METAL-TRANSFER-MICROMOLDING OF AIR-LIFTED RF COMPONENTS

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Abstract: This paper reports a metal-transfer-micromolding (MTM) technique for simultaneous implementation of metallized high aspect ratio molded polymer RF passive components, as well as coplanar waveguide feeding structures, in a high performance and potentially cost-effective fashion. Applications of the MTM technique in air-lifted RF components such as Ka-band monopole antennas and evanescent mode cavity resonators have been demonstrated. A 21.5% 10dB bandwidth for the monopole antenna, and an unloaded Q exceeding 500 for the resonators, are achieved from micromolded organic materials.

Keywords: air lifted monopole antenna, evanescent mode resonator, micromolding

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1. INTRODUCTION

There is presently a growing need for low-loss, high-Q passive components for broadband wireless systems operating at millimeter-wave (mm-wave) frequencies. An important requirement for these components is that their fabrication process must be inexpensive, meaning that systems are produced using low-cost materials by batch-processing. In addition, the components should be easily integrated into a compact, environmentally stable package. MEMS-based air-lifted three-dimensional (3-D) RF components to meet these demands have been demonstrated using a polymer back-bone structure, patterned either photolithographically [1,2] or stereolitho-graphically [3], followed by a metal overcoat. However, it is difficult to metallize and pattern an uneven 3-D structural surface such as an antenna. Often these processes rely on multiple deposition and lithographic steps potentially resulting in high fabrication cost and process complexity. Also, it is desirable to integrate these air-lifted RF components with different geometries onto the same substrate, which may further increase fabrication complexity.

Micromolding has emerged as a promising fabrication technology for microstructures due not only to the potential for low cost manufacturing, but also because it enables a wide choice of materials with desirable dielectric, mechanical and thermal properties. However, few efforts have been made to utilize micromolding technology in 3-D RF component fabrication and integration. One of the challenges is the selectively metal coating of the molded components as well as interconnects.

In this paper, a metal transfer mechanism that has been widely utilized in nano-transfer-printing (nTP) [4] is introduced into conventional micromolding, creating a metal transfer micro-molding (MTM) fabrication technology. Both fully-metallized air-lifted RF components as well as metallized interconnects can be formed simultaneously by the MTM process. We exploit this approach to fabricate and characterize air-lifted monopole antenna arrays and high-Q evanescent-mode resonators both in Ka-band.

2. MTM FABRICATION

The 3-D MTM process is described in Figure 1. A backbone structure of RF components is fabricated by standard photolithographic or stereolithographic approaches in which no metallization is performed. Then a negative PDMS mold is created by molding and is conformally coated with a thin Au layer. The Au layer is then patterned by a transfer printing process using a high energy surface such as polyester tape [4]. Polymer is then cast into the PDMS mold and solidified. The PDMS mold is then peeled off and the patterned metal layer is

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completely transferred to the molded structures.

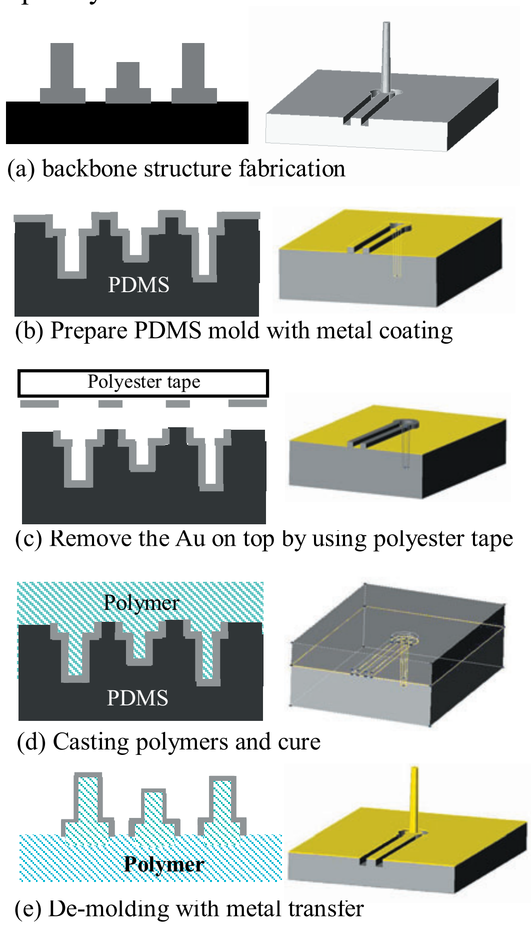

Figure 1 Process flow of metal transfer micromolding (MTM), and the demonstration of a MTM fabrication of vertical monopole antenna fed by CPW

The metal transfer mechanism is based on the extremely low surface energy (19.8mJ/m^2) of PDMS [4]. The transferred metal film works as a seed layer for subsequent electroplating or electroless plating processes. Both the backbone structure master and PDMS negative molds can be repeatedly used to generate new batches of devices by various polymers due to the reusable nature of molding.

Figure 2 shows an MTM fabricated monopole antenna array and cavity resonators in Ka-band. All monopoles and the cavities have different height profiles.

3. DEVICE CHARACTERIZATION

One of the most important mm-wave components is the antenna. Compared with a printed patch antenna, the air lifted monopole antenna inherently possesses the property of omni-directional radiation, broadband frequency response, and substrate indifference [3]. An array of cylindrical quarter-wavelength monopole antennas fed by coplanar waveguides (CPW) operating in Ka-band is fabricated to demonstrate the integration of the radiation structure at different resonant frequency as well as the CPW transmission lines. Figure 3 shows one of the monopoles fed by CPW.

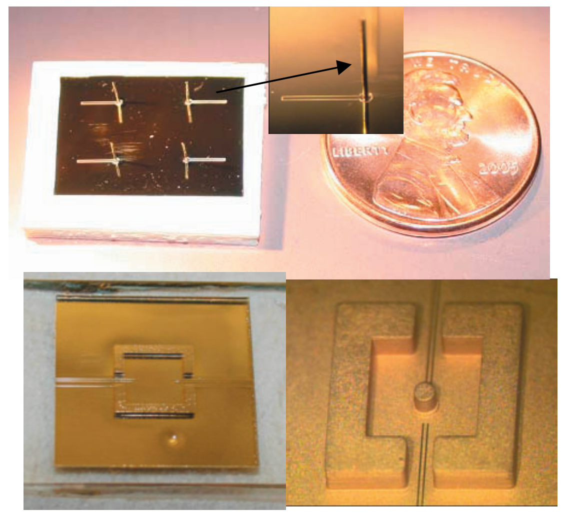

Figure 2 MTM fabricated antenna array and the CPW feed cavity resonators both in Ka band

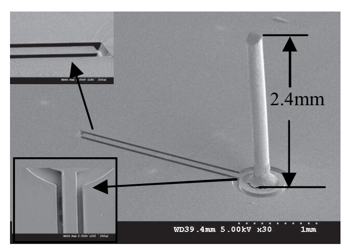

Figure 3 a SEM picture of the monopole antenna with height of 2.4mm

Both the monopoles and the substrate are made of molded epoxy resin with high aspect ratio of more than 10:1. The resonant frequency can be predicted by the following equation [5]:

$$h = 0.228\lambda \quad \text{(where h is the length of monopole)} \qquad (1)$$

Figure 4 shows the measured resonant frequencies of the monopoles that agree well with theory. The measurements also show a good

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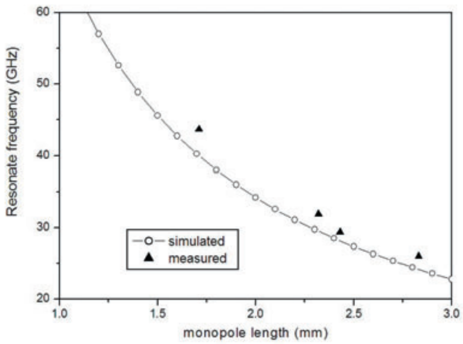
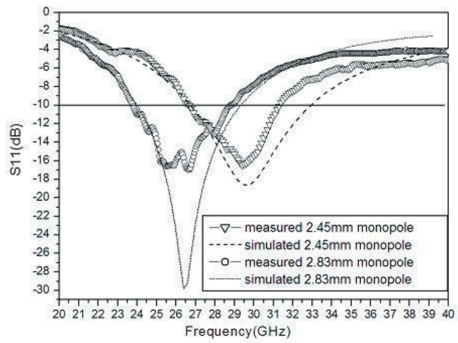
radiation bandwidth that agrees well with HFSS simulations. For example, at the resonant radiation frequencies of 26.3 and 29.6GHz, the 10dB bandwidths are as large as 21.5%.



(a)



(b)

Figure 4 Characteristics of MTM fabricated monopole antennas

Another very important mm-wave component is the high-Q resonator. Such resonators are required in many applications such as LANs, point to point communications, and automotive radar. There has been an increasing effort to develop cavity resonators to achieve high Q performance in a low-cost fashion. Compared with usual half-wavelength cavity-based resonators, evanescent-mode resonators have advantages such as a smaller size and an improved spurious-free region [6]. By loading a resonant cavity with a capacitive post, the resonant frequency of the cavity can be reduced, while a reasonably high unloaded Q factor is maintained [7].

However, the fabrication tolerances are extremely sensitive when the post height is close to the cavity height, representing a high loading factor. Micromolding, as a precision replica technology, has a wide process window which may enable the fabrication of these structures.

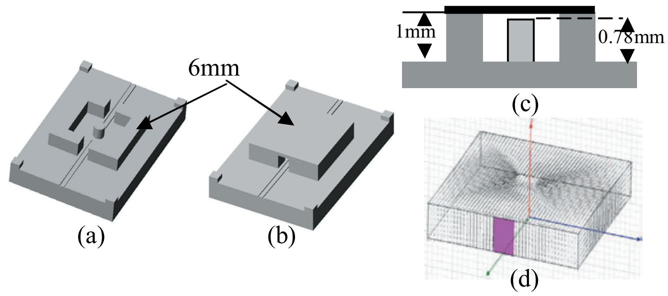


Figure 5 Schematic of the MTM fabricated evanescent mode cavity resonator

Figure 5 shows the schematic of the CPW fed cavity resonator. 5(a) shows the molded cavity structure with capacitive post, and after a top plate bonding the final device is shown in 5(b)(c). The cavity is design to be 6mm (35.3GHz) wide and 1mm high. By using the metal transfer technique, cavities with capacitive posts as well as CPW feedlines can be simultaneously formed. The CPW is used to feed the resonators via two openings on the sidewalls of the cavity. As shown in 5(d), the openings are parallel to the surface current flow, so the effect of the opening on the resonator performance is expected to be minimal. The CPW weakly couples electric energy into the cavity. The weak coupling enables the accurate determination of the unloaded Q of the resonator. Further, by using a CPW feed instead of coaxial cable, integration of other passive components on the same substrate is possible.

The height of capacitive post in the master structure made by stereolithography is 0.79mm instead of the 0.78mm design value. However, due the small fabrication tolerances of molding process, the dimension deviation of the molded structures is less than 1%. The measured resonant frequencies of a 6mm cavity resonator with or without capacitive post are as predicted by HFSS eigenmode simulation. As desired, the resonant frequency is significantly reduced (from 35GHz to 24GHz) due to the evanescent mode caused by the small gap (210µm) between the top of the capacitive post and the top of the cavity (Figure 6(a)). , i.e, for a given frequency of operation, a 45.8% size reduction has been achieved. The measured resonance shows good agreement with the HFSS10.0 simulation (Figures 6(b)(c)).

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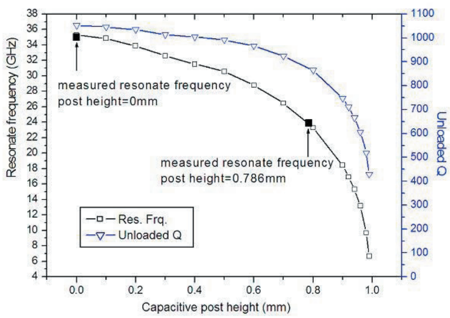
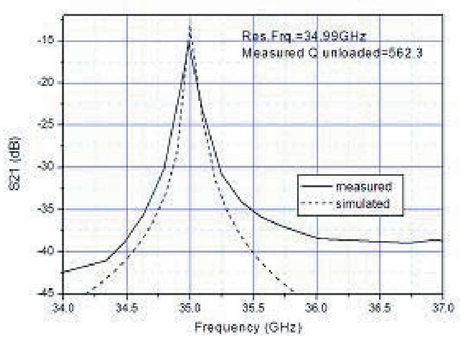
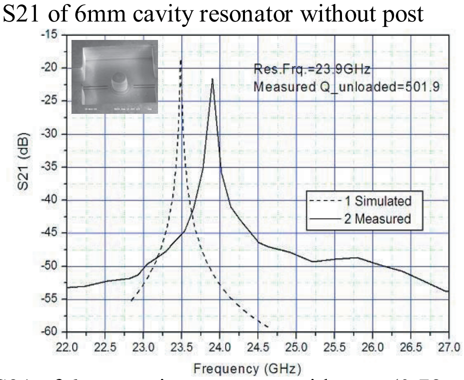


(a) Resonant frequency and unloaded Q versus post height



(b) S21 of 6mm cavity resonator without post



(c) S21 of 6mm cavity resonator with post (0.78mm high)

Figure 6 Characteristics of MTM fabricated cavity resonators

The unloaded Q can be derived from the measured curves by utilizing the formula:

$$Q_{unloaded} = Q_{loaded} / (1 - |S_{21}|) \quad (2)$$

High unloaded Q of more than 500 for both cavity resonators have been achieved (562.3 for half-wavelength cavity and 501.9 for evanescent mode cavity). The measured unloaded Q is less than that theoretically predicted (more than 800); this is attributed to the roughness of the sidewalls in the master devices produced by stereolithography. (Figure 6(c)). This indicates that in the MTM process, the master is critical; however, significant expense can be allotted to the master structure fabrication to achieve high part performance while still maintaining low part cost due to the nature of the MTM process.

4. CONCLUSIONS

Two millimeter-wave structures, an air lifted monopole antenna array and an evanescent cavity resonator, have been fabricated using the 3-D micro-metal-transfer molding (MTM) technology. RF characterization of these structures has been performed. Broad bandwidths of up to 21% have been achieved for the air lifted radiation structures, and a quality factor of more than 500 has been achieved for the resonators. This fabrication approach has a great potential for the fabrication of high performance organic RF devices from a wide selection of materials and is easily extended to other RF front-end components.

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REFERENCES

1. Y.-K. Yoon, et al, "Polymer-Core Conductor Approaches for RF MEMS," IEEE Journal of Microelectromechanical Systems (MEMS), vol. 14, no. 5, 2005, pp. 886-894
2. Y.-K. Yoon, et al, "Surface-Micromachined Millimeter-Wave Antennas", Transducers 05, Seoul,Korea, Vol. 1 pp. 1986-1989, Seoul,Korea, June 5-9, 2005.
3. Chappell, W.J, et al, "Applications of layer-by-layer polymer stereolithography for three-dimensional high-frequency components", IEEE Transactions on microwave theory and techniques, vol.52, Issue 11, 2004, pp.2567
4. J. A. Rogers, et al, "Nanotransfer printing by use of noncovalent surface forces", Applied Physics Letters, 85, 5730 (2004)
5. Warren L. Stutzman and Gary A. Thiele, Antenna Theory and Design, Chapter 2 and 5, John Wiley & Sons, Inc., New York, 1998.
6. A. Kirilenko, et al, "Evanescent-mode ridged waveguide bandpass filters with improved performance," IEEE Trans. Microwave Theory Tech., vol. 50, pp. 1324–1327, May 2002.
7 X. Gong, W. J. Chappell, and L. P. B. Katehi, "Reduced size capacitive defect EBG resonators," IEEE MTT-S Int. Microwave Symp. Dig.,vol.2, 2002, pp. 1091

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