-PhC structure with with a hole pitch much smaller that the operation wavelength is investigated and introduced in the fiber core of the Bragg fiber. High birefringence (up to the order of 0.01) of the Bragg fiber has been achieved since the 2D-EH-PhC structure can act as an anisotropic medium with different effective indices for transmission light of differently polarization. Birefringence property of the proposed Bragg fiber has been fully investigated for different mormalized areas or ellipticities of the elliptical air holes in the fiber core.

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Subwavelength microwave guiding by periodically corrugated strip line

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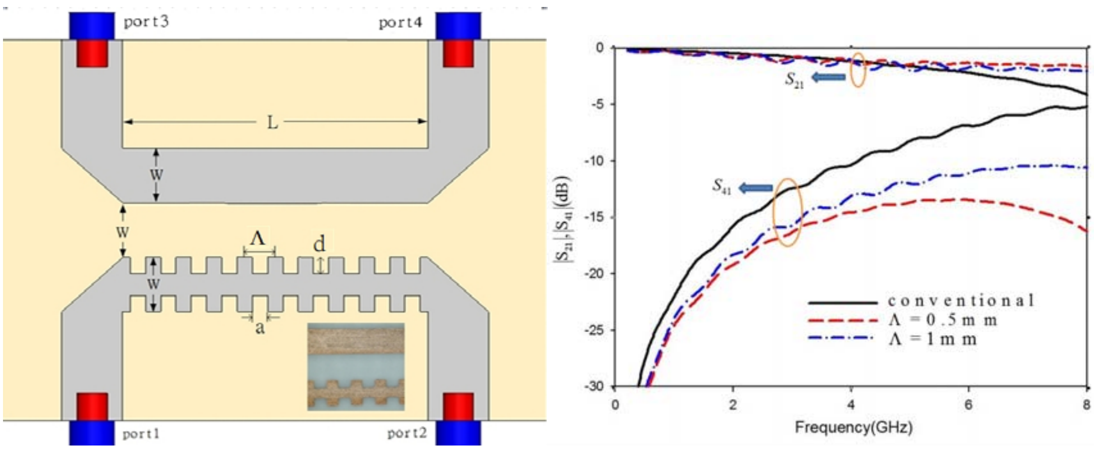
Abstract

A new type of microwave transmission line structure is proposed to reduce the crosstalk between transmission line circuits. In this structure, we corrugate the edge of the metal strip line with subwavelength grooves and with appropriate geometric parameters, such transmission lines can support highly localized spoof surface plasmon polaritons (SPPs) at microwave frequencies. Our theoretical simulation indicates that the crosstalk between such a transmission line and a conventional strip lines is very low at microwave frequencies, and this is further verified experimentally. Therefore, such transmission line structures have great potential applications in high speed circuit systems.

Recently, the signal transmission in high-speed circuits requiring conduction wires high density has attracted increased attention. Thus, crosstalk between conductor wires within the circuit has become a serious problem. One of the widely adopted methods to reduce the crosstalk is to decrease the coupling length and hence increase the rising time and move the strips farther apart, however such method leads to the growing of the circuit area and the decreasing of the transmission rate.

As a promising approach, SPPs provide the possibility of guiding electromagnetic (EM) waves beyond the diffraction limit. SPPs are electromagnetic excitations propagating as evanescent waves along the planar interface between a metal and a dielectric medium [1]. They have been at the centre of an unprecedented interest in the photonics community[2-6]. It would be greatly advantageous to take concept of highly localized SPPs to the microwave regime, which could open up a previously inaccessible length scale for microwave research, with promising applications in the miniaturization of microwave circuits as well as microwave imaging and sensing. At microwave frequencies, however, metals resemble a perfect conductor as their plasma frequencies are often in the ultraviolet part of the spectrum, leading to SPPs highly delocalized on both flat and cylindrical surfaces. As a consequence, SPPs suffer serious radiation loss (due to bends or nearby objects) and undesired coupling between adjacent waveguides. To enable high confinement of EM fields at lower frequencies, an idea of engineering surface plasmon at any frequency was proposed [7-9]. By cutting holes or grooves in flat metal surfaces, the penetration of EM fields into the metal increases and the frequency of existing surface plasmons can be tailored at will. The existence of such geometry-controlled SPPs, named spoof SPPs, has recently been verified experimentally in the microwave regime [10]. More recently, it has been reported that spoof SPPs at terahertz (THz) frequencies can be sustained on periodically corrugated metal wires [11-13]. The absorption loss of spoof SPPs in corrugated wires has also been studied at THz and microwave frequencies [14,15]. In this paper, a new type of transmission line corrugated with periodical subwavelength grooves is proposed to introduce SPPs into microwave regime for reducing the crosstalk between transmission line circuits. A directional coupler, whose two strip lines are separated by a distance of the line width, is designed and simulated numerically and measured experimentally over the frequency range 200MHz~12GHz. The results from measurement and simulation are in good agreement. This type of structure has potential application in high density microwave circuit and EMC systems.



(a) (b)

Fig.4 (a) Experimentally measured structure: periodically corrugated couple metal strip line, (b) experimentally measured data of S parameters with the groove depth $d = 0.3w$ and $\bar{a} = a / \Lambda = 0.5$.

In order to verify that the new strip line structure can reduce the crosstalk, we make an experimental investigation for our coupled strip line circuit with four ports as shown in Fig. 4(a). The confinement strength of EM waves on this new transmission line can be analyzed through the S-parameter measurements with the ZVB8 VNA manufactured by R&S. Signal is injected from port 1 into the circuit, then the S parameters were measured at four ports. Coupling between the conventional microstrip line and the periodically corrugated metal stripline with two different periods $\Lambda = 0..5mm$ and $1.0mm$ are measured individually for $\varepsilon_r = 3.37$ (Ro4003) with $w = 1.2mm$ and a stripline length of 10cm. There are two black curves represent S_{41} and S_{21} for the conventional coupler with symmetrical microstrip line, respectively. Up to 8GHz of the highest operation frequency of VNA, the magnitude of S_{41} increases gradually and the magnitude of S_{21} decreases as frequency increases. Two blue dash dot curves represent S-parameters between periodically corrugated metal stripline with $\Lambda = 1.0mm$ and conventional microstrip line, the magnitudes of S_{21} and S_{41} at f=8GHz equal to -2.004dB and -10.565dB, respectively, showing the suppression of crosstalk. For the additional case of periodically corrugated metal stripline with $\Lambda = 0..5mm$, the magnitudes of S_{21} and S_{41} at this frequency are equal to -1.621dB and -16.211dB, respectively, showing a better suppression of crosstalk, and apparently mitigation of energy decreases in the through-port. Highly confinement of EM waves is observed at microwave range since such subwavelength periodically corrugated metal stripline have low crosstalk characteristic, indicating great potential applications in high-speed circuit and EMC systems.

Conclusion

In conclusion, we have numerically and experimentally analyzed the guiding properties of periodically corrugated metal strip lines at microwave frequencies. We have presented the dispersion characteristics of these periodically corrugated metal strip lines. The asymptotic frequency of a corrugated metal strip structure can be tailored by varying the period of the structure. Strong field confinement of spoof SPPs at microwave frequency can be achieved in these waveguide structures. We have demonstrated experimentally that there is low coupling or crosstalk between a transmission line of this type and a conventional strip line. Therefore, this type of waveguide structure may be extensively used in electromagnetic compatibility area.

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無研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：吳俊傑	計畫編號：98-2221-E-216-001-
計畫名稱：二維微型小孔對光子晶體光纖光學特性的影響	

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	2	100%		
		專書	0	0	100%		
	專利	申請中件數	1	1	100%	件	
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		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

國外	論文著作	期刊論文	6	6	100%	篇	The optical properties of Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal structure Progress In Electromagnetics Research Letters (2009) 10, 87-95 TERAHERTZ SURFACE PLASMON POLARITONS ON A PERIODICALLY STRUCTURED METAL FILM WITH Journal of Electromagnetic Waves and Applications (2009) 2451-2480 BACKWARD GUIDING OF TERAHERTZ RADIATION IN PERIODIC DIELECTRIC WAVEGUIDES Journal of Electromagnetic Waves and Applications(2010)24, 557-564 Subwavelength microwave guiding by periodically corrugated strip line PROGRESS IN ELECTROMAGNETICS RESEARCH-PIER (2010)104, 113-123 Low-Frequency Surface Plasmon Polaritons Guided on a Corrugated Metal Striplines with Subwavelength Periodical Inward Slits Plasmonics DOI 10.1007/s11468-010-9169-0 Crosstalk reduction between metal-strips with subwavelength periodically corrugated structure ELECTRONICS LETTERS 2nd September 2010 Vol. 46 No. 18
		研究報告/技術報告	0	0	100%		

		研討會論文	2	2	100%		A novel fiber sensor based on a Bragg fiber with a defect layer Progress in electromagnetics research symposium 2009(PIERS) Highly birefringent Bragg fiber with a fiber core of 2-dimension elliptical-hole photonic crystal structure Progress in electromagnetics research symposium 2009(PIERS)
		專書	0	0	100%	章/本	
	專利	申請中件數	1	1	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
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		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)		無					

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

　　□實驗失敗

　　□因故實驗中斷

　　□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：□已獲得 ■申請中 □無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

本計畫一共發表六篇期刊論文，兩篇研討會論文，申請一項專利

期刊論文：主要發表於 Plasmonics, Electronics Letter 和 PIRE

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

1. 本計畫要感謝國科會光電學門的補助

2. 我們在執行計畫的過程發現許多有趣的現象，並將這些成果設計成實際元件，一方面發表於國際期刊，另一方面申請專利．我們深信由計畫所衍生出來的元件，應可用於實際的電路，由於國科會的補助，使得我的許多想法得以真正實現.

3. 參與的學生與老師在執行計畫的期間，相互奮鬥，學習最新期刊的知識，對於學生的就業與主持人未來研究工作的開展有極大的幫助.

4. 學生於參與期間發表期刊，對於學生的就業有極大的幫助.