Embedded Monofilament UV-LIGA Techniques for Microfabrication of Beam Tunnels in a 220 GHz Wideband Serpentine Waveguide Amplifier

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Abstract: *A 50 watt, wideband serpentine amplifier is under development to demonstrate a novel beam tunnel fabrication technique capable of forming arbitrarily long beam tunnels of very small diameter using a single Ultraviolet Lithography (UV-LIGA) exposure step.*

Keywords: UV-LIGA; SU-8; microfabrication; beam tunnel; serpentine waveguide.

Introduction

Photolithography techniques along with copper electroforming (collectively, UV-LIGA) show much promise for fabricating mmW and sub-mmW amplifier interaction circuits [1]. As operating frequency pushes toward the THz, tolerances become unmanageable for conventional fabrication techniques since the electron beam must be transported through ever smaller beam tunnels. With use of UV-transparent, refractive index-matched polymer monofilaments along with SU-8 mold forming, 3D structures have been demonstrated that allow arbitrarily small beam tunnels to be fabricated to arbitrary length along with slow-wave amplifier circuits (Provisional Patent Application filed, 2011).

Circuit Microfabrication

UV-LIGA techniques in accord with figure 1 were applied on a copper substrate using the SU-8 photoresists to layers over 850 μm thick with vertical aspect ratios up to 9:1. In-house copper electroforming and SU-8 removal by molten salts were performed [2-3].

To create the beam tunnels, UV-transparent polymer monofilaments are precisely positioned above the copper substrate (Fig. 1a) and are then embedded in photoresist (Fig. 1b), and subsequently exposed to UV (Fig. 1c). At this point, the SU-8 holds the shape of the interaction circuit and is combined with the polymer filament, which holds the shape of the beam tunnel [3]. All that remains is to electroform copper around the mold, as in Fig. 1d. The circuit is completed after removal of the SU-8 and filament (Fig. 1e). A photo of a completed serpentine waveguide (SWG) amplifier circuit is shown in Fig. 1f and was fabricated using a single UV-LIGA step, including beam tunnels. The polymer filaments in this new technique must meet several requirements, including ability to pass UV light, an index of refraction similar to SU-8, moderate tensile strength at up to 100 deg C, and resistance to chemical attack from a variety of solvents and from a sulfuric acid-based copper electroforming bath. ETFE meets these requirements acceptably, but is slightly sub-optimal in the match of index of refraction.

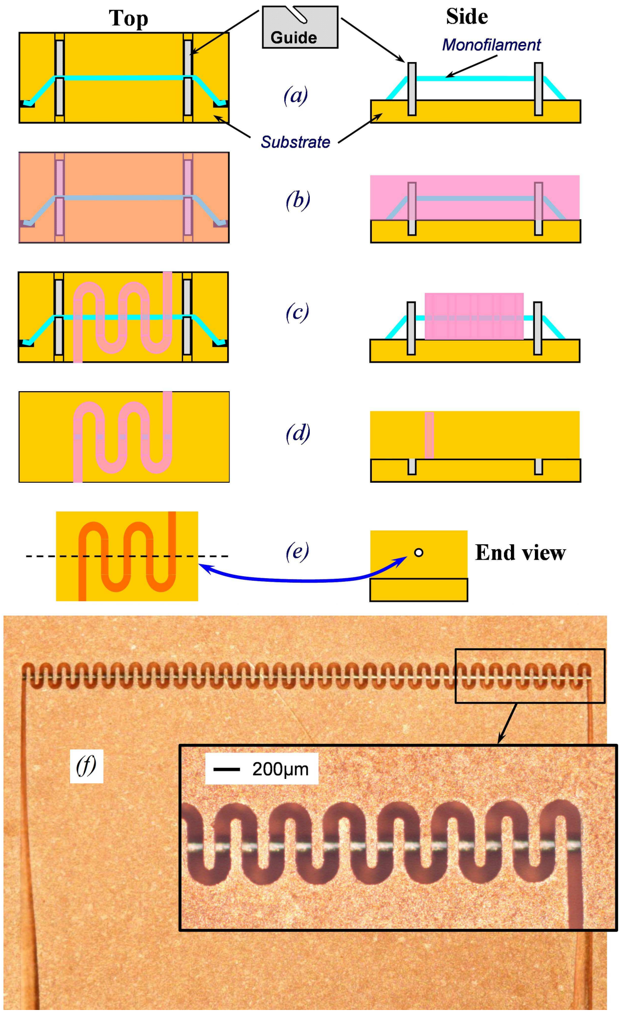

Figure 1. Polymer monofilament concept. (a) The monofilament is set in place above the substrate, (b) photoresist is applied, (c) UV-exposure and developing produces a 3D mold with the beam tunnel filament in place, (d) electroforming metal, (e) and dicing to size and the removal of the monofilament and photoresist completes the structure. Beam tunnel location shown by dashed line. (f) Photo of completed circuit with 0.0072" diameter gage pin inserted through beam tunnel.

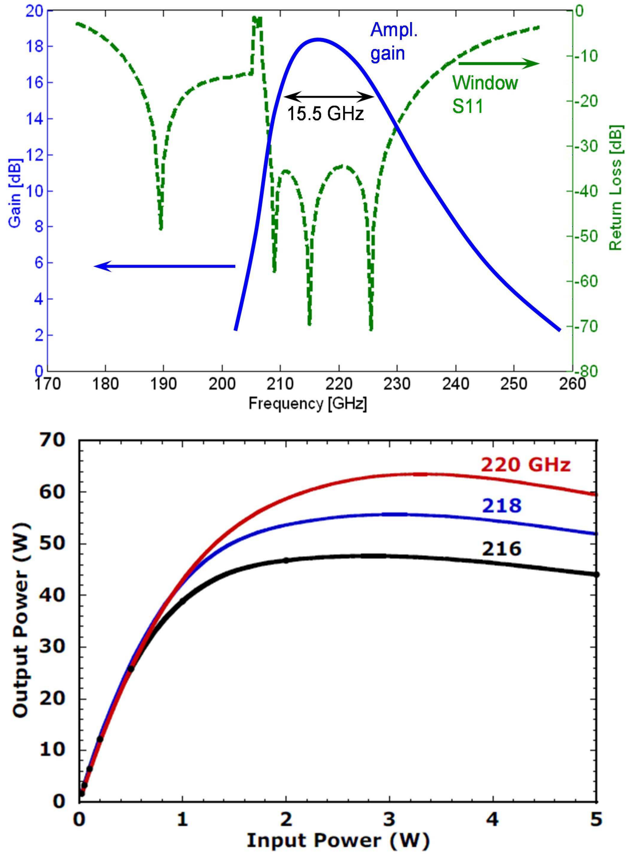

Figure 2: (Top) MAGIC 3D Prediction of small-signal amplifier performance (solid) and ANALYST prediction of window performance of 20 GHz bandwidth (dashed). (Bottom) Drive curve prediction in MAGIC 3D showing over 60 W output power at 220 GHz.

A major advantage of this embedded monofilament method is that an arbitrarily small round beam tunnel can be made to any arbitrary length. In addition, as long as it is possible to extrude the polymer, a variety of other beam tunnel shapes can be easily envisioned, including multiple round beams, ellipses, sheets, squares, etc. Moreover, by implementing multiple-layer fabrication, frequencies down to W-band are expected to be possible using these same techniques. The UV-LIGA process has already been tested at 670 GHz for an EIK ladder and produced corner radii down to 10-15 μm.

Serpentine Amplifier Design

The serpentine waveguide amplifier designed will operate from a single, round 11.7 kV, 120 mA electron beam. The beam will be generated by the same electron gun as our existing CPI 218.4 GHz, 5 W EIK using a spare set of parts. Figure 2 shows the predicted gain and drive curves in MAGIC 3D producing 18 dB small signal gain with a 15.5 GHz bandwidth. Using the existing 5 W EIK as the driver, over 60 W output power is expected from the tube.

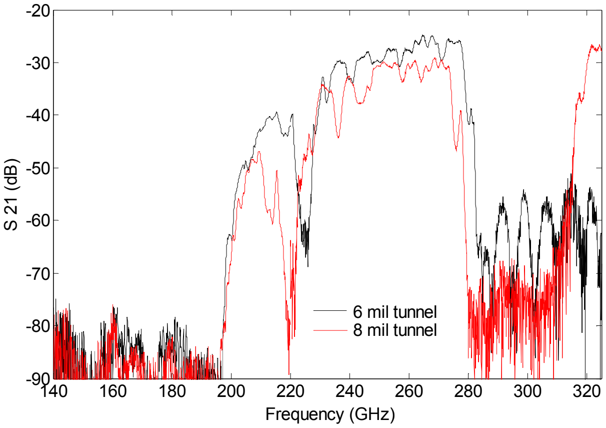

Figure 3. VNA cold test measurement results of a circuit with slight beam tunnel misalignment exhibiting a clear stopband around 220 GHz. The beam tunnel was upsized from 0.006" to 0.008" using tungsten wire and gage pins.

Windows made from BeO are predicted to yield better than -30 dB reflection over a 20 GHz bandwidth. A 30 mW solid state source will be used to demonstrate bandwidth and small signal gain. The SWG circuit is being constructed in-house at NRL using the techniques described, and the tube is planned to be completed at CPI, Inc. by mid-2012.

Initial Cold Test Measurements

Figure 3 shows an initial result of electromagnetic cold-testing over G- and H-bands (140-325 GHz) using a 2-port testing fixture of a circuit with slight beam tunnel misalignment. Unfortunately, the misalignment causes a deep stopband to appear around 220 GHz. Upsizing the beam tunnel caused a shift in stopband frequency, confirming that the beam tunnels play a key role in the problem. Further investigations are needed to determine the acceptable tolerance on beam tunnel alignment. More circuits are being fabricated targeting acceptable alignment.

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