Improved performance of high frequency multilayer CPW inductors on flexible substrates

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Advantages in ink-jet printable electronics have opened the door for the manufacturing of sensors and actuators, radio-frequency identification (RFID) tags, wireless modules, photovoltaic, and displays [1, 2].

In this paper, we present the modelling, fabrication, measurement technique and characterization of multilayer miniature coplanar waveguide (CPW) meander type inductors for high frequency applications. CPW inductors are fabricated in inkjet printed technology on a flexible plastic polyimide foil (50 μm thickness) with Dimatix material printer DMP-3000. Inductors are made with silver nanoparticle ink which contains 20% wt of silver.

Previously fabricated CPW inductors had a small value of Q-factor, reported in [3]. From the presented simulation results, it was seen that, in order to achieve higher Q-factor, the reduction of the serial resistance of CPW inductors was necessary. The decrease in serial resistance can be accomplished by increasing a thickness of the layer or/and concentration of silver containing in polymer silver ink. Because of that, we printed CPW inductors with one, two and three layers.

Multilayer printing is possible if sufficient time is allowed for the previous layer to dry before applying the next. Average drying time was around 30 minutes at 60°C for the used ink, during which the flexible substrate must be fixated by e.g. a vacuum pump to prevent misalignment between successive layers. For every next layer the drying time was increased by 15 minutes to adjust for the thickness increase. A visual indicator for the completeness of this step, after the mentioned time has passed, is a metallic glow that occurs around the edges where the evaporation rate is fastest. This also helps to distinguish if the new layer was printed or the nozzle seized firing.

When the printing is finished and the structure's validity, inspected with the integrated microscope, the substrate is heated to 60°C. Elevated temperature accelerates the solvent evaporation, ethanol in the case of the used ink, which coagulates the structure. The remaining content is the surfactant and ethanediol that evaporate on higher temperatures. The surfactant prevents the particles from agglomerating while the etandeiol increases ink's viscosity. After 30-60 minutes have passed the before mentioned metallic glow will appear and then the structures can be safely moved to the oven. Samples should be placed in a non-preheated oven to avoid rapid boiling of the ink. Temperature is set to 240° C for 45 minutes.

Around the CPW inductors is a ring-shaped ground plane, which is a replacement for the background metallization. In that manner, the structures are manufactured in a low-cost fabrication process.

Final obtain dimension of CPW inductors are 1.7 mm x 1.8 mm for one turn, and 3.1 mm x 1.8 mm for three turns. CPW inductors printed in one layer have thickness around 800 nm. Multiply layers are increasing thickness of inductors. In our case, up to 2.2 μm for three layers. Micrograph of CPW inductors with critical dimension are presented in Fig. 1. As it could be seen, CPW inductor printed in one layer has been match with CPW inductor printed in three layers with minimal tolerance (bellow 5%). This is encouraging result for multilayer printing in inkjet technology.

The printed structures were measured using the Agilent N5230A PNA-L vector network analyzer, Süss MicroTec RF probe station PM5, and coplanar ground–signal–ground (GSG)

Cascade Microtech probes (|Z| probes). The measurement results were obtained in the frequency range from 1 to 35 GHz. In Fig. 2, we present measurement results of CPW inductors, inductance and Q-factor between two ports (differential measurement). Printed structures have relatively high self-resonant frequencies, e.g. 16.94 GHz for CPW 1x200 µm, and 6.63 GHz for CPW 1x200 µm for three printed layers. Q-factor, as it predicted, grow with increasing thickness of silver layer. For CPW inductors from one to three layers, Q-factors have values from 2.3 to 4.1 for CPW 1x200 µm and values from 1.4 to 3.1 for CPW 1x200 µm.

Bigger Q-factor will be obtain using non-conventional process of sintering, named photonic curing and this will be our further research.

[1] R. Vyas, V. Lakafosis, H. Lee, G. Shaker, L. Yang, G. Orecchini, A. Traille, M. M. Tentzeris, and L. Roselli, “Inkjet printed, self powered, wireless sensors for environmental, gas, and authentication-based sensing,” *IEEE Sensors J.*, vol. 11, no. 12, pp. 3139–3152, Dec. 2011.

[2] M. M. Tentzeris, R. Vyas, V. Lakafosis, T. Le, A. Rida, and S. Kim, “Conformal 2D/3D wireless modules utilizing inkjet printing and nanotechnology,” *Microw. J.*, vol. 55, no. 2, pp. 20–40, Feb. 2012.

[3] A. B. Menicanin, L. D. Zivanov, M. S. Damnjanovic, A. M. Maric: “Low-Cost CPW Meander Inductors Utilizing Ink-jet Printing on Flexible Substrate for High Frequency Applications”, *IEEE Transactions on Electron Device*, Vol. 60, No. 2, Feb. 2013, pp: 827 - 832.

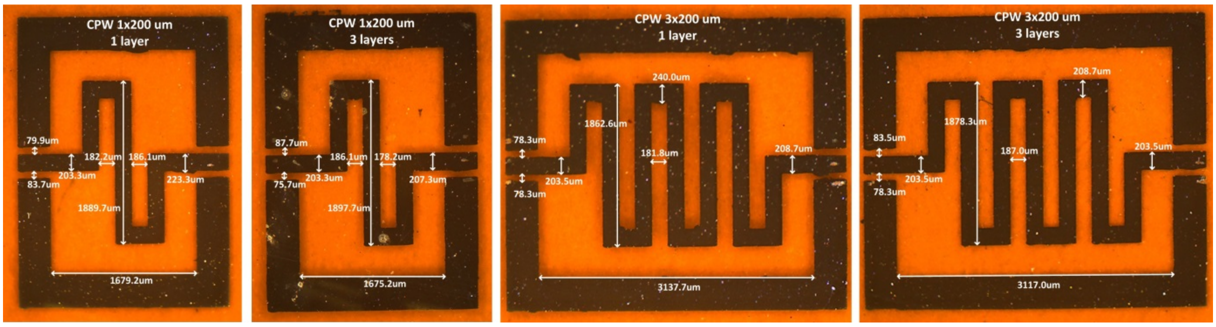

Fig. 1. Micrograph of CPW inductors, printed in one and three layers (with critical dimensions).

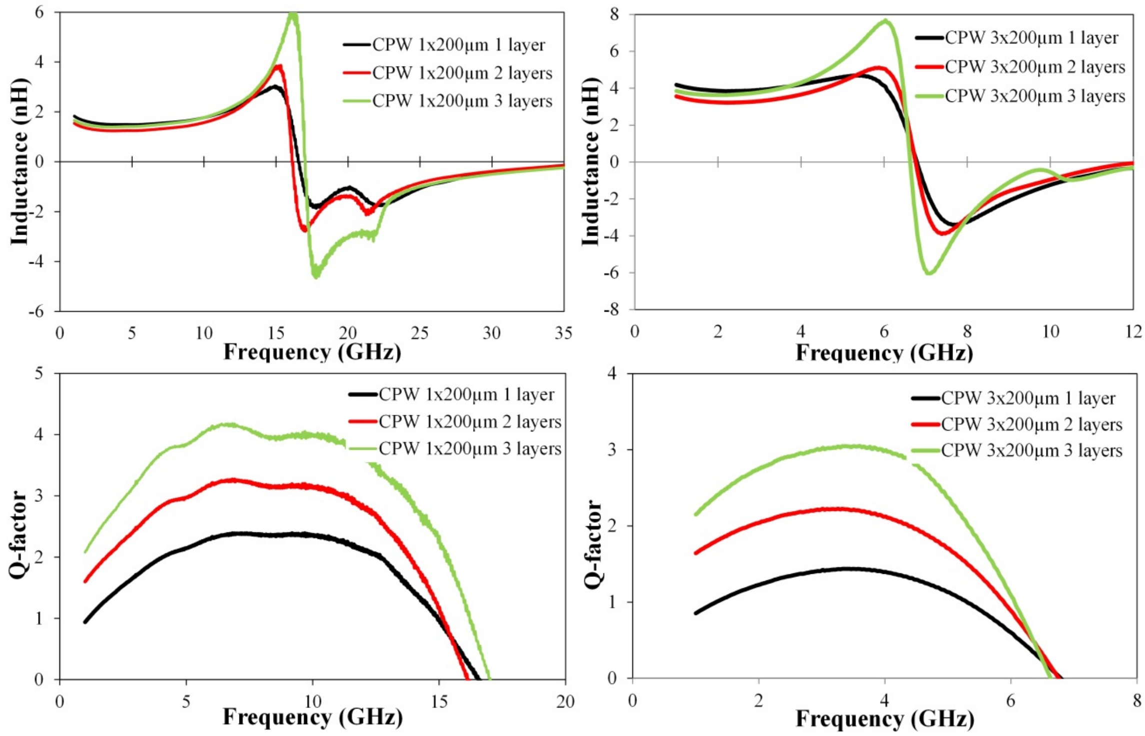

Fig. 2. Measured inductance and Q-factor of meander-type CPW inductors with 1 turn (CPW 1x200 µm) and with 3 turns (CPW 3x200 µm).