An all-printed passive component technology for low-cost RFID

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Introduction – There has been tremendous interest in direct printing of electronics for low-cost electronics applications due to its low fabrication cost. In particular, low-cost RFID is a compelling application, since it may enable the development of ubiquitous tags for inventory control and supermarket checkout applications. To date, little work has been done on the passive components necessary to realize low-cost RFID. The requirements placed on these are stringent; high-Q inductors and well-behaved capacitors are required for power-harvesting and communication. We recently described a plastic-compatible printed interconnect technology [1]. Here, for the first time, we demonstrate an all-printed passive component technology on plastic, including inductors, capacitors, and multilevel interconnects. This represents an important step towards the development of ultra-low-cost RFID on plastic.

Process – All structures were printed on Dupont ST505 Melinex film, which offers good thermal stability up to 200°C, using a custom-built inkjet system with a 60μm diameter nozzle MicroFab piezo-head. Low-resistance conductors were printed using a 10 wt. % 2nm diameter hexanethiol-encapsulated gold nanocrystal solution in α-terpineol [2], which anneals to form a conductive film at 130 °C. 160°C-190°C substrate heating was used during printing. The dielectric used was a Pyralin-diluted PI2555 polyimide from HDMicrosystems, printed at 90 °C, and cured at 190 °C. Various structures were printed, including inductors, capacitors, and multilevel interconnect bridging structures.

Results and Discussion – Lines were printed using 5μm-spaced overlaid drops. Thickness was adjusted using multiple print head passes. The use of multiple passes had little impact on linewidth (Fig. 1), while dramatically lowering sheet resistance (Fig. 2). This results from the use of elevated substrate temperatures (160°C-190°C) during printing, which minimizes spreading of the jetted drop while ensuring good annealing. Printed lines were profiled to obtain average heights (Fig 3). Conductivity of ~30% of bulk gold was obtained (Fig. 4), with a sheet resistance of ~25mΩ/square. These represent the lowest values ever reported to our knowledge, and are crucial to achieving the high-Q inductors necessary for adequate range of power harvesting and communication. We have fabricated low and high-frequency inductors (Fig. 5). The measured inductance of the low-frequency inductor, designed for use in a 13.56MHz tag was found to be 350nH, close to the expected value of 360nH as simulated using ASITIC. Series resistance (~58Ω for a 3-layer structure) also matched well with simulated values (Fig. 6).

Capacitors and multilevel interconnects were fabricated using the polyimide dielectric. By using multiple passes of spatially-offset dielectric drops, extremely high yield was ensured (Fig 7). Print-induced pinholes are almost completely eliminated. Step coverage of the overlaying conductor line is excellent, with excellent yield up to steps ~4μm tall (Fig 8). To test the dispersion characteristics of the dielectric (K ~4.5), the capacitance of a 600x600 μm capacitor (Fig. 9) was measured at frequencies from 1 kHz to 1 MHz (Fig. 10). The resulting dispersion is acceptably low since the highest expected operating frequency for low-cost RFID is 13.56MHz. The specific capacitance was 1.5nF/cm² using a conservative 3μm thick dielectric. Further optimization should allow this to be increased for smaller capacitor sizes.

Conclusion – For the first time, we have demonstrated all-printed passive components on plastic substrates using inkjet printing. Devices are well-behaved and match simulated values extremely well. These devices represent an important step towards the development of low-cost RFID systems.

Fig 1: Printed line width variation with # of layers. In general, drops overlay very well: linewidth increases only slightly.

Fig 2: Sheet resistance variation with # of layers.

Fig 3: Avg. line height variation with # of layers.

Fig 4: Fractional conductivity as a function of # of layers and substrate temperature during printing.

Fig 5: A 350nH inductor designed for use in a 13.56MHz RFID tag. The crossover on the left is isolated using a polyimide interlayer.

Fig 6: Variation in series resistance and Q with # of layers.

Fig 7: Electrical Integrity of crossover isolation as a function of # of polyimide layers. For 3-layer crossovers, yields are not limited by pinholes due to printing.

Fig 8: Integrity of step coverage as a function of step height.

Fig 9: A parallel plate capacitor. The top and bottom plates are inkjetted gold, while the dielectric is inkjetted polyimide.

Fig 10: Variation in capacitance vs. frequency, indicative of minimal low-frequency dispersion of polyimide dielectric.