行政院國家科學委員會專題研究計畫 成果報告

超導機制，渦旋運動與電磁超介質的性質研究
研究成果報告(精簡版)

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中文摘要： 在此報告中,有兩類子題,一為研究超導薄膜中渦旋運動,另一為一維光子晶體及在圓柱中多層金屬薄膜上皺紋結構中,太赫茲或微波段下,spoof 表面電漿子的傳播.在第一類,鈮薄膜上作成不同半徑之圓形釘札中心所形成的四方晶格,探討它的渦旋釘札行為.在磁傳導量測結果,呈現臨界電流匹配高峰及一些遺失的高峰.釘札中心半徑愈大,遺失高峰的標示數愈高.此一現象藉由分子動力學模擬及釘札中心的間隙上之渦旋和在釘札中心上的渦旋互相作用解釋之.在第二類中,以合適結構的金屬凹槽結構就低於金屬電漿頻率下,可看到引導次波長隧道電漿子(CPPs).與可見光頻率之CPPs作比較,更多不同的物理機制會藉由表面的圖樣引入,以致它顯現更優越的特色,甚至能將可見光頻率之CPPs的缺點去除.我們有針對 spoof 表面電漿子應用到具髮夾結構的微帶線上,發現能把傳輸線間的寬帶交叉談顯著降低.我們延續上一計畫,針對環狀缺陷的光子晶體結構,含有極薄且強吸收金屬層研究窄帶反射和穿透濾波器.發現在某一設定波長,會呈現反射率與透射率同時出現高峰,高峰的波長相依著圓柱波之 azimuthal 模數.高峰之高度隨著層數改變.其他相關課題也經略述之在此一報告.

中文關鍵詞： 渦旋釘札,四方晶格,鈮之薄膜,分子動力學模擬,spoof 表面電漿子,微帶線,週期性波長髮夾結構,交叉談,環狀光子晶體,窄帶濾波器,圓柱波,隧道電漿子,電漿頻率,有效折射率方法.

英文摘要： In this project, we have done two category subjects in our research results. One category is to study the vortex motion in superconducting film. Another category is to study the optical properties of one dimensional photonic crystal and multilayer annular ring structure in cylinder, spoof surface Plasmon polaritons (SPPs) propagate in corrugated structure on metallic film for terahertz or microwave regime. In the first category, square arrays of circular pinning centers of various diameters were patterned in Nb thin films to explore their vortex pinning behavior. Periodic critical current matching peaks and some ’missing peaks’ were observed in magnetotransport measurements. This phenomenon is explained by molecular dynamics simulations and is caused by the interaction between interstitial vortices and vortices occupying the pinning centers. In second category, we study subwavelength guiding of channel plasmon polaritons (CPPs) is realized by a properly structured metallic groove at frequencies far below the plasma frequency of metal. Compared with CPPs at visible frequencies, more versatile physical mechanisms can be introduced in these CPPs by surface patterning, so that they can exhibit superior features as visible CPPs, while eliminating the potential drawbacks of the latter. Such designer CPPs are explained physically with the effective-index method and verified experimentally in the microwave regime. An application of Spoof SPPs is propsed. A new type of microstrip line on which the spoof SPPs can propagate in microwave band is developed and a scheme for reducing the wide-band crosstalk between transmission lines is proposed. The microstrip line structure is designed by introducing periodic subwavelength hairpin structure on the edge of conventional microstrip lines. Numerical methods are used to analyze the dispersion relation and guiding bandwidth in microwave regime. We experimentally verify that such periodically structured microstrip lines support spoof SPPs in the frequency range between 200 and 8 GHz. The spoof SPPs mode can be highly localized on the surface of the structured microstrip lines, and so the crosstalk between different structured microstrip lines is very weak.Other related results and subjects are also briefly described in this report.

英文關鍵詞： vortex pinning , square arrays , Nb thin film, molecular dynamics simulations ,spoof surface plasmon polaritons, micro-strip line, periodic sub-wavelength hairpin structure, cross talk, annular photonic crystal, narrowband filter, cylindrical wave, channel plasmon polaritons, plasma frequency, effective-index method.

超導機制、渦旋運動與電磁超介質的性質

研究報告

Project Number: NSC 99-2112-M- 216-002

Project Investigator: 楊宗哲 Tzong-Jer Yang, Professor

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100, 12, 01

Abstract

In this project, we have done two category subjects in our research results. One category is to study the vorte motion in superconducting film. Another category is to study the optical properties of one dimensional photonic crystal and multilayer annular ring structure in cylinder, spoof surface Plasmon polaritons (SPPs) propagate in corrugated structure on metallic film for terahertz or microwave regime. In the first category, square arrays of circular pinning centers of various diameters were patterned in Nb thin films to explore their vortex pinning behavior. Periodic critical current matching peaks and some "missing peaks" were observed in magnetotransport measurements. The larger the diameter of the pinning centers, the higher the index of the missing matching fields observed. This phenomenon is explained by molecular dynamics simulations and is caused by the interaction between interstitial vortices and vortices occupying the pinning centers. In second category, we study subwavelength guiding of channel plasmon polaritons (CPPs) is realized by a properly structured metallic groove at frequencies far below the plasma frequency of metal. Compared with CPPs at visible frequencies, more versatile physical mechanisms can be introduced in these CPPs by surface patterning, so that they can exhibit superior features as visible CPPs, while eliminating the potential drawbacks of the latter. Such designer CPPs are explained physically with the effective-index method and verified experimentally in the microwave regime. An application of Spoof SPPs is propsed. One example is a new type of microstrip line on which the spoof surface plasmon polaritons (SPPs) can propagate in microwave band is developed and a scheme for reducing the wide-band crosstalk between transmission lines is proposed. The microstrip line structure is designed by introducing periodic subwavelength hairpin structure on the edge of conventional microstrip lines. Numerical methods are used to analyze the dispersion relation and guiding bandwidth in microwave regime. Besides, we experimentally verify that such periodically structured microstrip lines support spoof SPPs in the frequency range between 200 and 8 GHz. Compared with the quasi-transmission electron microscopy mode in conventional microstrip line, the spoof SPPs mode can be highly localized on the surface of the structured microstrip lines, and so the crosstalk between different structured microstrip lines is very weak, for example, the crosstalk between one conventional microstrip line and one structured microstrip line ranges from 219.89 to 262.39 dB (which is much lower than the crosstalk between two conventional microstrip lines) when the distance between the two microstrip lines is the same

as the width of the microstrip line. Therefore this new kind of periodically structured microstrip line would be of great use in high-density microwave circuits and high-speed systems to guarantee signal integrity. We continue last year project to study the filtering properties for a narrowband reflection-and-transmission filter in an annular defective photonic crystal containing an ultrathin and strongly lossy metallic film are theoretically investigated based on the transfer matrix method for the cylindrical Bragg waves. At a certain design wavelength, simultaneous peaks in reflectance and transmittance can be found. The peak wavelength is shown to be dependent on the azimuthal mode number of the cylindrical waves. The peak heights in reflectance and transmittance can be directly varied by the stack numbers. In addition, the influence of the starting radius in reflectance and transmittance is also illustrated. Other related subjects are also briefly described in this report.

Keywords: vortex pinning , square arrays , Nb thin film, molecular dynamics simulations ,spoof surface plasmon polaritons, micro-strip line, periodic sub-wavelength hairpin structure, cross talk, annular photonic crystal, narrowband filter, cylindrical wave, channel plasmon polaritons, plasma frequency, effective-index method.

I. Introduction

In this year , my project covers two different topics. One focuses on the vortex dynamic in the regular defect lattice on Nb thin film. Another one focus on .digging out new properties of Spoof Surface Plasmon Polaritons on a special corrugated periodic structure and application of Spoof SPP to reduction cross-talk of a new type structure of micro-strip lines. I also cooperate with Prof. C. J. Wu to study properties of one dimensional different photonic crystal structures. Such cooperation, we come out several excellent results and published in well-known international journals. I also cooperate with Prof. S. Q. Shen to study new properties of Electromagnetic- Induced- Transparency in Alkali gas medium to form periodic structures. This comes out several preliminary results. A special one writes up a chapter in Photonic Crystal book published by In-Tech Europe. In the following, I shall divide into several sections to describe sub-subjects I mention above.

II. Square arrays of circular pinning centers in Nb thin films

In this subject, we analyze missing matching peaks in Nb thin film for square arrays of circular pinning centers and come out one paper in Journal of Applied Physics 109, 083920 (2011). The essential results are periodic critical current matching peaks and some “missing peaks” were observed in magnetotransport measurements. The larger the diameter of the pinning centers, the higher the index of the missing matching fields observed. This phenomenon is explained by molecular dynamics simulations and is caused by the interaction between interstitial vortices and vortices occupying the pinning centers.

The sizes of the pinning sites in all our three samples are relatively large and comparable with the distance between them.At certain temperatures our experiments revealed that the magnitude of the critical current peak suddenly drops at the nth matching field and seems to be missing, where n could be 3, 4, or 5. At the following (n + 1) th matching field, the critical current reaches about the same value as at the nth matching field and the peak is obvious. The experiments also demonstrated that pinning sites with larger diameters cause this drop at higher matching fields. In molecular dynamic simulations we found that this phenomenon can be explained by the interaction between the interstitial vortices and the multi-vortices which occupy pinning centers. From the phase diagrams obtained from our simulations the phenomenon described above can be easily understood.

The experimentally observed feature that pinning sites with larger diameter depress the critical current at higher matching fields is explained by numerical simulations. We found that this phenomenon is caused by the interaction between the interstitial vortices and the multi-vortices occupying pinning centers. For example, in the case of two neighboring matching fields where only one interstitial vortex is present in every interstitial position, we can see that the first matching peak is missing and the second matching peak is still obvious. The comparison with experiments needs to be further elaborated. We used more or less arbitrarily chosen pinning strength. We took into account that near the edge of the pinning sites the superconducting order parameter could be depressed, so that the effective size of the pinning sites can be considerably larger than the diameter of the pinning sites. So we used more or less arbitrarily chosen effective pinning site radius r_p. We did not consider the possibility that giant vortices can occur. This work is in progress.

III. Subwavelength guiding of channel plasmon polaritons

In this subject, we construct a properly structured metallic groove at frequencies far below the plasma frequency of metal to study subwavelength guiding of channel Plasmon polaritons. In this study, we do experimental work and simulation with theoretical analysis. The results come out very good agreement. We write up these results into a paper to send to Applied Physics Letters editor and very soon to get response to accept with a minor revision. Here I give a brief description our essential results as following.

Plasmonic metamaterials formed by periodical textures on metal surfaces address the challenge of routing waves on subwavelength scale at low frequencies (particularly in terahertz regime). Plasmonic metamaterials support surface waves whose dispersion and spatial confinement can be engineered by surface patterning. since these surface waves mimic the properties of surface plasmon polaritons (SPPs) at visible frequencies, they are termed as designer (or spoof) surface plasmon poalritons. Recently, the physical similarity of designer SPPs with natural SPPs has been established with an effective-medium model, and the existence of such designer SPPs has later been verified experimentally in both microwave and terahertz regimes. More recently, waveguide scheme based on designer SPPs has become a focus of research for subwavelength routing terahertz radiations. In visible regime, the most attractive scheme of SPPs is channel plasmon polaritons (CPPs) guided at the bottom of V-shaped grooves carved into a planar metal surface, which have superior features of subwavelength field confinement, low propagation loss, efficient transmission through sharp bends, and compatibility with planar technology. For CPPs, a waveguide parameter (Vcpp) can be introduced to characterize their modal behaviors, and they are propagating when Vcpp>0.5*pi. Thus, at visible frequencies, the groove depth is required to be of the order of wavelength. When switching to lower frequencies, where Vcpp scales as the square of the groove depth divided by wavelength, the groove depth needs to be several dozens (terahertz) or hundreds (microwave) of wavelength, and this limits CPPs to be extended to terahertz and microwave regimes. Since the features of designer SPPs are mainly controlled by surface geometries, it is more flexible in physics to strongly confine the designer SPP field in the plane transverse to the propagation direction, compared to natural SPPs in the visible regime. In this letter, we report the realization of subwavelength guiding of designer CPPs at low frequencies by a metallic groove whose walls are properly structured.Compared with visible CPPs, we can introduce additional physical mechanisms in designer CPPs, so that they possess superior properties as visible CPPs, while eliminating the potential drawback of the later, i.e., the mode hybridization with wedge plasmon polaritions (WPPs) at the groove edges.The designer CPP guiding by such groove is also verified experimentally in microwave regime.

The envisioned structure is a metallic groove consisting of alternating triangular (V-shaped) grooves with length a and rectangular (U-shaped) grooves with length (d_a). The V- and U-shaped grooves have the same width w and depth H, and the angle of the V-shape grooves is u¼ atan (w/2H). We utilize the full-vector finite element method (FEM) to solve numerically the CPP modes. In the perfect conductor approximation, which is valid for metals in microwave or terahertz regimes, all magnitudes of the modes are scalable and we can take the period d as the unit length. Two CPP modes can be sustained by this groove, and the dispersion curves lie outside the shaded area bounded by the dispersion relation of vacuum, which means them nonradiative. The field of the fundamental mode is highly confined at the bottom of the subwavelength groove, while the second mode has a field loosely extended in the groove. Evidently, the fundamental mode is laterally confined on a scale smaller than the wavelength (k) in vacuum. Hereafter, we will consider only the fundamental CPP mode because it exhibits a better confinement. To get a deep sight into the designer CPPs, we apply the effective index method (EIM) for waveguide analysis to our structured groove as in the case for the V-groove in visible regime. It is known that the effective index of designer SPPs on a single corrugated metal surface increases with indentation depth. In our structured groove, the periodic indentation on each wall gradually deepens along the groove depth. Compared to the visible V-groove, in the present groove structure, besides decreasing separation distance between two groove walls (along the groove depth), there exists an additional mechanism to enhance the gradient of the effective index (neff) of coupled SPPs in the groove depth direction, making the fields more effectively confined at the groove bottom. More importantly, we keep the indentation depth to be zero at the groove edges, which leads to neff=1, hence the possibility of WPP hybridization vanishes fundamentally.

We have shown that a structured groove consisting of alternating V- and U-shaped grooves can sustain designer CPPs strongly confined at the groove bottom. Like visible CPPs, this designer CPPs can achieve 100% transmission through a sharp bend. The proposed designer CPPs have been verified experimentally in the microwave regime. Due to the superior features of designer CPPs, we expect that they have a wide variety of potential applications in terahertz or microwave regimes.

IV. corrugated metal strip lines with subwavelength periodic hairpin slits

Here we study the cross-talk problem in the corrugated metal strip lines with subwavelength periodic hairpin slits. The structure of device is simulated first by numerical simulation, then constructed accordingly. The measurement of this device is made and analyzed. We found the experimental results are agreed with our simulated results very well. The explaination also is made finally. The paper is written up and submitted to IET Microwave, Antenna & Propagation, the peered review process spent about one year. Now this paper is published in 2012 issue. The following, I summarized our important results of this paper.

A new type of microstrip line on which the spoof surface plasmon polaritons (SPPs) can propagate in microwave band is developed and a scheme for reducing the wide-band crosstalk between transmission lines is proposed. The microstrip line structure is designed by introducing periodic subwavelength hairpin structure on the edge of conventional microstrip lines. Numerical methods are used to analyse the dispersion relation and guiding bandwidth in microwave regime. Besides, the authors experimentally verify that such periodically structured microstrip lines support spoof SPPs in the frequency range between 200 and 8 GHz. Compared with the quasi-transmission electron microscopy mode in conventional microstrip line, the spoof SPPs mode can be highly localised on the surface of the structured microstrip lines, and so the crosstalk between different structured microstrip lines is very weak, for example, the crosstalk between one conventional microstrip line and one structured microstrip line ranges from 219.89 to 262.39 dB (which is much lower than the crosstalk between two conventional microstrip lines) when the distance between the two microstrip lines is the same as the width of the microstrip line. Therefore this new kind of periodically structured microstrip line would be of great use in high-density microwave circuits and high-speed systems to guarantee signal integrity.

Surface plasmon polaritons (SPPs) on metal surface are the electromagnetic (EM) excitations that propagate along the metal – dielectric interface, and their fields are evanescent in both the metal and the dielectric. SPPs provide a new solution in order to highly localise the EM fields on the metal surface, and therefore are widely

explored in recent years. For this reason, we expect that SPPs will be of great interest for designing circuits with low crosstalk (and hence the length scale of circuits is minified) if they were introduced into the microwave regime. However, metals resemble perfect electric conductor (PEC) in microwave regime, so that EM fields cannot be tightly confined on smooth metal surfaces, since the plasma frequency of metal is generally in the infrared band. Accordingly, it is impossible to directly apply SPPs to microwave transmission lines. Recently, a conception of low-frequency SPPs, where the penetration of EM fields into the metal increases when the subwavelength holes are cut in the metal surface, has been proposed. The working frequencies of the EM modes that can be referred to as spoof SPPs on such periodically structured metal surface are determined by the geometric parameters of the structure. The mechanism of spoof SPPs was well explained physically in Garc ı' a de Abajo, F.J.:Phys. Rev. Lett., 2005,: 95, (23),233901; Rev.Mod. Phys., 2007, 79, pp. 1267 – 1290.Such design in microwave regime has been theoretically analysed in (Wu, J.J., Yang, T.J., Shen, L.F. : J. Electromagn. Waves Appl., 2009, 23, pp. 11 – 19) and experimentally verified in (Hibbins, P.B., Evans, R., Sambles, J.R. : Science, 2005, 308, (5722),
pp. 670 – 672) . In this paper, a novel microstrip line structure whose edge is periodically corrugated with subwavelength hairpin slits is suggested. Such a hairpin-structured microstrip line supports the spoof SPPs in microwave regime, which improves the confinement of the EM fields on the microstrip line. Thus, such structured microstrip line can be used to design microwave circuits with low crosstalk and hence to provide a new way to reduce the scale of circuits, and a directional coupler composed of a conventional and a hairpin-shaped microstrip line is designed to verify this intriguing feature of the structured microstrip line. We find that such a coupler
has much lower crosstalk in comparison with the coupler consisting of two conventional microstrip lines. Another benefit is that it is much more simple to machining, without any complex process such as via holes or air notch. Therefore the hairpin-structured microstrip line will have potential application in high-density microwave circuits.

V. An annular defective photonic crystal containing an ultrathin metallic film

This subject is a part of my Post-doctor Dr. Mei-Soon Chen research work. We finish it and found very interesting results and wrote up a paper submitted to Optical Communications journal for peered review. It comes out published in 2012. Here I summarized our results in the following.

The filtering properties for a narrowband reflection-and-transmission filter in an annular defective photonic crystal containing an ultrathin and strongly lossy metallic film are theoretically investigated based on the transfer matrix method for the cylindrical Bragg waves. At a certain design wavelength, simultaneous peaks in reflectance and transmittance can be found. The peak wavelength is shown to be dependent on the azimuthal mode number of the cylindrical waves. The peak heights in reflectance and transmittance can be directly varied by the stack numbers. In addition, the influence of the starting radius in reflectance and transmittance is also illustrated.

Using the one-dimensional defective photonic crystals (PCs) to design and fabricate a narrowband transmission filter (NTF) has attracted much attention over the past two decades. Such an NTF also called the multilayer Fabry-Perot resonator has a structure of (HL)ND(HL)N or (HL)ND(LH)N, where H and L respectively denote the high- and low-index dielectric layers, N is the stack number, and D is referred to as the defect layer. Layers H and L are commonly taken to be quarter-wavelength, i.e., nHdH=nLdL=λ 0/4, where nH, nL are their refractive indices, dH, dL are their thicknesses, and λ 0 called the design wavelength is usually chosen to be located in the vicinity of center of the photonic band gap of the host PC, (HL)N. An NTF is a filter that has a sharp transmission peak in the transmission spectrum, which can always be achieved by increasing the value of N. Recently, a new narrowband filter, which can exhibit simultaneous peaks in reflection and transmission, has been investigated. It is thus called a narrowband reflection-and-transmission filter (NRTF), in contrast to the usual NTFwhich has a resonant peak only in the transmission spectrum. To achieve the simultaneous peaks in reflection and transmission, it is necessary to introduce certain absorption in the structure. In a lossless system, the power balance equation is R+T=1, where R is the reflectance and T is the transmittance. It is thus impossible to have simultaneous peaks inR and T in a lossless system because R and T are complementary each other. However, simultaneous peaks in R and T can be obtained if the system is lossy. In this case, the power balance equation is R+T+A=1,where A is the absorptance coming from the lossy medium. With this idea, a planar NRTF is designed as Air/M/ (LH)N1/2L/(HL)N2/H/Sub, where M is the metal layer playing the role in absorptance, N1 and N2 represent the stack numbers of the periodic bilayers, 2 L acts as a defect layer, and Sub is the substrate. In this design, there are two limits in M. One is that metal layer must be an ultrathin film, i.e., its thickness dM must be much less than the design wavelength. The other is that, in the vicinity of design wavelength, its imaginary part and real part of the complex refractive index (nM=n - jk) must be comparable, i.e., n≈k. In this NRTF the stack numbers N1 and N2 are not necessary to be large, which probably is a superior feature compared to the usual NTF where a large stack number is often required. An NRTF can be applied in the color decoration since it has both maximum reflection and transmission at the design wavelength. In this paper, we consider NRTF in a geometry of annular multilayer structure, where the above-mentioned planar one dimensional NRTF Air/M/(LH)N1/2L/(HL)N2/H/Sub is assumed to be bent into the annular shape. Here, Air is now in the core region with a starting radius of ρ 0, and the first circular ring is taken to be M, the ultrathin metal layer, and layers L and H are arranged in sequence. This type of NRTF is called the annular NRTF (ANRTF). To explore the reflection and transmission in this annular filter, we shall adopt the transfer matrix method for the cylindrical Bragg waves developed by Kaliteevski et al. It will be found that, the same as the planar NRTF, the simultaneous peaks in reflectance and transmittance can also be obtained in the ANRTF. Some related issues will be examined. First, the ratio of peak heights between reflectance and transmittance, i.e., Rmax/Tmax, can be modified by different stack numbers, N1 and N2. Second, the positions of peak reflection and transmission can be shifted as a function of the azimuthal number of the cylindrical wave. Finally, the role played by the starting radius ρ 0 in R- and T-spectrum will be illustrated. It is know that an annular photonic crystal (or annular Bragg reflector) plays an important and useful role in modern laser system with a portion of vertical emission . By creating a ring defect into the annular periodic multilayer structure, an annular resonator is also available. It is thus of potential interest to explore a resonator or filter with simultaneous resonant peaks in R and T in the annular geometry.

Ⅵ. Circuit Analog of Three- and Four-Level Electromagnetically Induced Transparency

Over the past two decades, quantum coherent control via atomic phase coherence has led to a number of physically interesting phenomena such as electromagnetically induced transparency (EIT) and the effects that are relevant to EIT, including inversionless light amplification, cancellation of spontaneous emission, multi-photon population trapping], phase coherence control as well as EIT-induced negatively refracting materials. EIT is such a quantum optical phenomenon that if one resonant laser beam propagates in a medium (e.g., an atomic vapor or a semiconductor-quantum-dot material), the beam will get absorbed; but if two resonant laser beams instead propagate inside the same medium, neither would be absorbed. Thus the opaque medium becomes a transparent one. Such an interesting optical behavior would lead to many applications, e.g., designs of new photonic and quantum optical devices. Since it can exhibit many intriguing optical properties, EIT has attracted extensive attentions of researchers in a variety of areas of atomic physics, optics, and condensed state physics. For example, some unusual physical effects associated with EIT include ultraslow light, superluminal propagation, and optical storage with atomic vapors, some of which are expected to be beneficial (and powerful) for developing new technologies in quantum optics and photonics. Although EIT is a quantum optical effect arising in atomic systems, yet it has various analogs in classical physics regime. Such analogs can be referred to as “classical EIT” effects or “EIT-like” phenomena, which can also exhibit “destructive interference” between two (or among three) resonant systems. In the literature, new schemes based on optical and photonic scenarios,such as planar metamaterial analogue of EIT for plasmonic sensing, plasmonic analog of EIT, circuit analog of EITas well as EIT-like effect in micromechanical resonators, have been suggested or experimentally demonstrated. It should be noted that almost all these classical analogs of EIT are those of three-level systems. As a four-level EIT system can exhibit a more significant dispersion sensitive to probe frequency than that in a conventional three-level system , the quantum optical properties of four-level EIT (such as double-control quantum interference, transient turn-on and -off dynamics) as well as its application to photonic device design (e.g., photonic switches and logic gates), have captured intensive attentions of many researchers . Obviously, the impact would be enormous if we can experimentally verify the circuit analog of both three- and four-level EIT. In this paper, we shall report our work on such a classical EIT-like effect, including their classical analog of relevant quantum coherence involved, e.g., destructive quantum interference among transitions pathways driven by both probe and control fields. Since a two-level resonant atomic system can be simulated by a simple LC circuit, three- and four-level electromagnetically induced transparency (EIT) that occur due to light-atom interaction can find its classical counterpart in circuit analog. As the optical response of an EIT atomic medium (including atomic vapors and semiconductor-quantum-dot dielectrics) can be controlled via tunable quantum interference induced by applied external control fields, in the scheme of circuit analog, such a controllable manipulation is achieved via capacitor coupling, where two LC loops are coupled by a capacitor that can represent the applied control fields in atomic EIT. Both numerical simulation and experimental demonstration of three- and four-level EIT were performed based on such a scenario of circuit analog. The classical "coherence" relevant to quantum interference among transitions pathways driven by both probe and control fields in EIT atomic systems has been manifested in the present circuit analog of EIT.

This work had been published in Advanced Materials Research Vols.415-417, 1340, 2012.

VI. Peculiar properties of One dimensional Photonic Crystal

This topic I cooperate with Prof. C. J. Wu to study. The results are written into a series of papers listed in my publication list. The described results are not written here. You may directly see all these published papers.

VIII. Future work

In the coming year, I plan to do electromagnetic induced transparency medium in multilayer medium to study Goos-Hachen shift effect, especially on EIA (electromagnetic induced amplification) situation. The application of Spoof SPP will continue on our previous work and also dig out a new properties of new structures. For one dimensional photonic crystal , I will continue to cooperate with Prof. C. J. Wu to dig out peculiar properties of new system. For instance, to calculate the effective Plasmon frequency in binary or ternary system.

XI. Acknowledgement

I would say in this project we had done very rich results and applications. We are going to apply patent of EIT system in 2011. 16 papers are published and several conference papers are also published.Many papers presented in the international conferences and inside country conferences. You may see my publication list. Hence I sincerely thank National Science Council to support my trip to attend international conferences and my Ph. D. salary to do research oeacefully, project funding to let me do several experimental test our idea and computer simulation.

X. Publication list in 2010 and 2011 :

2010-2011 Research Achievement

TZONG-JER YANG

Professor; **Ph. D. Program in Engineering Science, College of Engineering;** Department of Electrical Engineering, Chung Hua University, Hsinchu, Taiwan, Rep. of China. (2007 – Present)

(I). **International conference and Symposium: Session Organizer, Session Chair.**

1. **Session organizer in PIER international conference 2011 in Marrakesh, Morroco. (March 20-23, 2011).**
2. **Session organizer and Session Chair in PIER international conference 2011 in Suzhou, China. (Sept. 12-16, 2011).**
3. **Session organizer and Session Chair in PIERS international conference 2011 in Suzhou, China. (Sept. 12-16, 2011).**

(II). Publication List: 2009 – 2011

2010 Papers:

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3. R. Cao, Lance Horng, J.C. Wu, **T.J. Yang**, T.C. Wu, "Pinning effects in Nb thin films with artificial pinning arrays", **Journal of Superconductivity and Novel Magnetism** 23, 1051-1054, (2010). (IF=0.831)
4. Heng-Tung Hsu, Kuan-Chung Ting, **Tzong-Jer Yang,** Chien-Jang Wu, "Investigation of photonic band gap in a one-dimensional lossy DNG/DPS photonic crystal", **Solid State Communications** 150, 644-647 (2010),(online published on 24 Dec., 2009). (IF=1.837)

5. J. M. Chen, **J. M. Lee**, S. W. Huang, K. T. Lu, H. T. Jeng, C. K. Chen, S. C. Haw, T. L. Chou, S. A. Chen, N. Hiraoka, H. Ishii, K. D. Tsuei, and **T. J. Yang**, "intra-site and inter-site electronic excitations in multiferroic $TbMnO_3$ probed by resonant inelastic X-ray scattering", **Phys. Rev. B 82**, 094442 (2010).(IF=3.475) *

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7. Chien-Jang Wu, Yao-Li Chen, **Tzong-Jer Yang**, "Effective surface impedance of a high-temperature superconductor film in semiconductor plasma substrate at mid-infrared frequency", **Journal of Superconductivity and Novel Magnetism**, 23,545-550(2010).(online 25 February, 2010). (IF=0.831)

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9. Chien-Jang Wu, Zheng-Hui Wang, **Tzong-Jer Yang**, "Angle- and Thickness-Dependent photonic band structure in a superconducting photonic crystal", **Journal of Superconductivity and Novel Magnetism**, 23, 1395- 1399, 2010. online publication, 26 May, 2010. (IF=0.831)

10. J.J. Wu, Y.H. Kao, H.F. Lin, **T.J. Yang,** D.C. Tsai, H.J. Chang, C.C. Li, I.J. Hsieh, L.F. Shen, and X.F. Zhang, "Crosstalk reduction between metal-strips with subwavelength periodically corrugated structure", **Electronics Letters**, 46, No. 18,1273-1274, 2nd September 2010. (IF=0.971)

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14. T.C. Liao, J.J. Wu, J.Q. Sheng, **T.J. Yang,** " "The Sensitive Band Structure of an EIT Photonic Crystal and Its Application to Photonic Logic Gate Design" , to be published in **International Review of Physics, Vol. 4, Oct. 2010. (no IF, no SCI)**

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17. Wei-Hsiao Lin, Chien-Jang Wu, **Tzong-Jer Yang**, and Shoou-Jinn Chang, "Terahertz multichanneled filter in a superconducting photonic crystal", **Optics Express** 18, 27155-27166, 20 December 2010.(online published 9 Dec 2010.)(3.709)

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21. **H.T. Hsu, M.H. Lee, T.J. Yang, Y. C. Wang, and C. J. Wu,** "A multichanneled filter in a photonic crystal containing coupled defects", **Progress in Electromagnetics Research, Vol. 117, 379-392, 2011. (published on 15 June, 2011) (IF= 3.763)**

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6. Mei-Soong Mei, Chien-Jang Wu, **Tzong-Jer Yang**, "Investigation of optical properties in near-zero-permittivity operation range for a superconducting photonic crystal", **ICPEPA-7**, 15-20 August 2010, Copenhagen and Sonderborg, Denmark.
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11. The-Chau Liau, Jin-Jei Wu, Jian-Qi Shen, **Tzong-Jer Yang,** "Extraordinary ray response on LHM and EIT Bi-layered medium", **The 15 th National Conference on Vehicle Engineering,** Nov. 26, 2010, Southern Taiwan University, Tainan, Taiwan, R.O.C.
12. Teh-Chau Liau, Jin-Jei Wu, Jian Qi Shen**, Tzong-Jer Yang,"**Band structure of 1 D infinite periodic dielectric and EIT Bi-layered medium", **Optics and Photonics 2010** Taiwan, Dec. 3-4, 2010, Nan-Taiwan University, Tainan, Taiwan, Rep. of China.

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15. Jin Jei Wu, Her-Lih Chiueh, **Tzong-Jer Yang**, Di Chi Tsai, Hung Erh Lin, Bear Hu, Ricardo Wu, Daniel Wang, Hung Jung Chang, Chun Cheng Li, and Ing-Jar Hsieh, "Low frequency surface Plasmon polaritons on a periodically structured metal strip with high confinement of fields", **PIERS 2011 Morrakesh,** March 20-23, Morocco.
16. Jin-Jei Wu, Tzong-Jer Yang, Her-Lih Chiueh, Linfang Shen, Wei-Lein Ouyang, "Novel Characteristics of Reducing Wide-band Crosstalk for Guiding Microwave in Corrugated Metal Strip Lines with Subwavelength Periodic Hairpin Slits", PEIERS 2011 in Suzhou, Sept. 12-16, China.
17. Wei-Hsiao Lin, Chien-Jang Wu, Tzong-Jer Yang, and Shoou-Jinn Chang, "Analysis of Multiple Filtering Properties in a Superconductor-dielectric Superlattice at Terahertz Frequency ", PEIERS 2011 in Suzhou, Sept. 12-16, China.

18. Teh-Chau Liau, Jin-Jei Wu, Jianqi Shen, Tzong-Jer Yang, "EIT-based coherent control effect sensitive to probe frequency and control field intensity in a periodic layered medium", PEIERS 2011 in Suzhou, Sept. 12-16, China.

19. **Tzong-Jer Yang**, Her-Lih Chiueh, Ing-Jar Hsieh, Jian Qi Shen, Ta Chun Hou, Jin Jei Wu, " Novel Characteristics for Reducing Crosstalk in Corrugated Metal Strip Lines with Subwavelength Periodic Hairpine Slits", **International Photonics Conference 2011.**(IPC 2011), Dec. 8-10,2011, Tainan, National Cheng Kung University.

(V). Affiliation and **honors:**

1. **Investigator** of The physical society of Republic of China.(two year terms)
2. **Member** of AAPT(American Association of Physical Teachers).
3. **Member** of The Physical Society of Republic of China.
4. **Member of Sigma Xi.**
5. **Life member** of Material Science Society of Republic of China.
6. **Fellow of Electromagnetics Academy.**

(IV). Books

1. **"Bernoulli Potential in Superconductors"** 一書，作者爲 Pavel Lipavsky, Klaus Morawetz, Jan Kolacek, Ernst Helmut Brandt, and **Tzong-Jer Yang**, published in 2008 by Springer Verlag Publisher in the book series: **Lecture Notes 733 in Physics, ISBN 978-3-540-73455-0.**
2. **"Principle of Physics:** A Calculus Approach**", Authors:** Raymond A. Serway, John W. Jewett, Jr., Shang-Fang Tsai, Jenh-Yih Juang**, Tzong-Jer Yang,** published in 2011 by CENGAGE Learning Asia Pte Ltd. **ISBN-13: 978-981-4336-66-6. ISBN-10: 981-4336-66-1.**
3. **"Photonic Crystals - Introduction, Applications and Theory,"** ISBN 978-953-51-0431-5, edited by Alessandro Massaro, published by In Tech-Access Publisher in March 30, 2012. One Chapter entitled "EIT-Based Photonic Crystals and Photonic Logic Gate Design", Teh-Chau Liau, Jin-Jei Wu, Jian Qi Shen, Tzong-Jer Yang.

到大陸中國科學原院物理所訪問研究一星期
(2010.7.31-2010.8.6)

楊宗哲
中華大學電機工程系

一、訪問經過

在7月31日搭乘長榮航空，再度到大陸訪問科學院物理所教授顧本源討論Inverse problem的方法(楊一顧方法)，上一次在六月底左右曾訪問他，曾蒙他將楊一顧方法約略介紹一下，但因為他身體狀況已比去年拜訪時還差，且中氣不足，所以拜訪時間也為一星期，這次再度拜訪，乃是我經過一個月消化他上次所給的資料及存疑問題，並需趕在他身體尚可狀態下，跟他抽空好好地請益和討論。這次也難得與他的長期合作者楊國楨院士會面，談判他們的楊一顧方法，提及方法中的要訣可說收益較多，同時，我也想到如何將他們的方法應用於一維plasmanic系統的問題，從穿透係數和反射係數反推回去求出系統有效介電常數或磁化常數(permeability) 除了與他們討論，楊一顧方法如何應用於一維電漿子系統外，我也順便去參加附近的研討會，在暑假期間科學院或鄰近學校舉辦的研討會很多。這次，我去參加在物理教學上的看法和觀點。

二、訪問後心得

對於這次訪問的心得，主要偏重於學術上的研究問題，在學術方面可分成二個部份，一為與顧本源教授、楊國楨院士討論楊一顧方法的應用於一維電漿子系統的反演問題，另一為物理教育之研討會。

(a) 與顧本源教授、楊國楨院士的學術討論

顧教授的女博士仍處於修養狀態，他帶病親自撥出時間到科學院物理所與我約定時間解說和討論楊一顧方法的精 及要訣，並提醒我在使用時，數值處理上需注意的地方，然後由他引介楊國楨院士與我見面，並談及他們目前如何使用楊一顧方法於二維電漿子問題，但碰到一些瓶頸以致讓我聯想到先處理一維的電漿系統，我就將目前學術界引入有效電漿頻率，藉由反射率及穿透率反推回去，求此一有效電漿頻率，那麼是否可以利用楊一顧方法以反演方式求有效電漿頻率，他們支持我的看法，所以在往後的研究中，我將朝此一方向作研究課題。

另外，顧教授有感於身體狀況愈來愈差，盼望我能收下他的女博士生畢業後到台灣當博士後研究員，我答應盡力而為。

(b)物理教育研討會

在此教育研討會中認識大陸一些大學教育界的菁英，其中大學物理的編輯委員和主編，及物理與工程應用的編委，同時得到他們贈送約半年的期刊，其中內容有些值得一看，除了這些贈品外，也聽了一些演講者的物理教學看法及心得，

底下列出一些較為新奇的觀點：

1. 提出物理數學式子給予物理的詮釋，有助於學生建立或了解物理的涵意，並與數學做了區隔。
2. 物理公式以因果律作為物理詮釋的出發點，可隱含會有新物理現象的存在，引導學生走向研究的一種方向或途徑。
3. 物理的演示實驗，可引起學生對物理的興趣，而不至於產生對物理的厭惡感，另外，以演示實驗解說物理的原理，可使學生知道怎樣驗證物理原理的淺顯途經之一，在這次的研討會，有一些中小學身親身體驗物理的演示實驗，場面顯現熱烈，很有意思。

三、建議

在訪問的過程中，若有小型相關之研討會，值得參與，會獲得許多有意義的活動和靈感，建議國科會鼓勵教授們做國外短期(二星期內)的訪問，以建立相互合作研究的管道。

四、感謝

此次活動承蒙國科會的資助，始能順利成行，使我能有機會與對方作深入的討論和展開合作研究的課題。

Novel Characteristics of Reducing Wide-band Crosstalk for Guiding Microwave in Corrugated Metal Strip Lines with Subwavelength Periodic Hairpin Slits

Jin Jei Wu[1], **Tzong-Jer Yang**[1], **Her-Lih Chiueh**[2], **Linfang Shen**[3], **Weilien Ou Yang**[1], **and Chih-Hsiang Wen**[1]

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[3]Department of Information Science and Electronic Engineering Electromagnetic Academy, Zhejiang University, Hangzhou 310058, China

Abstract— A new type of microstrip line on which the spoof surface plasmon polaritons (SPPs) can propagate in microwave band is developed and a scheme for reducing the wide-band crosstalk between transmission lines is proposed. The microstrip line structure is designed by introducing periodic subwavelength hairpin structure on the edge of conventional microstrip lines. Numerical methods are used to analyze the dispersion relation and guiding bandwidth in microwave regime. Besides, we experimentally verify that such periodically structured microstrip lines support spoof SPPs in the frequency range between 200 MHz and 8 GHz. Compared with the quasi-TEM mode in conventional microstrip line, the spoof SPPs mode can be highly localized on the surface of the structured microstrip lines, and so the crosstalk between different structured microstrip lines is very weak.

無研發成果推廣資料

99 年度專題研究計畫研究成果彙整表

計畫主持人：楊宗哲			計畫編號：99-2112-M-216-002-				
計畫名稱：超導機制，渦旋運動與電磁超介質的性質研究							
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	0	100%		
		專書	0	0	100%		
	專利	申請中件數	2	0	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	
	參與計畫人力（本國籍）	碩士生	0	0	100%	人次	
		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	16	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	2	0	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	
	參與計畫人力（外國籍）	碩士生	2	0	100%	人次	
		博士生	2	0	100%		
		博士後研究員	1	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）

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）

My academic research achievement is two category,one for spoof Surface Plasmon Polaritons had been proved to applied in microwave regime, another for vortex dynamics in Nb thin film had found new experimental results and explained by molecular dynamics. Totally we published 16 papers in International well-known journals.