A Technique for Fabricating Free Standing Electrically Thick Metallic Mesh and Parallel Wire Grids for Use as Submillimeter Wavelength Filters and Polarizers

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SUMMARY

The electrically thick *dichroic plate* [1] has been used widely as a frequency selective surface at infrared wavelengths since the early 1960's [2]. At these high frequencies plates formed of metal mesh with a thickness and mesh size in the range of several microns can make excellent high pass filters. These dimensions are compatible with standard optical photolithographic processing techniques [3] and the resulting filters can be either free standing or dielectrically backed.

Dichroic plates have also been used extensively at much lower frequencies (several GHz to 300 GHz) [4-5] and the required size of the perforations and the thickness of the metallic sheet are such that conventional machining techniques (milling and drilling) can be used in their fabrication.

In the submillimeter wavelength bands (300-3000 GHz) photolithographic techniques are not suited to etching or growing the electrically thick metallic sheet required to get the desirably sharp cutoff response from the dichroic plate. In addition, the perforation size and spacing is such that conventional drilling is impractical and laser drilling leaves poorly defined holes and irregular septa. This short paper describes a fairly simple procedure we have developed for producing electrically thick free standing metallic mesh for use throughout the submillimeter wavelength bands. The same techniques can be used to fabricate free standing parallel wire grid polarizers currently made by hand or machine assisted winding of fine wire around a prefabricated mandrel.

The measured and computed performance of a square mesh dichroic plate made with the described techniques and having a cutoff frequency around 950 GHz are presented at the end of the paper.

INTRODUCTION

The dichroic plate consists of a thick metallic screen perforated in a regular manner with uniform holes. The hole width must be approximately 1.2 times the cutoff frequency of the dominant waveguide mode in the hole (a function of the hole cross-sectional shape) and the hole to hole spacing should be as small as possible. For fast cut-off and low loss the plate thickness should approach half a guide wavelength for the dominant mode in the holes. More exact design criteria can be calculated using the equations derived by Chen [6].

It is relatively easy to satisfy the requirements of grid spacing and wall thickness using standard photolithographic techniques, however it is exceedingly difficult if not impossible to use these techniques to produce electrically thick plates, a must for achieving the high cut-off response required for many filter applications.

In order to make metallic mesh with an overall thickness of several mils and still maintain a narrow hole to hole wall width we have worked out a simple technique which combines mechanical dicing, metal evaporating and copper electroforming.

The fabrication procedure combines techniques used in the processing of semiconductor material with those used in the fabrication of small metal parts to produce a free standing square lattice of square holes in a copper plate with a minimum lattice wall thickness of approximately .0005". The aspect ratio of wall thickness to depth can vary from less than 1:1 to at least 6:1 with much larger values possible. The technique can be used to produce electrically thick dichroic plates with passbands as low as 200 GHz and as high as 4 THz or parallel wire grid polarizers covering a similar frequency range.

FABRICATION

The fabrication steps for producing the thick metallic mesh are detailed in the figures which follow this text.

Fig. 1: We begin with an undoped silicon wafer whose surface area exceeds the final grid area by at least .050" (this extra area will be used to form a metallic border which surrounds the grid and makes it self supporting). The wafer thickness should exceed the grid thickness by at least .010" to facilitate subsequent handling. Square wafers are easier to surround with a metallic border but round wafers could also be used.

Fig. 2: The silicon wafer is placed on a high speed dicing saw table (our samples were made with a Tempress model 602) with its edges (if a square or rectangular wafer is used) squared to the saw cut

direction. The dicing saw spindle is loaded with a standard diamond impregnated cutting wheel whose thickness matches the desired wall thickness for the final dichroic plate (some saws will produce a slight overcut on the width of the groove and this should be taken into account ahead of time). The saw depth is adjusted to produce a cut equal to or slightly deeper than the desired final dichroic plate thickness. The saw step size is set to the desired final grid constant (hole size plus wall thickness). The saw is then placed in step and repeat mode and is used to slice parallel channels across the entire wafer (250 slots takes approximately 20 minutes with the table feed set to 2"/second).

Fig. 3: The silicon wafer is then rotated 90 degrees (usually available as a fixed rotation increment on most dicing saws) and the saw is again used to slice parallel channels across the entire wafer. This results in a wafer with a waffle pattern on its surface extending partially but not completely through the material. For a parallel wire mesh this step is obviously omitted.

Fig. 4: To produce a self supporting edge around the grid the saw blade is changed out for a much thicker wheel and a .050" area around the perimeter of the wafer is ground off to the same depth as the narrow channels.

Fig. 5: At this stage we have formed the inverse of the desired grid pattern in the silicon wafer. The next several steps involve the fabrication of the metal grid itself through an evaporative and electroforming process. The silicon wafer is cleaned in 10% hydrofluoric acid (extremely important as it removes the oxide layer that prevents subsequent adhesion of the evaporated thin film which follows). The wafer is then placed in a vacuum evaporation chamber (channel side towards source) with a collimating baffle between the wafer and the evaporation boat. A thin adhesion layer of titanium (50-100 angstroms) followed by 2500-5000 angstroms of gold is then evaporated onto the wafer (copper can also be used). The baffle (with about a 10:1 aspect ratio of length to width) serves to collimate the incoming beam such that a metal deposit is formed only at the bottom of the channels and on the tops of the squares (little or no metal is deposited on the side walls of the slots).

Fig. 6: The plated wafer is taken out of the evaporator and again put in the dicing saw to remove the metal which has adhered to the tops of the squares (this step is not absolutely necessary but it facilitates subsequent processing). A wide blade (.025") is used to allow the top metallic layer to be removed in a very few number of passes. The operation is followed by cleaning in ethyl alcohol.

Fig. 7: The wafer is now placed in a teflon holder and a metallic clip is used to make cathodic contact to the gold layer which has been deposited in the relieved region around the perimeter of the silicon. It is then put into a copper electroforming bath (nickel could also be used) at an initial current density of 30 mA/cm^2 (subsequently adjusted down to 20 mA/cm^2) and left there until the channels have been completely plated up. One of the major problems encountered in electroplating high aspect ratio holes or slots is pinching off of the hole due to lateral growth outwards from the side walls before the enclosed volume has been filled with electroform. This problem was eliminated by arranging the processing steps so as to make sure the side walls of the channels contain no evaporated gold (remain non conducting). Copper can then grow up only from the bottom of the channel and no pinch off occurs. Aspect ratios of greater than 5:1 are possible with this technique.

Fig 8: When the channels have been filled with copper the wafer is removed from the electroform bath and the top surface is rubbed on fine emery paper to remove any copper which has grown on the central squares.

Fig 9: The silicon is now etched away in boiling potassium hydroxide, a process that takes several hours. As a final step the grid can be gold plated if desired.

PERFORMANCE

As a preliminary test of the fabrication procedures we designed a dichroic plate with a grid constant of 0.0090", a wall width of 0.0015" and a plate thickness of 0.0083" using the single mode approximations derived by Chen [6]. The finished grid had a 2.0" square aperture. Uniformity and flatness were measured to be better than ±0.0002" and tighter tolerances are possible with more care during the fabrication process.

The mesh was mounted and clamped in a simple aluminum frame (no stretching was required) and its power transmission coefficient was measured in a Bruker model FTS120HR high resolution scanning Fourier Transform Spectrometer [7]. The spectrometer resolution was better than 1 GHz and the noise floor was about 20dB below the peak power level at 600GHz. The measured transmission curve at normal incidence is shown in Fig. 10. The computed performance using the single mode approximation in [6] for a square hole in a square lattice is also shown. The agreement is quite good.

Measurements at incident angles other than 90 degrees are not presented because no polarizing grid was available at the time the measurements were made in the spectrometer. These measurements will be made over the next several months.

CONCLUDING REMARKS

A method for fabricating thick metallic mesh with a grid constant as low as .0025" and wall thickness to depth aspect ratios greater than 5:1 has been described. The method can be used to produce sharp cutoff submillimeter-wave filters and polarizers previously realizable only in thin screen form or on a dielectric backing. The uniformity and flatness of the final grids are competitive with any current fabrication method and the relative simplicity of fabrication makes them cost effective in small quantities.

The transmission curve of the free standing mesh at normal incidence agrees well with the approximate analysis in [6]. The behavior at other incident angles will be measured in the next several months for grids having square and rectangular holes.

Other applications for the fabrication process include high aspect ratio screens containing any electroformable hole pattern or shape and three dimensional cage-like structures which could be formed from silicon cubes.

ACKNOWLEDGEMENTS

Special thanks are due to Dr. M. Birk, Dr. D. Peterson, Dr. H. Pickett and Mr. T. Crawford for measuring the sample grid on their Fourier Transform Spectrometer and Mr. Robert J. Dengler for dicing the silicon wafers.

NOTES AND REFERENCES

[1]. The term dichroic plate will be used here to refer to a conducting sheet perforated with uniform periodically spaced holes. Over a limited frequency range the plate has high pass filter characteristics which depend upon the electrical size, shape and spacing of the perforations as well as the thickness of the conducting sheet itself. The term 'dichroic' refers to the property of a surface for reflecting light of one wavelength while transmitting light of other wavelengths, hence the relationship to a filter.

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[3]. R. Ulrich, "Far-infrared properties of metallic mesh and its complementary structure," Infrared Physics, vol. 7, pp.37-55, Pergamon Press, 1967.

[4]. R.T. Woo and A.C. Ludwig, "Low loss dichroic plate," NASA Patent Application No. NPO 13171-1, Sept. 21, 1972.

[5]. H.M. Pickett, J. Farhoomand and A.E. Chiou, "Performance of metal meshes as a function of incidence angle," 1983 IEEE MTT-S International Microwave Symposium Digest, pp. 106-107, May 31-June 3, 1983.

[6]. C.C. Chen, "Transmission of microwaves through perforated flat plates of finite thickness," IEEE Trans. MTT, vol. MTT-21, pp. 1-6, Jan. 1973.

[7]. The Bruker FTS120HR scanning Fourier Transform Spectrometer was recently installed by Dr. H. Pickett, Dr. M. Birk and Dr. D. Peterson at JPL and they have very kindly allowed us almost first use of the instrument in measuring our sample grid. This measurement, which took only minutes using the spectrometer, would have required several days of effort using conventional submillimeter-wave techniques and the results would not have been as accurate or the sample space as complete.

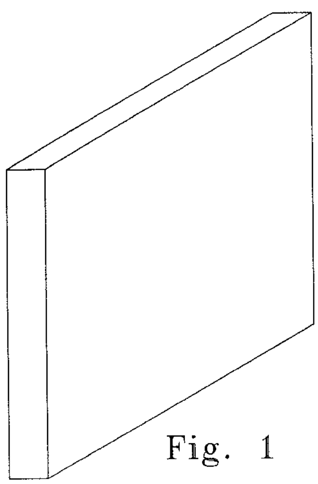

Fig. 1

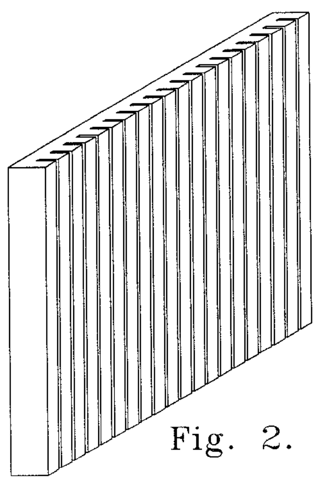

Fig. 2.

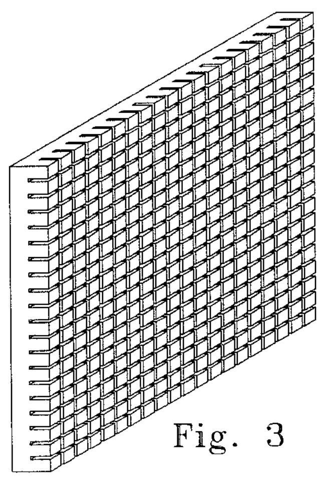

Fig. 3

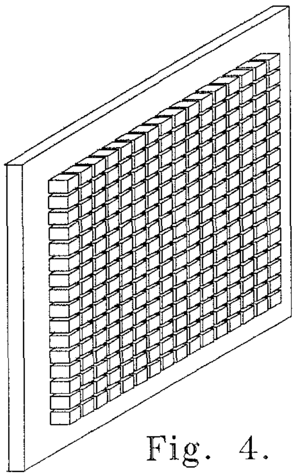

Fig. 4.

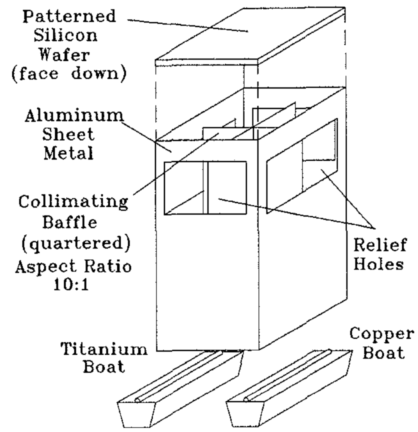

Fig. 5.

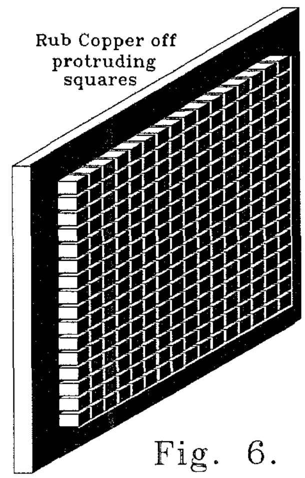

Fig. 6.

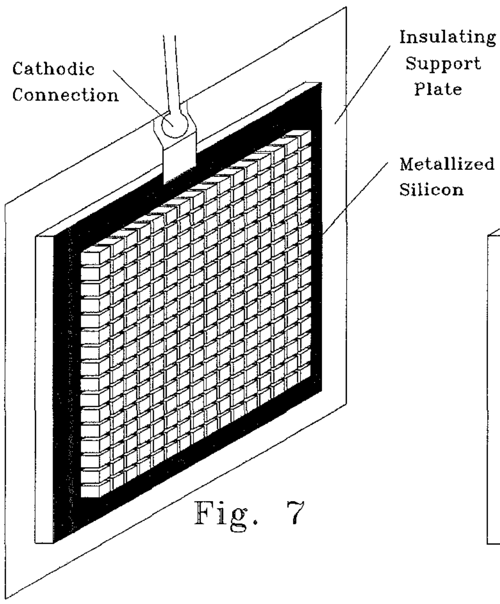

Fig. 7

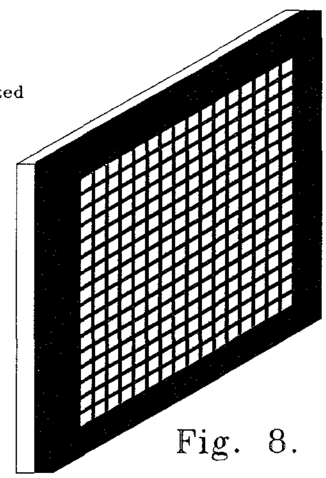

Fig. 8.

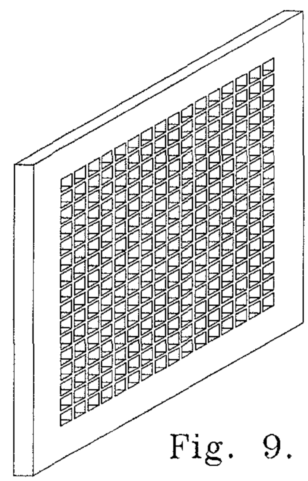

Fig. 9.

Fig.10