Post-Process Fabrication of Multilayer mm-Wave On-Package Antennas with Inkjet Printing

Bijan K. Tehrani, Benjamin S. Cook, Manos M. Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA

***Abstract*—This work outlines and demonstrates for the first time the utilization of inkjet printing processes for the fabrication of on-package mm-wave antenna structures. A multilayer, fully printed 30 GHz square patch antenna with a 120 μm thick dielectric substrate is fabricated directly onto an IC chip package through the use of metallic and dielectric inks. A probe station is used to measure the return loss of the fabricated on-package antenna, showing excellent agreement with simulations. This well defined process of fully additive antenna fabrication demonstrates the integrity of the inkjet printing process for on-package and on-chip antenna fabrication up to mm-wave frequency ranges.**

I. Introduction

The current state of wireless electronics is advancing toward the development of highly functional, versatile, and ubiquitous integration with emerging technologies. Specifically, millimeter-wave (mm-wave) wireless communication, ranging in operational frequency from tens to hundreds of gigahertz, has been gaining interest in such applications as automotive radar automation and wireless gigabit local area networks. These applications call for well-integrated small-scale topologies and packaging schemes in order to ensure efficient operation. For this reason, antenna integration with the integrated circuit (IC) die and package is a desired field of research.

Typical fabrication methods for on-chip and package-integrated antenna structures involve the use of subtractive cleanroom procedures. As an alternative to these methods of fabrication, inkjet printing offers a fully additive method of electronic device fabrication. Multilayer mm-wave antenna structures have been demonstrated as a viable option for efficient and robust antenna fabrication, where low-cost and environmentally advantageous integration with on-chip and on-package wireless systems is made possible [1], [2].

This work aims to outline and demonstrate inkjet printing processes for the fabrication of mm-wave on-package antenna structures to be used with package-integrated feeding methods, such as wireless die coupling and through-package vias [3], [4]. A multilayer 30 GHz patch antenna is fabricated on a standard IC chip package. Utilizing metallic inks for conductors and dielectric inks for thick substrates, a multilayer structure is fabricated directly onto an IC chip package and measured to verify the integrity of the injket-printed system.

II. Materials

In order to fabricate a fully printed on-package antenna structure in a post-processing fashion, both metallic and dielectric inks are required. The following inks are printed with the Dimatix DMP-2831 inkjet printing platform at a 20 μm drop spacing to fabricate the antenna structure on a standard small outline integrated circuit (SOIC) chip package.

Metal layers are patterned using Cabot CCI-300 silver nanoparticle ink, a 20 w% dispersion of silver nanoparticles within an alcohol solution exhibiting a viscosity of 12 cP and surface tension of 30 dyn/cm. Once the metallic layers are printed, solvent material is evaporated with a thermal ramp from 60 to 120 °C, followed by a final sintering at 120 °C for 1 hour, yielding a single layer thickness of 500 nm and conductivity of 1.1e7 S/m.

Dielectric layers are patterned using a long-chain polymer ink, enabling the deposition of fully-additive dielectric structures exceeding 100 μm while maintaining desired surface uniformity. This ink is a formulation of 35 w% SU-8 polymer with a UV-crosslinking agent, yielding a viscosity of 13.4 cP and a surface tension of 30 dyn/cm. Once printed, the dielectric pattern undergoes a soft thermal bake at 95 °C for 10 min, followed by an exposure of 365 nm UV light, and concluded with a hard thermal bake at 95 °C for 7 min. The printed dielectric film exhibits a single layer thickness of 4 to 6 μm, a dielectric constant (ϵ_r) of approximately 2.8 and a loss tangent (tan δ) of 0.04 at 30 GHz [5].

III. Inkjet Printing Fabrication

The inkjet printing fabrication of the multilayer on-package patch antenna is a multistep process of depositing dielectric and metallic inks to create a fully-additive post-processed structure. Fabrication begins with the deposition and curing of 2 layers (10 μm) of SU-8 dielectric ink in order to provide isolation from the IC package and smoothen the rough package surface. Next, 5 layers (2.5 μm) of silver nanoparticle ink are deposited and cured to pattern the ground plane of the antenna.

To pattern the thick dielectric substrate, two 7-layer printing and curing sessions of the SU-8 polymer ink are performed. The utilization of this multi-session printing scheme allows for the realization of thick dielectric patterns while maintaining an acceptable surface uniformity, avoiding the convex surface profile resulting from a single-session deposition of too much ink material [5]. Fig. 1 shows profile scans of the printed dielectric substrate after the first and second 7-layer sessions.

After the printing and curing of the 14-layer (120 μm) dielectric substrate, 3 layers (1.5 μm) of silver nanoparticle ink

978-1-4799-7815-1/15/$31.00

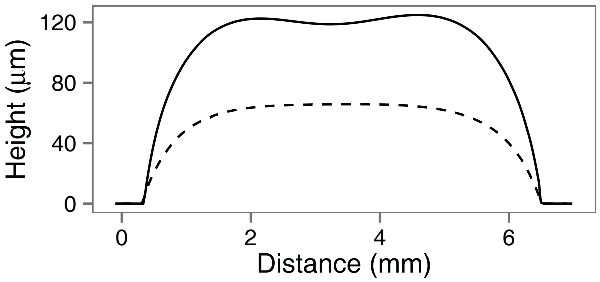


Fig. 1. Profilometer scans of (– –) 7-layer and (—) 14-layer multi-session inkjet-printed dielectric substrate.

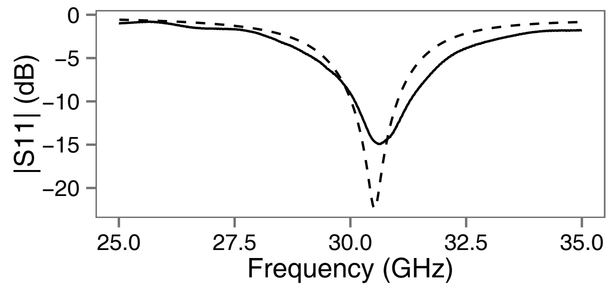


Fig. 3. Return loss of (– –) simulated and (—) fabricated antennas.

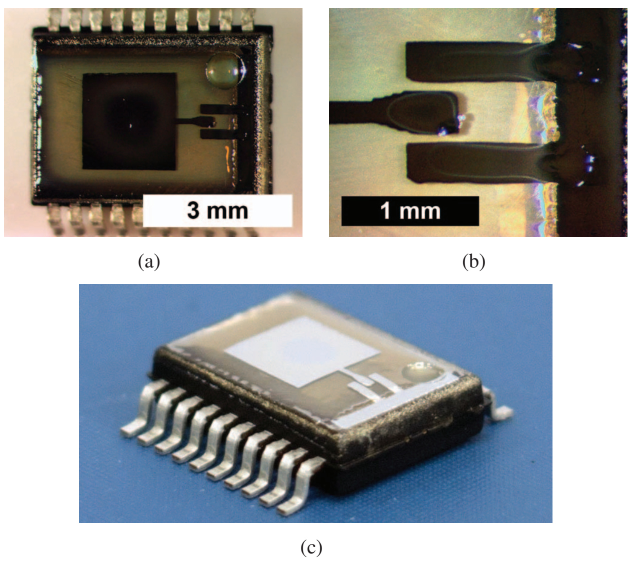
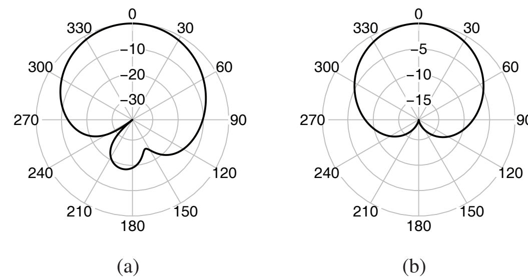


Fig. 2. Inkjet-printed on-package 30 GHz patch antenna: (a) top view, (b) CPW feed and via detail, and (c) perspective view.



(a) (b)

Fig. 4. Simulated (a) YZ and (b) XZ normalized radiation pattern cuts.

are printed and cured, completing the fabrication. The inkjet-printed on-package patch antenna is shown in Fig. 2, including top view, perspective view, and detail of coplanar waveguide (CPW) feed and vias.

IV. Measurement Results

The return loss of the fabricated on-package mm-wave patch antenna is measured with an Anritsu 37369A VNA utilizing 250 µm pitch probes from Cascade Microtech. The measured and simulated return loss of the printed patch antenna is shown in Fig. 3. Measured results for return loss compare well to simulations, exhibiting a 0.3% deviation in resonance frequency from the simulated 30.5 GHz.

Simulated radiation pattern cuts in the YZ and XZ planes are shown in Fig. 4, displaying a large broadside directivity typical of a square patch antenna. Realized broadside (+Z) gain is found in simulation to reach 1 dB, where efficiency is affected by the CPW-to-microstrip feed transition and the CPW vias to ground required for probe measurement.

V. Conclusion

This work outlines and demonstrates for the first time a process of inkjet printing fabrication for the post-process realization of fully-additive multilayer antenna structures for on-package and package-integrated applications. Nanoparticle-based metallic and thick polymer-based dielectric inks are used to fabricate a fully-printed mm-wave on-package patch antenna with a printed dielectric substrate exceeding 100 µm. Surface profilometer and return loss measurements are performed to verify the integrity of the fabrication process. The additive nature of inkjet printing demonstrated introduces a higher degree of versatility and cost efficiency for the fabrication and utilization of on-chip and on-package antennas for mm-wave applications.

References

[1] B. Cook *et al.*, "Multilayer inkjet printing of millimeter-wave proximity-fed patch arrays on flexible substrates," *Antennas and Wireless Propagation Letters, IEEE*, vol. 12, pp. 1351–1354, 2013.

[2] J. Bito *et al.*, "Fully inkjet-printed multilayer microstrip patch antenna for Ku-band applications," in *Antennas and Propagation Society International Symposium (APS/URSI), 2014 IEEE*, July 2014, pp. 854–855.

[3] Y.-P. Zhang and D. Liu, "Antenna-on-chip and antenna-in-package solutions to highly integrated millimeter-wave devices for wireless communications," *Antennas and Propagation, IEEE Transactions on*, vol. 57, no. 10, pp. 2830–2841, Oct 2009.

[4] S.-H. Wi *et al.*, "Package-level integrated antennas based on ltcc technology," *Antennas and Propagation, IEEE Transactions on*, vol. 54, no. 8, pp. 2190–2197, Aug 2006.

[5] B. Tehrani *et al.*, "Fully inkjet-printed multilayer microstrip and T-resonator structures for the RF characterization of printable materials and interconnects," in *Microwave Symposium (IMS), 2014 IEEE MTT-S International*, June 2014, pp. 1–4.