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Thick capacitive meshes on polyimide substrates

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Abstract

Thick capacitive meshes of nickel on substrates of thickness 25 μm have been produced by electroplating into a photoresist mould. The Micro-Stripes program by Flomerics has been used for the interpretation of the experimentally measured far infrared spectrum. The measured reflection resonance mode and the transmission wave guide mode agree well with the analytical predictions.

Keywords: Resonant mesh; Capacitive; Infrared filter; LIGA

1. Introduction

Thin inductive metal meshes are made of metal foils with holes. Inductive meshes have been used in the infrared to mm-region as Fabry–Perot reflector plates [1] and band pass filters. The complementary structure is called a capacitive mesh and has been used as band stop or low pass filter [2]. Capacitive meshes have metal where the inductive mesh has openings and they require a substrate for their realization. The substrate has the effect that the resonance wavelength shifts to longer wavelength. In Fig. 1 we show a schematic of these meshes and of the labelling of the geometrical parameters. The metal thickness of thin inductive and capacitive meshes are small, that is 1–2% of the periodicity constant, and Babinet's principle in electromagnetic formulation may be applied. It tells us that the transmittance of complementary screens is complementary. Therefore, inductive and capacitive meshes, having the same geometrical parameters, have the same resonance wavelength. Inductive meshes have a peak in transmittance and capacitive meshes in reflectance.

Thick metal meshes with cross-shaped openings have been produced, using the LIGA method, by Ruprecht et al. [3]. These meshes had a periodicity constant of 20 μm and thickness of 11, 20 and 29 μm. Their properties have been described and studied by Möller et al. [4]. They found that the

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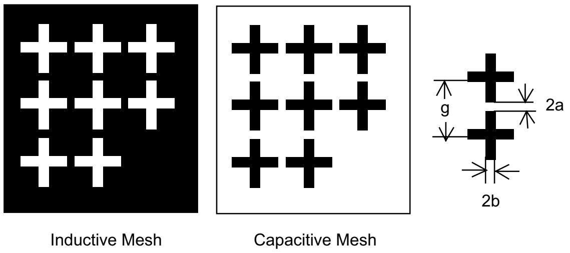

Fig. 1. Schematic of inductive and capacitive meshes. Periodicity constant g, separation $2a$, width of crosses $2b$. Black corresponds to metal.

transmittance could be interpreted with transmission peaks corresponding to resonance and wave guide modes. The resonance mode depends on the periodicity constant of the mesh and the shape of the crosses, but not much on the thickness of the mesh, while the wave guide mode depends strongly on the thickness of the mesh.

Thick metal meshes do not follow Babinet's principle, and thick metal meshes of the capacitive type have never been produced. Sternberg [5] has studied the properties of these type of meshes in the 20–200 μm wavelength region using the MicroStripes simulation program [6]. The transmittance can be interpreted with a resonance mode in reflection and a transmission peak corresponding to a wave guide mode.

In this paper we report the fabrication of thick capacitive meshes using a UV-LIGA method and confirm the predictions of the simulations.

2. Manufacturing of the meshes

The different steps of the fabrication process used to produce thick capacitive meshes embedded in a polymer, that is reasonably transparent in the wavelength region of interest, are depicted in Fig. 2. Initially a thin layer (100 nm) of gold was evaporated onto an oxidized Si monitor wafer (thickness 300 μm). This layer has two tasks: it is the starting layer for the electrochemical deposition and a separation layer for the lift-off, since gold does not stick to silicon. A single layer of positive photoresist (AZ 4533 from Clariant) was spun to a thickness of 13 μm. The sample was then soft baked prior to the exposure process. A Hg-lamp was used to expose the sample through a chrome mask (hard contact).

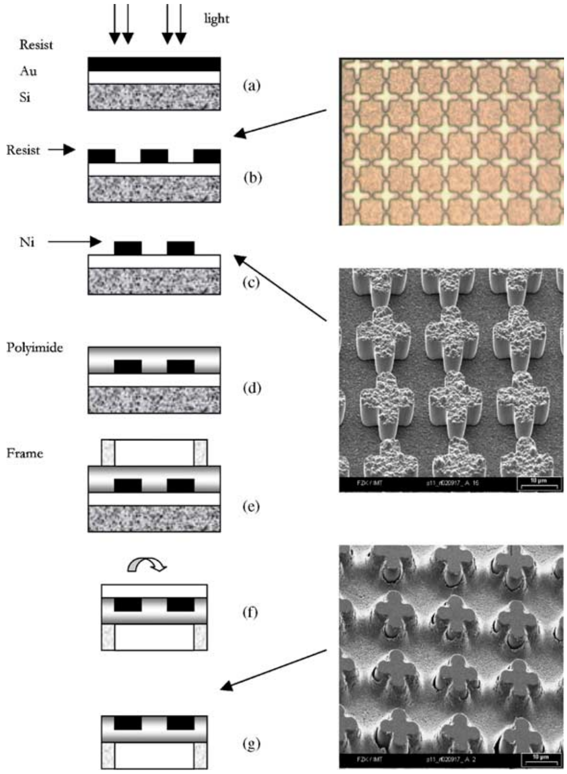

Fig. 2. Fabrication of a resonant mesh: (a) exposing the resist, (b) developing the resist, (c) electroplating of Ni and stripping, (d) embedding into polyimide, (e) mounting the frame, (f) separating from substrate, and (g) RIE of the thin separating layer (Au).

The photoresist was developed in a 1–4 solution of potassium hydroxide (AZ 400 K) and distilled water at 23 °C for 6 min. After 2 min in a mild oxide-plasma (de-scumming) Ni was electrochemical deposited for 25 min using a current density of 0.1 mA/mm^2 with a growth rate of 12 μm/h, yielding 5 μm of Ni. After stripping, a photosensitive polyimide precursor was spin-coated to a thickness of 50 μm and subsequently cross-linked by exposure to UV light. The final curing by heat treatment leads to imidization of the cross-linked material, which yields polyimide.

The loss of solvent during hard bake reduces the polyimide thickness to about half its initial value. In the next step, a frame was glued onto the polyimide, which covers the patterned areas. After the glue has hardened, the polyimide and the gold layer were cut around the frame. A simple bath in water with some drops of household tenside (dish wash liquid) was used to separate the embedded structures from the silicon substrate. Capillary forces draw the liquid between the gold layers on the silicon and displaced it finally. As a final step the gold was etched using reactive ion etching (RIE).

Two samples were fabricated using a mask with cross-shaped geometrical dimensions of $g = 20$ μm, $2a = 8$ μm, and $2b = 4$ μm. Sample 1 was embedded into a 25 μm thick layer of polyimide while sample 2 was embedded into a 35 μm thick polyimide. For both samples, using a microscope, the distance between the crosses was determined to be $2a' = 9$ μm and the width of the cross-arms $2b' = 6$ μm. Though numerically similar, a close inspection revealed that the crosses of sample 1 resembled the ones shown in Fig. 2 with rounded corners, while the crosses of sample 2 were considerably more distorted. For sample 1 we measured the thickness of the sample carefully and found a range of 4.5–5.5 μm.

3. Infrared transmission spectra

A Bruker–Fourier transform spectrometer was used for the measurement of the far infrared spectra shown in Fig. 3. The two upper curves are the transmittance spectra of two films of polyimide of thickness 25 and 35 μm. The transmittance of the samples show contributions from Fabry–Perot interference modes. A polyimide refractive index of $n = 1.5$ was calculated from the measured film transmittance.

The two lower curves in Fig. 3 show the transmittance of both, sample 1 (grey line) and sample 2 (black line). The geometrical difference in the sample pattern shows up in Fig. 3 by the difference between the spectra in the 24–35 μm region. These differences are clearly attributable to the differences of the samples, namely the thickness of the polyimide, the distortions from the ideal shape, the irregularities and homogeneities within the area illuminated during the measurement, and the varying thickness of the electroplated nickel

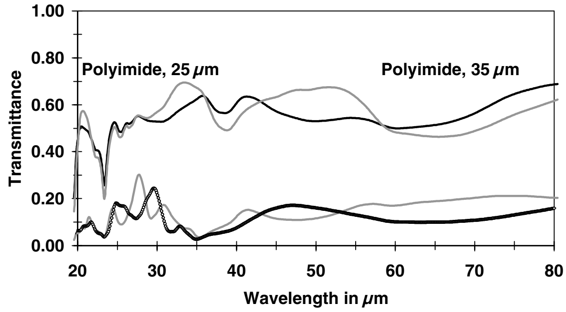

Fig. 3. FTIR spectra. Upper two curves are polyimide of thickness of 25 and 35 μm. Lower curves: grey line: cross-shape mesh (sample 1) with $g = 20$ μm, $2a = 9$ μm, $2b = 6$ μm, thickness between 4.5 and 5.5 μm embedded into 25 μm of polyimide. Black line: cross-shape mesh (sample 2) with identical parameters but strong distortions of the crosses embedded into 35 μm of polyimide.

over this area. In particular, as mentioned in Section 1, the average of the latter determines the wavelength at which the wave guide mode occurs. A comparison has been made of calculated and experimentally observed spectra for exact crosses and ones with slightly rounded corners, respectively [7]. This study showed that in the submillimeter wave region not much difference was observed. Therefore, the distortions from the ideal shape may essentially be excluded in explaining the differences leaving the deviations from supposedly identical average thickness and from ideal periodicity as the cause of the differences. As mentioned in Section 1, this is in agreement with the calculations performed in [4].

The Micro-Stripes program [6] has proven to be a reliable tool for analysing thick and thin inductive meshes and dielectrics [8]. We used this program to simulate the spectra for sample 1. In Fig. 4 we show the experimental and simulated data. The thin line represents the spectrum of a film of thickness 25 μm; the black line the experimental data of sample 1; and the grey line the simulation for sample 1 with the following simplifications: crosses on a 25 μm thick nonabsorbing slab of refractive index $n = 1.5$ (rather than embedded), thickness of the structures 5 μm (neglecting its variation), and $g = 20$ μm, $2a = 9$ μm, $2b = 6$ μm (neglecting global and local distortions as well as a

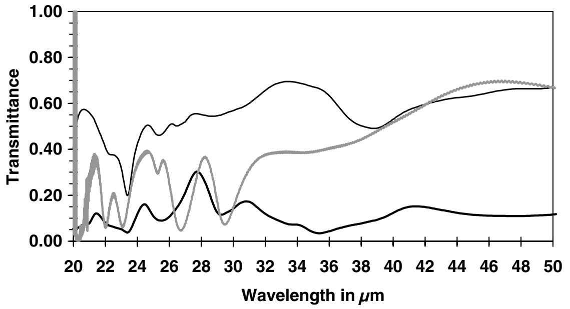

Fig. 4. Comparison of experimental data and simulations for sample 1. Thin line: polyimide, 25 μm. Grey line: simulation of cross-shaped mesh with $g = 20$ m, $2a = 9$ μm, $2b = 6$ μm, $t = 5$ μm on nonabsorbing dielectric slab of thickness 25 μm and refractive index $n = 1.5$. Black line: enlarged view of (the grey line of) Fig. 3 for sample 1.

deviations from verticality). With respect to the wavelength for which maxima and minima occur in the wavelength range between 23 and 30 μm, there is good agreement of the simulation with the experimental data.

For the assignment of the wave guide mode, we have studied how the transmittance changes with varying thickness of free standing capacitive crosses with geometrical parameters $g = 20$ μm, $2a = 8$ μm and $2b = 4$ μm. There is a broad reflection resonance peak for thicknesses of 1 and 3.2 μm in the spectral region from 23 to 32 μm. Similar as found for inductive meshes [9], the wave guide mode appears as transmission peak at thickness 6.4 μm. We have repeated the simulation for the capacitive mesh with $g = 20$ μm, $2a = 9$ μm, $2b = 6$ μm, and $t = 5$ μm on a substrate of polyimide of index $n = 1.5$ and thickness 25 μm, shown in Fig. 4. This pattern, slightly shifted, appears also in the observed data.

4. Summary and conclusion

A UV-LIGA approach has been used to produce, for the first time, thick capacitive meshes with a thickness of 25% of the periodicity constant $g = 20$ μm. Though the shape and the homogeneity of the crosses were less than ideal, the infrared spectra agree fairly well with simulations and the differences may be attributed to the sensitivity of the transmission spectra to geometric variations [4] prevalent within the sample. The simulations and the experimental data of the thick capacitive mesh show parts of the resonance mode at 26.7 and 29.4 μm, but most important, the wave guide mode at 28.2 μm. The low transmittance of the crosses resulted from the appreciable absorption of films of thickness 25 and 35 μm.

Capacitive meshes may prove to be useful to obtain band pass filters for the infrared. In order to get to usable infrared filters, the experimental precision must be improved. The imperfection in sidewall angle, the inhomogeneity in line width as well as the local and global inhomogeneous thickness of the embedded polyimide are expected to have an influence on the spectrum. Higher precision and a higher thickness may be obtained using the original LIGA method with X-ray lithography. For useful applications, the polyimide substrate should have a thickness of only 1–2 μm or, even better, one should use thin films that are non-absorbing in the wavelength region of interest.

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