行政院國家科學委員會補助專題研究計畫成果報告

※※※※※※※※※※※※※※※※※※※※※※※※※

※　　　　　　　　　　　　　　　　　　　　　　　※

※　　新型週期性多層介電質結構之散射特性研究　　※

※　(Study on the scattering characteristics of a new　※

※　　type of periodic dielectric structures)　　※

※　　　　　　　　　　　　　　　　　　　　　　　※

※※※※※※※※※※※※※※※※※※※※※※※※※

計畫類別：☑個別型計畫　□整合型計畫

計畫編號：NSC 90-2213-E-018-001

執行期間：90 年 8 月 1 日至 91 年 7 月 31 日

計畫主持人：李清和

計畫參與人員：吳奈曄、徐健明

本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份

□赴大陸地區出差或研習心得報告一份

□出席國際學術會議心得報告及發表之論文各一份

□國際合作研究計畫國外研究報告書一份

執行單位：國立彰化師範大學　電子工程學系

中華民國 91 年 10 月 31 日

新型週期性多層介電質結構之散射特性研究
(Study on the scattering characteristics of a new type of periodic dielectric structures)

計畫編號：NSC 90-2213-E-018-001
執行期限：90 年 8 月 1 日至 91 年 7 月 31 日

主持人：李清和　國立彰化師範大學　電子工程學系
E-mail: iecher@cc.ncue.edu.tw
計畫參與人員：吳奈曄、徐健明
國立彰化師範大學　電機工程學系 碩士班

中文摘要

本計畫以模態匹配法及 Floquet 原理來分析一新型多層介電質週期性結構之 TE 波散射特性。整個計劃共分為四部份：第一部份探討高度、週期及入射角等變量對不同剖面形狀之介電質週期性結構散射特性之影響，其中介電質週期性結構之剖面形狀包含階梯形、單「十」字、單「工」字、雙「十」字及雙「工」字等。而第二部份所探討之結構與第一部份之者類似，但底層由空氣改為一導體平板，此部份結果將與第一部份相類似之結構做一比較。在第三部份中我們以導體微帶加於上述介電質週期性結構之最上層，藉以探討其對反射及透射特性之影響。最後，在第四部份中我們於介電質週期性結構之最上層與中間層加入導體微帶，使其成為一雙光柵結構，以研究其散射特性。預期本研究之成果將可作為此方面研發人員與相關結構設計者有用之參考。

關鍵詞：模態匹配法、Floquet 原理、週期性結構、散射特性、雙光柵結構

Abstract

A mode-matching technique in conjunction with the Floquet’s theorem is employed in this research to analyze the scattering characteristics of a new type of periodical structures for TE incident waves. The work of this project is divided into four parts. In the first part, the periodic dielectric structures with staircase, single as well as double crisscross and "I"-shaped profiles are studied. In the second part, the scattering characteristics of similar periodical structures as those studied in the first part but with a ground plane in the bottom layer will be analyzed. Results obtained from both cases will be compared. For the third part, a metallic strip is added on top surface of each period to construct a strip grating with a periodic dielectric substrate. The effects of varying the metallic strip width, thickness, and position on the scattering characteristics are examined. Finally, a bi-grating structure with metallic strip placed also in one of the inner dielectric layers is studied. Analysis similar to that of single grating structure will be performed. Results obtained in this research are expected to serve as useful references for researchers and designers working in this field.

Keywords: mode-matching method, Floquet's theory, scattering characteristic, bi-grating.

1. Introduction

Periodical dielectric layers have been of considerable interest for many years [1-5]. Because of their inherent frequency-selective behaviors, periodical structures have found many applications in the microwave, millimeter, and optical frequency bands. In scattering applications, periodical structures are usually made of metal [1]. Since losses associated with metals increase with frequency, periodical structures composed of composite materials are getting more and more attention [2], [5]. Because of the advantage of low absorption as compared to metallic screens, a periodical dielectric layer is an alternative candidate to be designed as a frequency-selective surface [4].

In this project, a mode-matching method, combined with Floquet theory [6], is formulated to analyze a new type of periodical dielectric structures consisting of two different dielectrics. Results on the frequency-selective reflection and transmission characteristics for some sample configurations are presented and, wherever possible, are compared with data available in the literature.

2. Sample Results and Discussion

Some sample structures of Fig. 1 are computed in this work, and a set of typical results is presented here. In Fig. 2, a single periodical dielectric layer which consists of two rectangular cross-sectioned dielectrics cascaded in juxtaposition in a unit cell was studied. The magnitude squared reflection coefficient, $|r_0|^2$, and transmission coefficient, $|t_0|^2$, as functions of the normalized frequency are plotted. Our results are almost identical to those obtained by Bertoni *et al.* [3]. This structure can be used as a dichroic (dual-frequency) reflector since there are two total reflections occurring at $k_0 h \cong 5.32$ and at $k_0 h \cong 5.83$. The coincidence of the two curves in the figure implies that all scattered Floquet modes, except mode 0, are cutoff in the *z* direction, and hence the power conservation, $|r_0|^2 + |t_0|^2 = 1$, is satisfied.

Fig. 3 demonstrates the results of $|r_0|^2$ and $|t_0|^2$ for a structure modeled by four dielectric layers (referred to Fig. 1). The phenomena of multiple total reflections and total transmissions are also observed. Moreover, in the displayed frequency range, the two curves coincide. Thus, the same implication to Fig. 2 also applies here.

The inset of Fig. 4 shows that there are only two regions in the whole space. This structure is important in the study of diffraction grating used in spectroscopy [2] and the study of surface scattering. The curves for $|r_0|^2$ and $|t_0|^2$ do not coincide with each other except at some specific frequencies. It is found that the reflected power is carried by the 0th Floquet mode and the transmitted power spreads in the $n = -1, 0, 1$ Floquet modes.

Results for other structures of Fig. 1, such as the single crisscross and "I"-shaped profiles are shown in Figs. 5 and 6. The one for double crisscross profiles is plotted in Fig. 8, and those for the periodic structures with conductor strip added on top or bottom surface are presented in Figs. 9 and10.

3. Self-Evaluation

Although we present here just some representative results, almost all of the work outlined in the project proposal was completed. Results obtained in this work can serve as useful reference for researchers and designers working in this field.

References

[1] K. A. Zaki and A. R. Neureuther, "Scattering from a Perfectly Conducting Surface with a Sinusoidal Height Profile: TE Polarization," *IEEE Trans. Antennas and Propagation*, vol. AP-19, pp. 208-214, Mar. 1971.

[2] S. -L. Chuang and J. A. Kong, "Scattering of wave from periodic surfaces," *Proc. IEEE,* vol. 69, pp.1132-1144, Sep. 1981.

[3] H. L. Bertoni, L. S. Cheo, and T. Tamir, "Frequency selective reflection and transmission by a periodic dielectric layer," *IEEE Trans. Antennas Propagation,* vol. AP-37, pp. 78-83, Jan. 1989.

[4] H. -C. Chu, S. -K. Jeng and C. H. Chen, "Reflection and Transmission

Characteristics of Single-Layer Periodic Composite Structures for TE Case," *IEEE Trans. Antennas and Propagation,* vol. 45, no. 7, pp. 1065-1070, July 1997.

[5] J. F. Kiang, "Backscattering of TE wave by periodical surface with dielectric cover," *IEEE Trans. Antennas and Propagation,* vol. 46, no. 2, pp. 176-180, Feb. 1998.

[6] R. E. Collin, *Field theory of guided waves.*2nd ed., New York: IEEE PRESS, 1991.

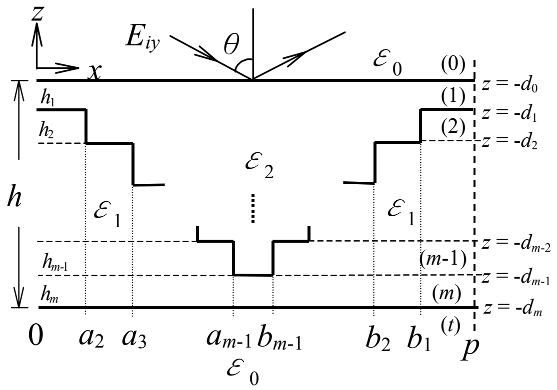

Fig. 1. Multilayered model for a unit cell.

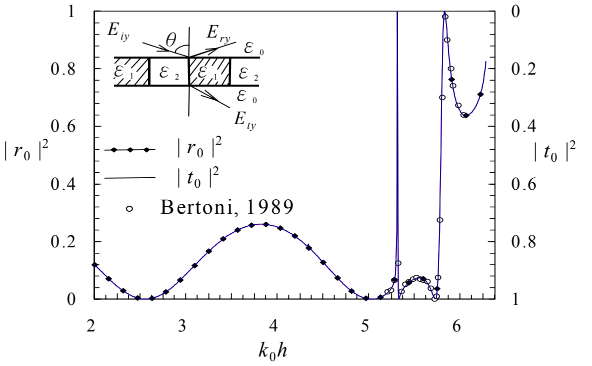

Fig. 2. Magnitude squared of r_0 and t_0 with a single layer with $m = 3$, $h_2/p = 1.713$ ($h = h_2$), $h_1 = h_3 = 0$, $a_2 = p/4$, $b_2 = 3p/4$, $\varepsilon_2 = 2.56\,\varepsilon_0$, $\varepsilon_1 = 1.44\,\varepsilon_0$, and $\theta = 45^\circ$.

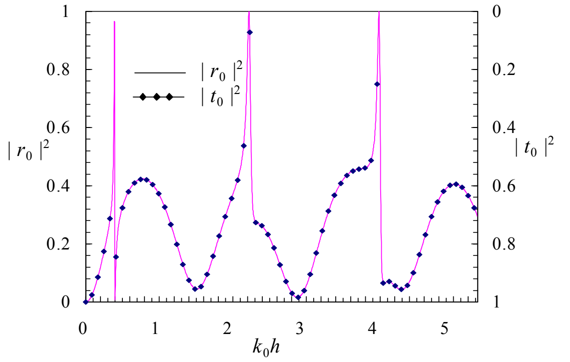

Fig. 3. Magnitude squared of r_0 and t_0 with $m = 4$, $p = 5/6\,\lambda_0$, $a_2 = p/5$, $b_2 = 4p/5$, $a_3 = 2p/5$, $b_3 = 3p/5$, $\varepsilon_2 = 3\,\varepsilon_0$, $\varepsilon_1 = 6\,\varepsilon_0$, $h_1 = h_2 = h_3 = h_4 = h/4$ and $\theta = 0^\circ$.

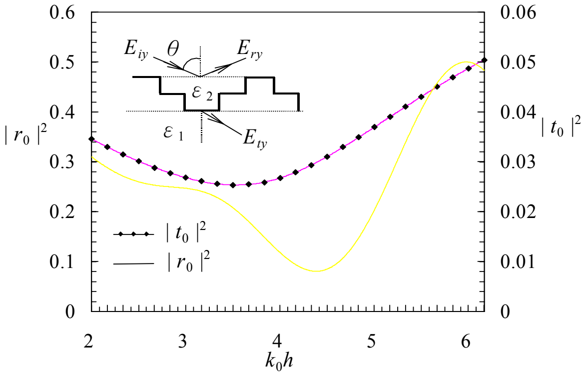

Fig. 4. Magnitude squared of r_0 and t_0 with $m = 4$, $p = 5/6\,\lambda_0$, $a_2 = p/5$, $b_2 = 4p/5$, $a_3 = 2p/5$, $b_3 = 3p/5$, $\varepsilon_2 = \varepsilon_0$, $\varepsilon_1 = 3\,\varepsilon_0$, $h_1 = h_4 = 0$, $h_2 = h_3 = h/2$ and $\theta = 0^\circ$.

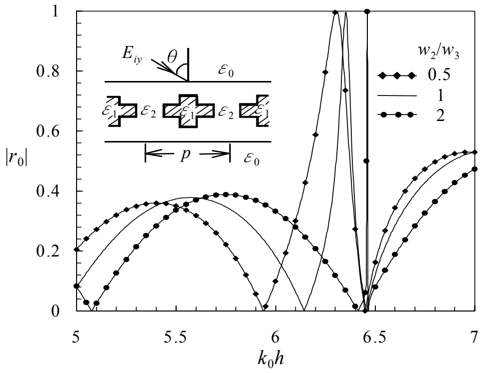

Fig. 5. Magnitude of r_0 with $m = 5$, $p = 2/3\lambda_0$, $\varepsilon_1 = 6\varepsilon_0$, $\varepsilon_2 = 3\varepsilon_0$, $h/p = 2.037$, $h_1 = h_2 = h_3 = h_4 = h_5 = h/5$, $a_2 = a_4$, $b_2 = b_4$, $a_3 = 1/4\lambda_0$, $b_3 = 5/12\lambda_0$ *and* $\theta = 0^\circ$ ($w_2 = 2a_2$, $w_3 = a_3 - a_2$).

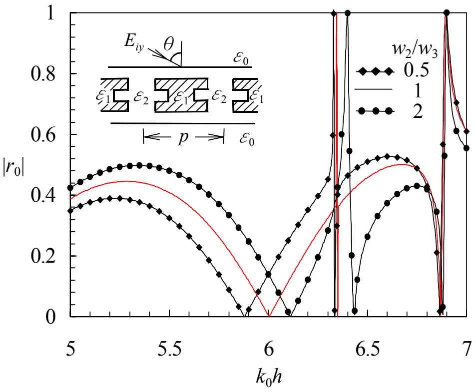

Fig. 6. Magnitude of r_0 with $m = 5, p = 2/3\lambda_0, \varepsilon_1 = 6\varepsilon_0, \varepsilon_2 = 3\varepsilon_0$, $h/p = 2.037$, $h_1 = h_2 = h_3 = h_4 = h_5 = h/5$, $a_2 = a_4 = 1/4\ \lambda_0$, $b_2 = b_4 = 5/12\ \lambda_0$ *and* $\theta = 0^\circ$ ($w_2 = 2a_3$,$w_3 = a_2 - a_3$).

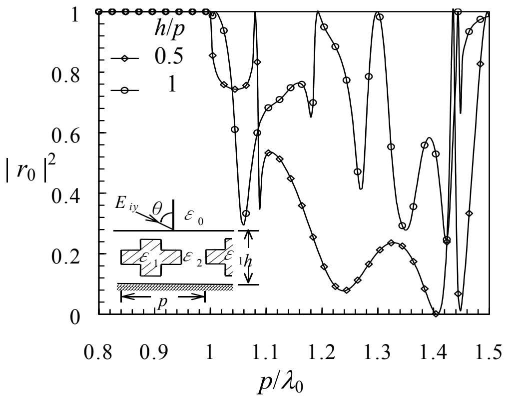

Fig. 7. Variation of the magnitude squared of r_0 with normalized period for the grounded periodical structure with single crisscross shaped profile: $m = 5$, $p = 12$ mm, $\varepsilon_1 = 6\varepsilon_0$, $\varepsilon_2 = 3\varepsilon_0$, $h_i = h/5$ ($i = 1, 2, \ldots, 5$), $a_2 = a_4 = p/8$, $a_3 = 3p/8$, $b_2 = b_4 = 7p/8$, $b_3 = 5p/8$, and $\theta = 0^\circ$.

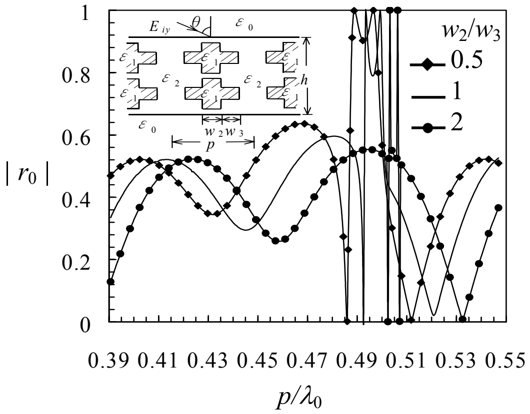

Fig. 8. Variation of the magnitude of r_0 with normalized period for a periodical structure with double crisscross shaped profile: $m = 9$, $p = 20$ mm, $\varepsilon_1 = 6\varepsilon_0$, $\varepsilon_2 = 3\varepsilon_0$, $h/p = 3.6666$, $h_i = h/9$ ($i = 1, 2, \ldots, 9$), $a_3 = a_7 = 3p/8$, $b_3 = b_7 = 5p/8$, and $\theta = 0^\circ$. ($w_2 = 2a_2$, $w_3 = a_3 - a_2$.)

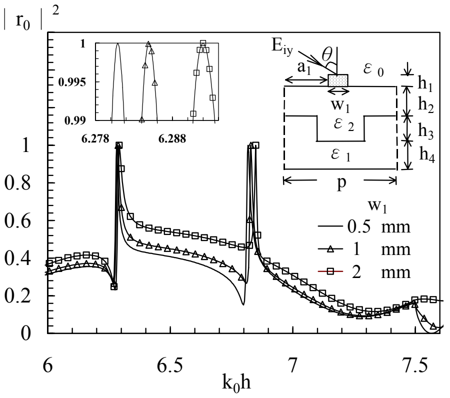

Fig.9. Variation of $|r_0|^2$ versus frequency with strip width as a parameter. The structural parameters are $\varepsilon_1 = 2.56\varepsilon_0$, $\varepsilon_2 = 1.44\varepsilon_0$, $a_1 = (p-w_1)/2$, $h_1 = 10$ μm, $h_3 = 20$ mm, $p = h_3/2.037$, $a_3 = p/4$, $b_3 = 3p/4$, $h_2 = h_4 = 0.01h_3$, and $\theta = 45°$.

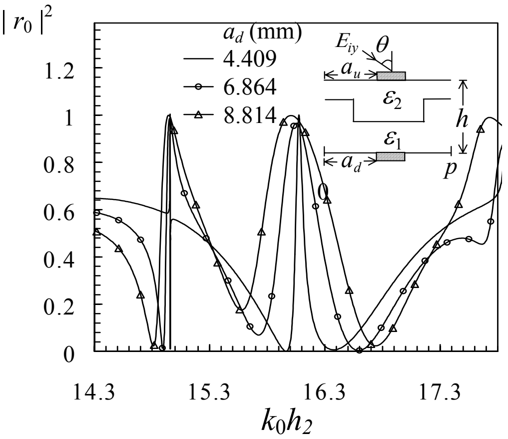

Fig. 10. Power reflection coefficient versus frequency with the position of the lower strip as a parameter. The parameters are $m = 3$, $\varepsilon_1 = 2.56\varepsilon_0$, $\varepsilon_2 = 1.44\varepsilon_0$, $a_u = (p-w_u)/2$, $w_u = w_d = 0.5$ mm, $h_u = h_d = 10$ μm, $h_1 = h_3 = 2$ mm, $h_2 = 20$ mm, $p = 9.818$ mm, $a_2 = p/4$, $b_2 = 3p/4$, *and* $\theta = 45°$.