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PPPL-2586

UC-426

DR# 0600-9

PPPL-2586

POLARIZATION CHARACTERISTICS OF WIRE MESH AT 119 μm

By

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JANUARY 1989

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC82-76-CMO-3073.

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Polarization Characteristics of Wire Mesh at

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PPPL--2586

DE89 006874

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Abstract

Polarization characteristics of the transmitted beam through the various sizes of metal wire grid meshes are examined experimentally at 118.8 μm . When these results are compared to Chen's wave guide theory, we have obtained excellent agreement. In particular, when the incident beam polarization is neither parallel (TM) nor perpendicular (TE) to the wire grid axis, a linearly polarized incident beam can be made elliptic due to the phase difference between the TE and TM modes.

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I. Introduction

In a far infrared and sub-millimeter wavelength region, optical properties of inductive metal wire mesh have been investigated in numerous applications such as beam splitters^{1,2} and bandpass filter^{3,4} designs. Recently, Pickett et al.⁵ verified that Chen's wave guide analysis⁶ can be applied to the short wavelength ($\lambda = 118.8\mu m$) region as long as adequate mode numbers are included in the calculation. Among the optical properties, polarization characteristics of the reflected and/or transmitted beams are extremely important in some applications of polarimetry and interferometry.

In this paper, polarization characteristics of the transmitted beams through various sizes of metal meshes are experimentally studied using a CH_3OH laser ($\lambda = 118.8\mu m$). In particular, the characteristics of two typical Cu wire meshes, Mesh 1 ($64\mu m$ spacing) and Mesh 2 ($51\mu m$ spacing), are presented for a variety of incident beam polarizations and incident angles.

Both transmissivity and polarization measurements are in excellent agreement with the theoretical values obtained following Refs. 5 and 6. The experimental results showed that there are no changes in polarization when the wire grid axis is parallel (TM) or perpendicular (TE) to the incident beam polarization. Otherwise, a significant ellipticity can be introduced to the transmitted beam polarization. It is also demonstrated that the cause of ellipticity is the phase difference between TE and TM components of the incident beam with respect to the wire grid axis.

II. Comparison of theory with experiment

Following Chen's wave guide theory which models wire grid mesh as a two-dimensional array of waveguides, the electromagnetic fields near the mesh must satisfy the periodicity requirements imposed by Floquet's theorem; thus the fields are expanded in a series of Floquet modes. The fields in the aperture are expanded in waveguide modes. These fields are matched on each side of the mesh. The integral equation is numerically solved to obtain a transmission coefficient. Following Refs. 5 and 6, 225 Floquet modes and 21 waveguide modes are used in this calculation.

The experimental arrangement is schematically illustrated in Fig. 1. The beam polarization parallel and perpendicular to the y axis in Fig. 1 is defined as the TM mode and TE mode, respectively. An optically pumped CW CH_3OH laser ($\lambda = 118.8\mu\text{m}$, power $\approx 100\text{mW}$) was used as a source beam. The output laser beam was linearly polarized and chopped at 50 Hz. In order to eliminate the polarization change due to other optical components (aluminum coated mirrors, half-wave plate, and wire grid polarizers), each component was tested prior to the experiment and the output was recorded by lock-in amplifier.

A test wire mesh (Buckbee-Mears Inc.) was stretched on a metal frame (7 cm x 12 cm) and its dimensions were measured with a high resolution microscope. The measured wire spacing ($d = 64.3 \pm 1.3\mu\text{m}$) and width ($\delta t = 13.3 \pm 1.3\mu\text{m}$) were for Mesh 1. Mesh 2 had spacing ($d = 50.8 \pm 1.3\mu\text{m}$)

and width ($\delta t = 16.5 \pm 1.3 \mu m$). These measured values were used for the calculation of transmissivity and phase difference. A half-wave plate (quartz) for this wavelength was used in order to change incident beam polarization. The transmitted beam polarization resolved by a rotating polarizer (Cambridge Physical Sciences) was recorded for the variety of incident beam polarization angles (from $\Phi = 0^\circ$ to $\Phi = 90^\circ$). In this experiment, the wire mesh was fixed at $\theta = 45^\circ$ with respect to the incident beam.

As shown in Fig. 2a, changes in transmitted beam polarization and transmissivity for Mesh 1 were found to be a strong function of incident beam polarization. For incident beam polarization angles $\Phi = 0^\circ$ and $\Phi = 90^\circ$, the transmitted beam was linearly polarized. For other angles, the ellipticity of the transmitted beam was clearly demonstrated. In addition, the polarization of a doubly passed beam (transmitted and reflected) for the incident beam polarization angle ($\Phi = 20^\circ$) was highly elliptic as shown in Fig. 2b. On the other hand, little variation of polarization for Mesh 2 was observed. These observations can be explained by the phase differences measured in Figs. 3b and 4b.

The transmissivity for the TE and TM modes, obtained by rotating a wire mesh mount, as a function of incident angles for Mesh 1 is shown in Fig. 3a. It is noted that the TM mode transmissivity at $\theta = 45^\circ$ is as high as 0.98. On the other hand, the TE mode has a transmissivity of 0.55. Near $\theta = 60^\circ$ clear resonance characteristics are observed. The phase difference between the TE and TM modes as a function of incident angle is illustrated in Fig. 3b. The

difference is as high as 35° at $\theta = 45^\circ$. The calculated transmissivity for the TE and TM modes (solid and dotted line in Fig. 3a) and the phase difference (solid line in Fig. 3b) are in excellent agreement with the measured values. The experimental phase differences were obtained through a combination of transmissivity and polarization data. In this calculation, a Jones matrix⁷ was used for the representation of the polarization.

The experimental results for Mesh 2, shown in Figs. 4a and 4b, are also in a good agreement with the theoretically calculated values. It is also noted that Mesh 2 did not possess any resonance characteristics like Mesh 1. The TE and TM mode transmissivities at $\theta = 45^\circ$ were 0.17 and 0.33, respectively. The measured phase difference at $\theta = 45^\circ$ between TE and TM was 7° , which is significantly lower than the result for Mesh 1. Since this phase difference is proportional to the change of transmitted polarization, we can observe that Mesh 1 generates more ellipticity than Mesh 2.

III. Conclusion

In this paper, the experimentally measured transmissivity as a function of incident angles (from 0° to 80°) and two major polarizations (TE and TM) for two sample inductive metal wire meshes ($\approx 64\mu\text{m}$ and $\approx 51\mu\text{m}$ spacing) is compared with theoretical values. These results are consistent with the calculations of Refs. 5 and 6. In addition, polarization characteristics of the metal wire meshes are investigated. Chen's waveguide theory is compared

with the experimental values obtained via a Jones matrix representation of the polarization. The phase difference between the TE and TM modes of transmitted beam is found to be responsible for the generation of an ellipticity when the incident beam polarization is neither perpendicular nor parallel to the wire mesh axis.

Acknowledgment

This work is supported by U.S. Department of Energy Contract No. DE-AC02-76-CHO-3073.

References

- ¹ P. Vogal and L. Genzel, *Infrared Phys.* 4, 257 (1964).
- ² M.S. Durschlag and T.A. DeTemple, *Appl. Opt.* 20, 1245 (1981).
- ³ R. Ulrich, *Infrared Phys.* 7, 37 (1967).
- ⁴ J.M. Lamarre, N. Coron, R. Courtin, G. Dambier, and M. Charra, *Int. J. Infrared Millimeter Waves* 2, 273 (1981).
- ⁵ H.M. Pickett, J. Farhoomand, and A.E. Chiou, *Appl. Opt.* 23, 4228 (1984).
- ⁶ C.C. Chen, *IEEE Trans. Microwave Theory Tech.* 9, 627 (1970).
- ⁷ R.S. Longhurst, *Geometrical Phys. Opt.* (Longmans, New York, 1973) p.562.

Figures

FIG. 1. Experimental arrangement of transmissivity and polarization measurement. Φ is the incident beam polarization angle and θ is the wire mesh rotation angle.

FIG. 2. (a) Resolved polarization of a transmitted beam through Mesh 1 for a variety of incident beam polarizations.

(b) High level ellipticity is demonstrated by reflecting the transmitted beam for Mesh 1 with incident beam polarization angle $\Phi = 20^\circ$.

FIG. 3. (a) The measured transmissivities of Mesh 1 for the TE and TM modes are compared with the calculated values.

(b) Phase differences between the TE and TM are compared with theory.

FIG. 4. (a) The measured transmissivities of Mesh 2 for the TE and TM. Solid and dotted lines are theoretical values.

(b) The phase difference between the TM and TE modes is small compared to that for Mesh 1.

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Fig. 1

Fig. 2 (a)

Fig. 2 (b)

Fig. 3(a)

Fig. 3(b)

Fig. 4(a)

Fig. 4 (b)

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