DESIGN AND MANUFACTURING OF A MM–WAVE ACCELERATOR USING LIGA

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Abstract

The paper presents the design of a planar, double-periodic structure and, for the first time, its fabrication by deep X–ray lithography (LIGA) which was done at BESSY, Berlin, together with the *Institut für Mikro- und Medizintechnik*, TU Berlin.

It is a standing wave on-axis coupled structure with an operating frequency of 91.392 GHz and is designed for the π-mode. End cells, main coupler and RF parameters are matched numerically by means of the code GdfidL. The manufacturing of the structure with LIGA is described in detail.

1 INTRODUCTION

Very high frequency accelerating structures will explore new parameter ranges and new applications. Among other things, a very attractive feature and a potential breakthrough concept is an 'integrated' accelerator module, i.e. the manufacturing of accelerating structures, power sources and focusing elements with one technology and on a common support. The avenue to realize this vision is X-ray lithography (LIGA). It meets the requirements in fabricational precision, 1 micrometer tolerances and about 0.1 micrometer surface roughness, and it allows for nearly arbitrarily complicated structures as long as they stay planar.

That is where the skill of the design engineer is challenged: to develop and build planar structures and components.

Based on the concept of a doubled-sided, open muffin-tin structure [1] we have been working on different devices [2]. Since we believe that a constant impedance structure is easier to build and that a standing-wave (SW) structure with equal power dissipation facilitates cooling and operation we had at first designed a side-coupled SW muffin-tin [3]. However, the RF parameters, especially bandwidth and attenuation, were not very satisfactory. Therefore in [4], we presented an on-axis coupled double-periodic muffin-tin with a larger aperture, lower attenuation and large bandwidth.

In [4] only the geometrical design for the standing wave on-axis coupled structure was presented. The next step versus a prototype is manufacturing and engineering which is described in this paper.

2 MATCHED EXTERIOR DESIGN

2.1 First Design

In the first design, as shown in Fig. 1, two LIGA fabricated parts were planned to be inserted in the bottom and the top of a housing. A distance ring, including the apertures for power input and the beam, should be placed between the two inserts.

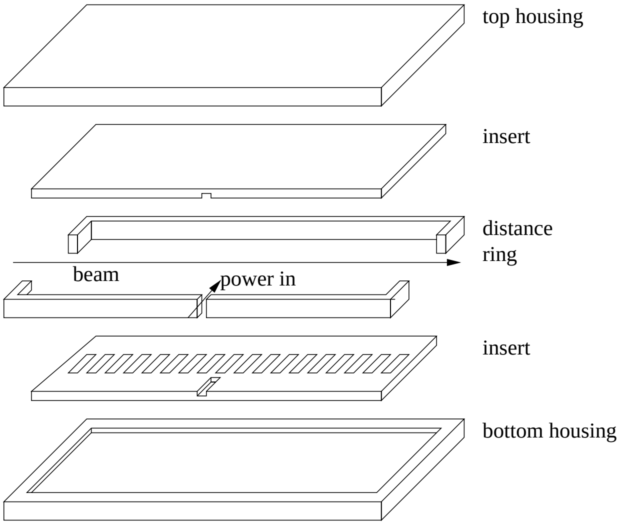

Figure 1: First design (schematic)

The problems that arose during the fabrication were:

- a good conducting connection between the LIGA parts and housing;
- the contact between the distance ring and the inserts;
- the alignment of the distance ring;
- the fabrication of the distance ring with small incisions planned for the matching of the waveguide to the groove-guide.

These problems were solved in a second design (where an advanced coupler was also used). Unfortunately, the structure is not yet finished, the exposure and electroplating is already done, but the parts are not tied up, so we can only present the manufacturing of the first design.

2.2 Second Design

In the second design it is planned to electroplate the LIGA parts directly on the bottom and the top housing, see Fig.

2. Special fiducial points and openings for high precision dowel pins were added in order to align the different layers.

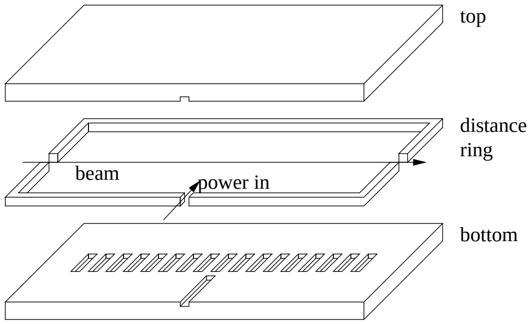

Figure 2: Second design (schematic)

3 THE LIGA PROCESS

3.1 Introduction to LIGA

“LIGA” is an acronym for the German words “**Li**thographie, **G**alvanik and **A**bformung”, i.e. deep X-ray lithography, electroplating and molding. In the fabrication of a prototype only the first two steps (deep X-ray lithography and electroplating) are necessary, so we will explain none of the others here. For general information on LIGA see [5].

Deep X-ray lithography The exposure of the resist – PMMA – is done with X-rays. The radiation breaks the chains of the polymer in the exposed regions (as shown in Fig. 3), which can be washed out then. The intensity of the exposure is an experimentally determined value, lower intensity will prolong the exposure, higher intensity is more problematic. If the intensity is too high, electrons will be knocked out from the copper by the photo effect, collide with other electrons and lift them to a higher niveau of energy. By falling back to their original niveau, photons will be emitted. This may result in an exposure of the resist from the opposite side which is not wanted.

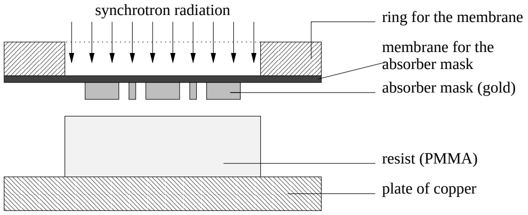

Figure 3: X-ray lithography

Electroplating In an electroplating bath copper grows between the remaining resist. The spare copper is removed up to the right height of the structure, see Fig. 4.

3.2 The masks

The final, 20 μm thick mask is made in steps:

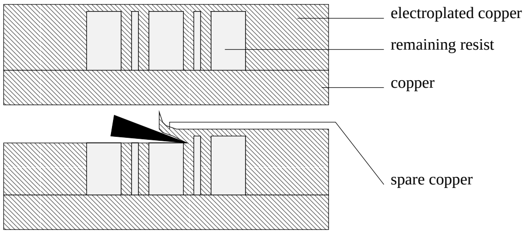

Figure 4: Electroplating and removal of the spare copper

1. Chromium Mask A first mask is generated from an AutoCAD file by Photronics MZD in Dresden, Germany, with an electron beam writer. The mask is thin and cannot stand the strong irradiation. It serves exclusively to fabricate an intermediate mask.

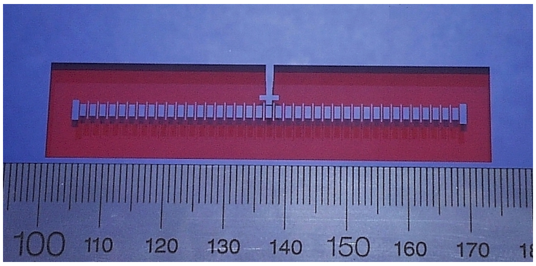

Figure 5: Chromium mask

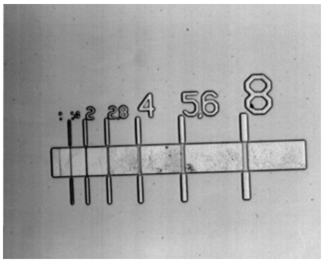

Figure 6: Intermediate mask with a test structure

2. Intermediate Mask The second mask is deposited on a 12.5 μm thick capton foil. The foil was prestretched and glued on a glas ring of 4” diameter. Since the thermal expansion of capton is larger than for glas, the arrangement was heated to 140^o C for 15 min and slowly cooled down, in a way that the foil is kept well stretched. On the foil Titanium and gold are sputtered in a thickness of 50 nm, titanium as an adhering layer for the gold, which is needed as a starting layer for electroplating. Photosensitive lacquer was added then. After irradiation and etching away of the resist a template for the negative of the chromium mask was generated. It served for plating gold in a thickness of about 1.5 μm.

3. Final Mask The final mask is similar to the intermediate mask, but the thickness of the capton foil was 125 μm. As photosensitive layer 20 μm PMMA was used. In order to avoid stress in the PMMA it was put in an oven at 140^o and cooled down to room temperature in twelve hours. During cool down, the temperature of 120^o, where PMMA changes from the liquid to the crystal phase, was held for about two hours. Without this slow cooling the stress in the PMMA results in sloughing of the PMMA from the resist (see Fig. 7). The exposure was done with the dipole at BESSY I, wavelength 2 nm, intensity 4 kJ/cm^3. The exposure time was 45–55 min, depending on the actual current of the beam. After exposure and etching gold was electro plated with a thickness of about 18 μm (see Fig. 8).

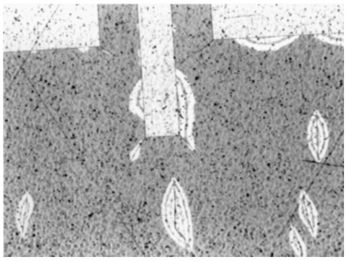

Figure 7: Fissures and sloughing of the PMMA

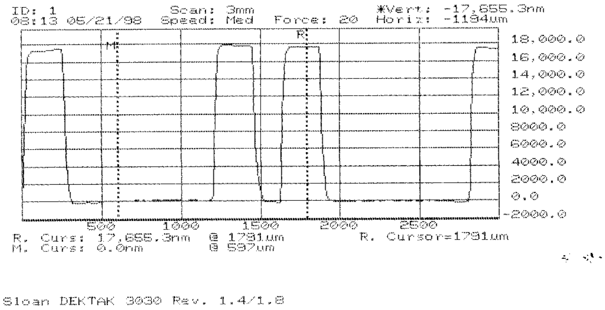

Figure 8: Electroplated gold’s thickness

3.3 *The structure*

Exposure The resist that was available in stress-free slices of $2\,\mathrm{x}100\,\mathrm{x}100\ \mathrm{mm}$ was glued on copper disks, diameter 4”, with liquid PMMA. The exposure was done at one of the three scanners at BESSY I with an intensity of $16\,\mathrm{kJ}/\mathrm{cm}^3$ and the duration of the exposure was about 7 h.

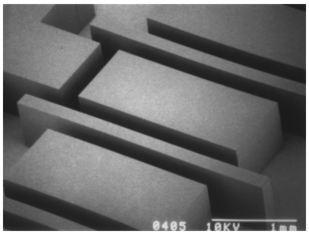

Figure 9: Exposured PMMA

In a first step only PMMA was exposed, to see if the time of the exposure is long enough. It was inspected by an electron microscope after beeing sputtered with gold, (Fig. 9).

Electroplating The electroplating was done using a bath of copper sulfate. Initial difficulties coming from hydrogen bubbles sticking to the surface were overcome by changing the bath constituents and improving the flow of the bath. The final bulk material as well as the surfaces were of good quality. The correct height of one half of the structure, Fig. 10, was obtained by taking off a layer (see Fig. 4) with a diamond cutter.

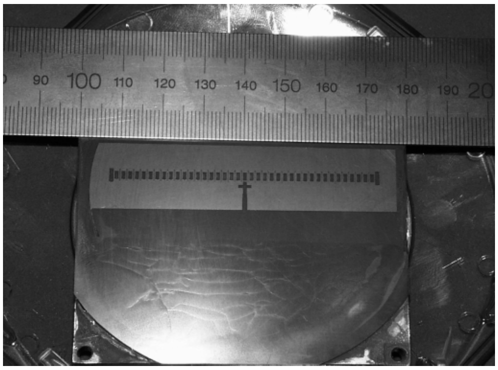

Figure 10: One insert for the structure

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[5] http://www.fzk.de/imt/eliga.htm