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1	20.06.05	Final draft	Tomas Lindström
2	20.07.05	Revised document	Tomas Lindström
3	03.10.05	Update with RF results.	Tomas Lindström

Content

Section 1 - OBJECTIVE

ÅMIC's aim within WP4 is to create a functional package containing passive structures like inductors, transformers, antennas, connection pads, and with/without wafer-level capping capabilities, *by assuming a low cost approach working with pre-formed polymer wafers.* Previous work has been reported in D4.5 "Polymer wafer-based passive component development feasibility", and in D4.9 "Zero-level packaging study: application to RFMEMS, and assessment of polymer". This report inside Task 4.2 deals with the manufacturing of the polymer wafer-based coil demonstrator.

Section 2 - ABSTRACT

In this report the manufacturing of polymer wafer-based spiral inductors is described. The coil was chosen as a suitable test component for the technology. The collaboration partner is ST Crolles. The idea is to use pre-formed polymer wafers in order to avoid repeated lithographical definition of metal electrodes including the underpass. The conclusion of this report is that spiral inductors can be manufactured with the proposed method and that the technology may lead to low cost RF components.

In this work coils with electrode width 60 µm, separation 30 µm, and outer diameter 600-1000 µm have been finalized. The 1, 3, and 5 turn designs are targeted to yield 1, 5, and 15 nH inductance. Due to some delay in completing the inductors and lack of resources for RF characterization the analysis of the component performance is not yet completed. Included in this report are some of the achieved measurement data, but not a thorough investigation of the factors contributing to the obtained results. In short we arrived at Q ~28@2.4 GHz for the 1-turn coil, and inductance L ~2 nH, Q ~23@2.4 GHz for the 3-turn coil, and inductance L ~10 nH, and Q ~15@2.4 GHz for the 5-turn coil, and inductance L ~20 nH.

The main process is divided into five parts: In the first step the polymer wafers are injection molded. In the second step the wafers are metallized. In the third step the wafers are resist coated by flexographic printing. In the fourth step the unwanted metal is etched away by wet chemical etching, and the resist is removed. In the fifth step the coils are assembled by bonding two wafers to complete the coil turns. The assembly relies on flexographic printing of adhesive followed by curing at high pressure. As a final optional step the wafers may be diced into smaller components.

The applied process times for the wafers are short; injection molding takes about 10 seconds, seed layer sputtering < 5 seconds, and resist printing < 5 seconds. The plating time is depending on the desired thickness, in our case it was ~1 µm/minute, and the corresponding metal etch was done in ~1 µm/15 seconds.

This work will be followed by the choice of passive device for second SiP (System in Package) integration demonstrator at T0+24 months.

Section 3 - MANUFACTURING PROCESS

3.1 BACKGROUND

The process is divided into five steps, and each of these steps is easily adapted for high volume manufacturing. In the first step the pre-formed polymer wafers are injection molded. In the second step the wafers are metallized. In the third step the wafers are resist coated by flexographic printing. In the fourth step the unwanted metal is etched away by wet chemical etching, and the resist is removed. In the fifth step the coils are assembled by bonding two wafers to complete the coil turns.

The assembly relies on flexographic printing of adhesive and high pressure bonding. As a final optional step the wafers may be diced into smaller components. The manufacturing scheme is outlined in Figure 1, and the expected process outcome is illustrated in Figure 2.

Figure 1. The pictures illustrate the corner stones of the coil manufacturing process. (a) Injection molding of pre-formed polymer wafers. (b) Metallization by for example sputtering (thin layers, typically < 1 µm) or plating (thicker layers, typically > 1 µm). (c) Coating the wafers with resist by flexographic (letter press) printing. (d) Wet chemical etch of the unwanted metal and wet removal of the resist. (e) Assembly of two wafers (coil halves) to complete the turns of the final component. This is done by flexographic printing of adhesive followed by high pressure bonding and curing.

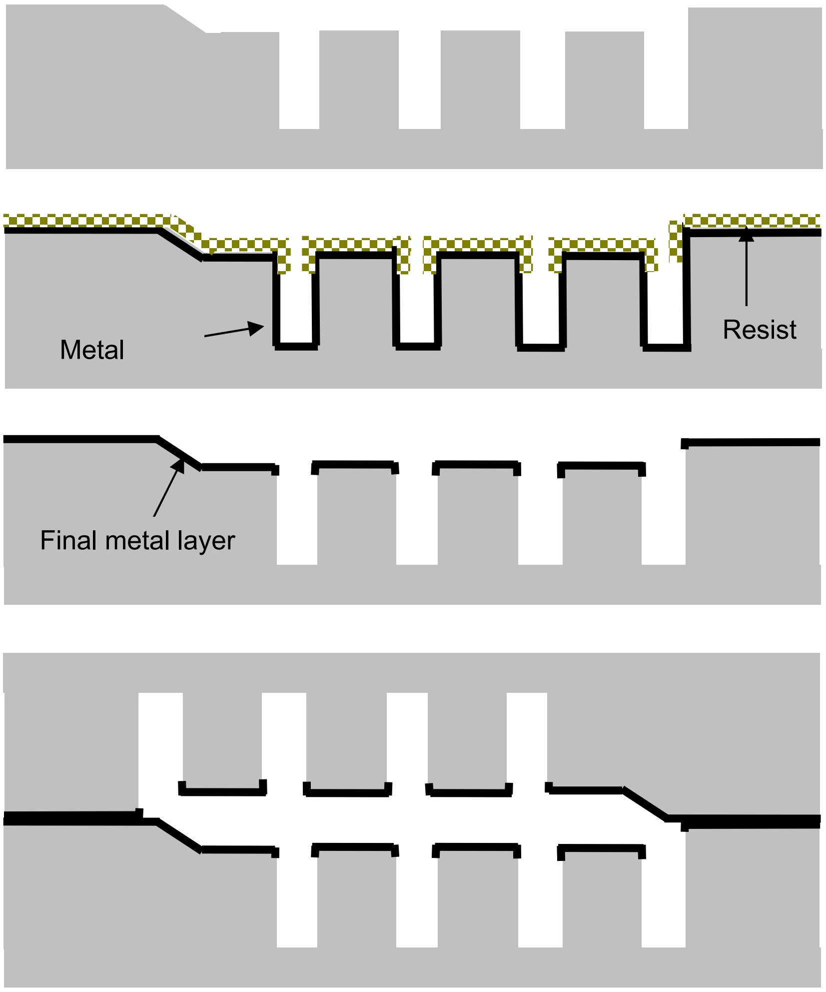

Figure 2. The images show the patterning approach of predefined electrodes. In the top figure the pre-formed polymer wafer is depicted. It consists of areas for the electrode patterns, and the underpass is at a recessed height. In the middle picture the wafer has been metallized and then flexographically printed with a thin layer of resist. In the next figure the unprotected metal has been etched away. The concept is depending on the resist not to fill the deep trenches, but only to cover the top region. In the bottom figure two wafers (halves) have been joined to complete the coil turns.

3.2 INJECTION MOLDING

The targeted pre-formed structures were processed by deep reactive ion etching (DRIE) in silicon. Figure 3 shows an example of the obtained silicon structures. The electrode underpass is located 10 µm beneath the top level. The areas outside the defined electrodes are 65 µm beneath the top level. The electrode width is 60 µm and the electrode separation 30 µm. This is slightly larger than the targeted 50 µm and 20 µm due to manufacturing tolerances. The silicon master structure is then transferred into a more durable nickel-based mold tool for the replication work. The cycle time of the injection molding process is about 10 seconds, and the material used is cyclo olefin polymer (grade Zeonor 1060 by Zeon Corporation). Figure 4 depict examples of molded polymer structures.

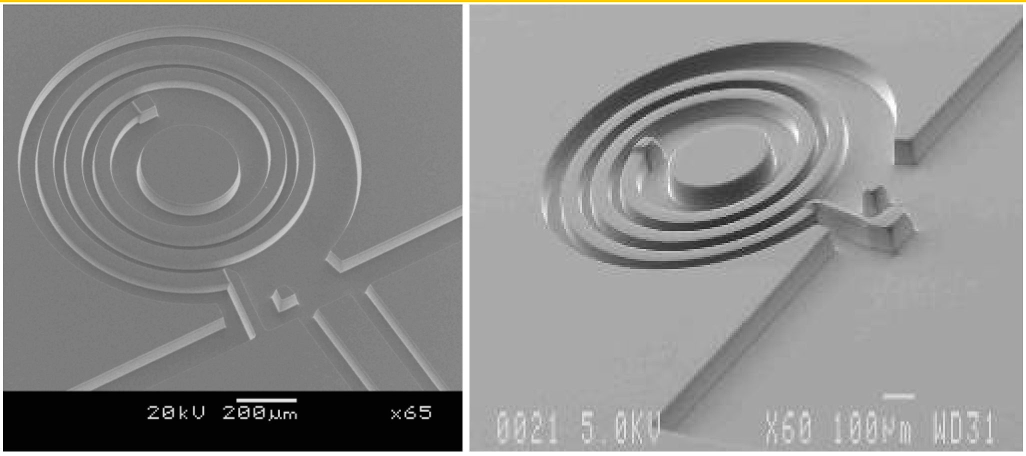

Figure 3. The SEM photographs show the processed silicon for the 5 turn coil with a small overlapping zone. The picture to the left depicts the bottom half, and the one to the right the top half. By joining these two halves the complete spiral electrode turns are obtained. Note also the 10 µm recession for the underpass.

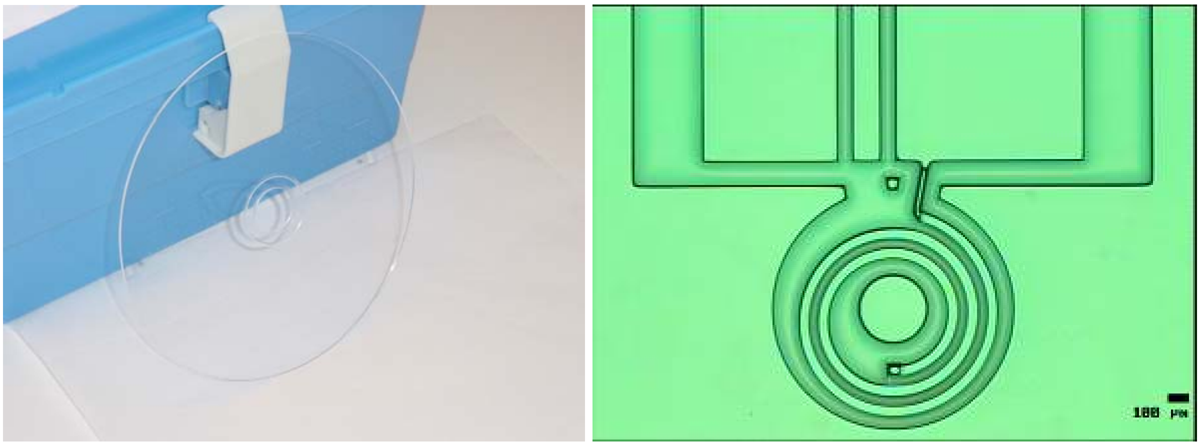

Figure 4. The picture to the left depict an example of a polymer wafer (aka CD/DVD) containing all the different coil designs, and picture to the right the bottom part of the molded 5-turn coil.

3.3 METALLIZATION

The polymer wafers are metallized with the electrode material. To improve adhesion a thin metal layer of Titanium or Chromium can be used. If a thin electrode layer is needed CD/DVD sputtering machinery provide a very fast process, 50 -100 nm of metal may be coated only in a few seconds. Sputtered layers are typically used for coating less than 1µm, for thicker layers plating is normally used. A thin sputtered layer may also be used as a plating base. In this work the electroless copper system Shipley Circuposit 3000 was planned to be used, however, the process turned out very unstable. Instead the Shipley Ronal Aurall 292 electroplated gold system was applied. Process time for the plating was 8 minutes. Metal thickness was measured with a mechanical stylus profilometer to be around 8 µm. Figure 5 shows an example of a metallized wafer.

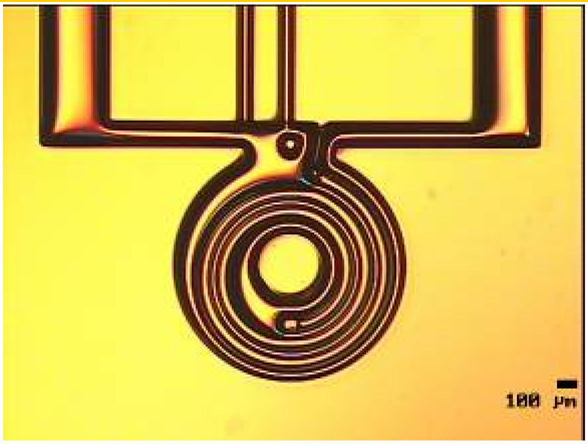

Figure 5. The picture shows a metallized 5-turn coil.

3.4 RESIST PRINTING

The patterning method relies on selective coverage of resist on a pre-formed wafer. By flexographic printing a thin layer (approx. 5 µm) of Shipley S1813 photoresist is applied homogeneously over the whole polymer wafer, but not in the trenches. The solution with the underpass at another height adds complexity, but this solved with a soft cliché capable of handling slight height variations. The process is based on CD/DVD label printing equipment, and the cycle time is very short, only a few seconds.

3.5 ETCH-BACK

The gold unprotected by the photoresist was etched away by an Aqua Regia solution (a mixture of $3HCl{:}1HNO_3$ and $4HCl{:}4HNO_3{:}9H_2O$). The etching time was less than 2 minutes. The resist was removed by washing the wafer in acetone followed by ethanol. Figure 6 depicts a coil that has been resist coated and then gold etched.

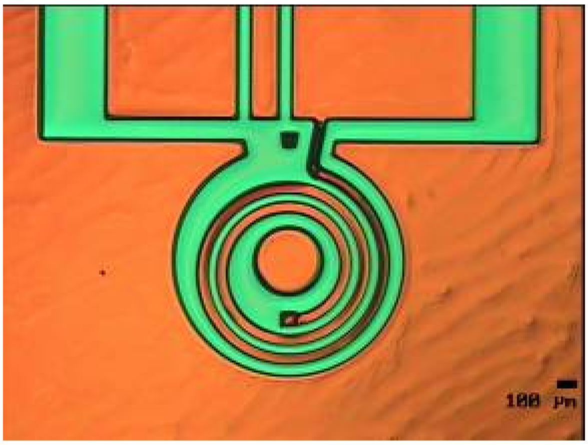

Figure 6. The picture depicts the 5-turn coil resist-coated and then gold etched.

3.6 ASSEMBLY

All the components are placed on one wafer. Two identical wafers (halves) are bonded together by flipping, and twisting, one wafer over the other in order to match bottom part of a specific inductor with its top part. By using steering pins the alignment is simplified. The assembly has to take place under high pressure in order to form a low resistive metal-metal contact between inductor turns. In order to facilitate the RF probing the top wafer will contain machined access holes.

A thin layer of Epoxy Technology's EpoTek 302-3M adhesive is flexographically printed on one of the wafers. This process takes only a few seconds, and basically the same equipment is used as for resist printing. The wafers are aligned and placed in the bonding station. Three levels of pressure were applied, approx. 3 bar, 26 bar, and 50 bar. This particular adhesive was cured > 1 hour, but beside from heat curing adhesives fast UV-curing adhesives may be used. Figure 7 show an example of completely assembled inductor.

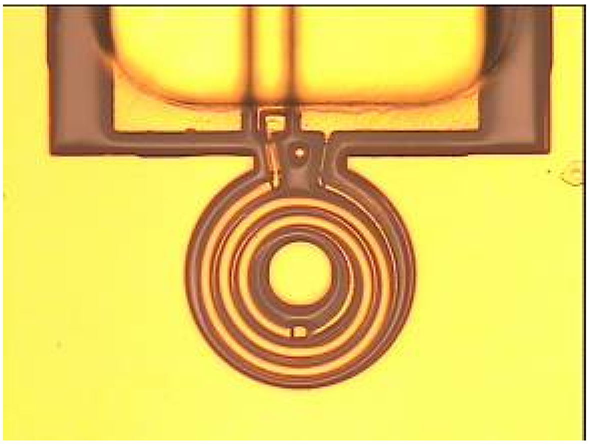

Figure 7. The picture depicts an assembled 5-turn coil with machined probe pad openeing.

Section 4 - RESULTS OBTAINED

Three main types of inductors have been assembled, the 1-, the 3-, and the 5-turn coil. The two larger ones with small and large electrode overlap zones, respectively. Test patterns for RF probes have also been made. The inductors will be tested as stand alone components. The coils have been checked for DC resistivity, and cross sections have been examined to control the underpasses have not collapsed due to the high bonding pressure. Unfortunately the full result from the RF characterization is still pending. A single measurement show that the tested coil is working.

4.1 MANUFACTURED COILS

Figures 8-10 show light optical microscope pictures of the obtained coils. Five different designs have been manufactured. A 1-turn coil, a 3-turn coil with a small and a large electrode overlap, and a 5-turn coil with a small and a large electrode overlap.

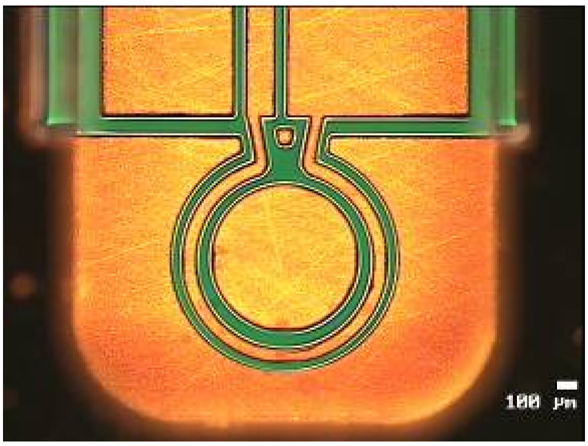

Figure 8. The picture shows the 1-turn coil (1).

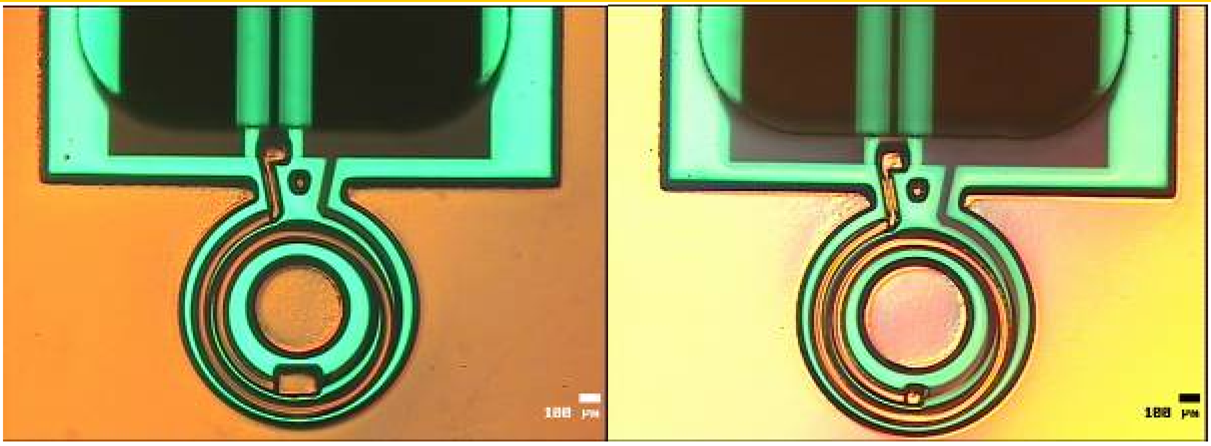

Figure 9. The picture to the left show the 3-turn coil with large overlap zone (3.1), and the one to the right the 3-turn coil with small overlap zone (3.2).

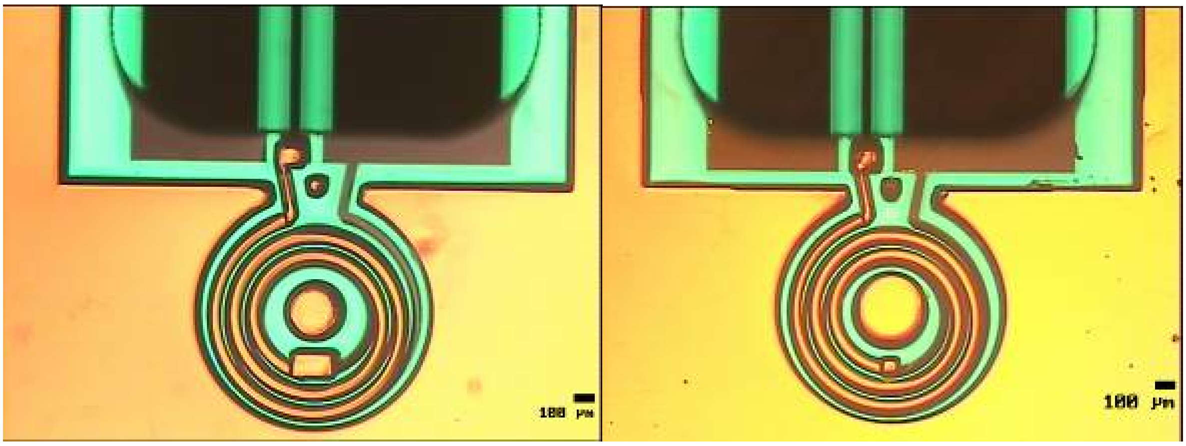

Figure 10. The picture to the left show the 5-turn coil with large overlap zone (5.1), and the one to the right the 5-turn coil with small overlap zone (5.2).

4.2 MANUFACTURED TEST PATTERNS

For the RF characterization three different probe pads are available, as seen in Figure 11 and 12. They are open-circuit, short-circuit, and purely resistive load. The probe pitch is 200 μm. The central probe pad is 150 μm, and the separation is 50 μm on each side. To reach the pads an opening of 2mm x 2mm in the top substrate is machined by CNC milling.

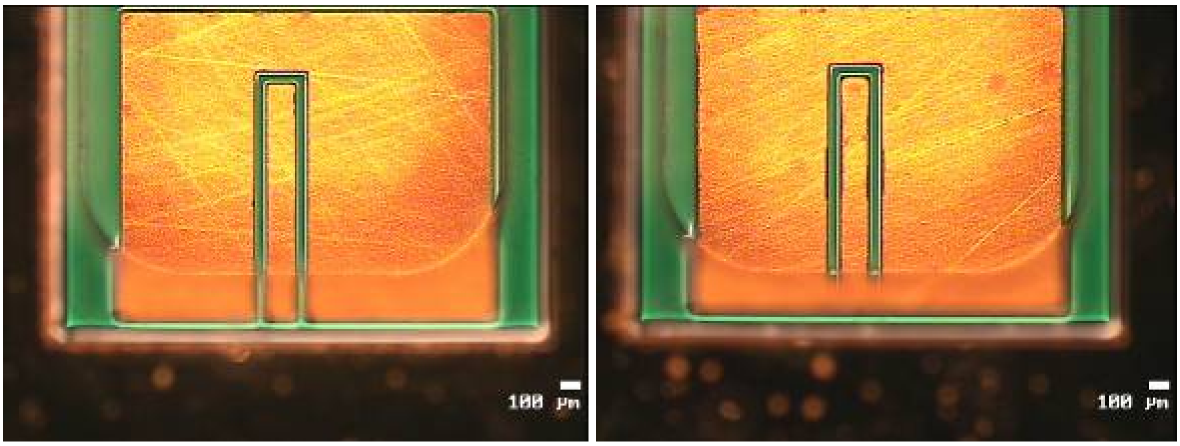

Figure 11. The open-circuit probe pad is shown to the left, and the short-circuit pad to the right.

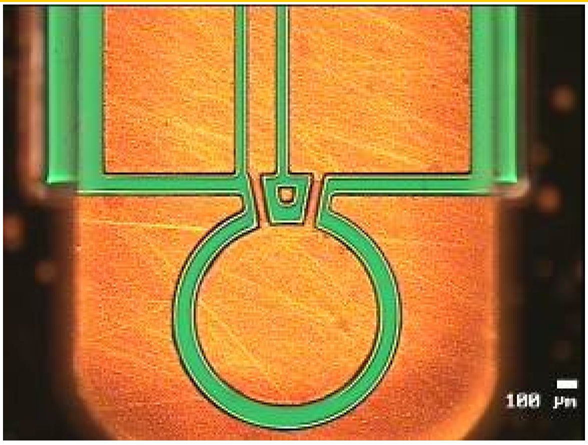

Figure 12. The picture depicts the probe pad used for pure resistive (ohmic) load.

4.3 CROSS SECTION OF ELECTRODE UNDERPASS

To verify that the bonding process do not collapse the underpass separation a cross section sample was made by splitting a coil in the middle. As apparent from Figure 13 the separation is still there and the coil is not short-circuited. The underpass also appears to be around the targeted 20 µm.

Figure 13. The pictures depict a cross section of a coil. The underpass has not collapsed during assembly, and as can be seen in the right image the size of the underpass is about 20 µm.

The cross section of a sample coil also reflects the gold thickness. As can be seen in Figure 14 the thickness is slightly less than 10 µm, which corresponds to the 8 µm from the profilometer.

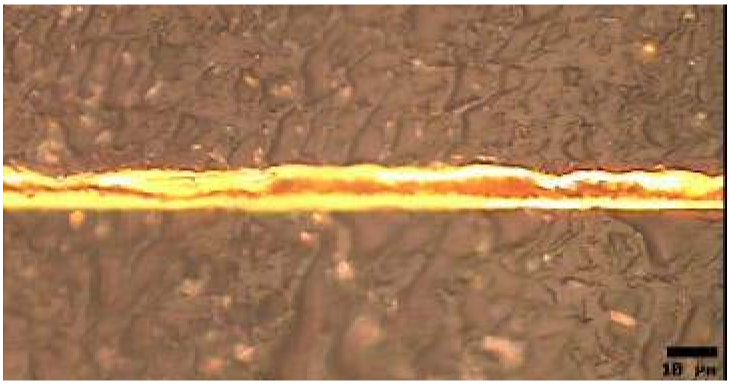

Figure 14. Cross section of coil indicating the electrode thickness to be about 8 µm.

4.4 RF CHARACTERIZATION

Test coils have been checked positively by AMIC for DC resistance. The inductors have been measured for inductance and Q-factor at CEA-LETI's DCIS Laboratory. The targeted frequency range is 2-4 GHz, with specific attention to 2.4 GHz. Due to some delay in completing the inductors and lack of resources for RF characterization the analysis of the component performance is not yet completed.

Included in this report are some of the achieved measurement data, but not a thorough investigation of the factors contributing to the obtained results. In short we arrived at Q ~28@2.4 GHz for the 1-turn coil, and inductance L ~2 nH, Q ~23@2.4 GHz for the 3-turn coil, and inductance L ~10 nH, and Q ~15@2.4 GHz for the 5-turn coil, and inductance L ~20 nH. Figure 15 depicts some examples of obtained RF spectra.

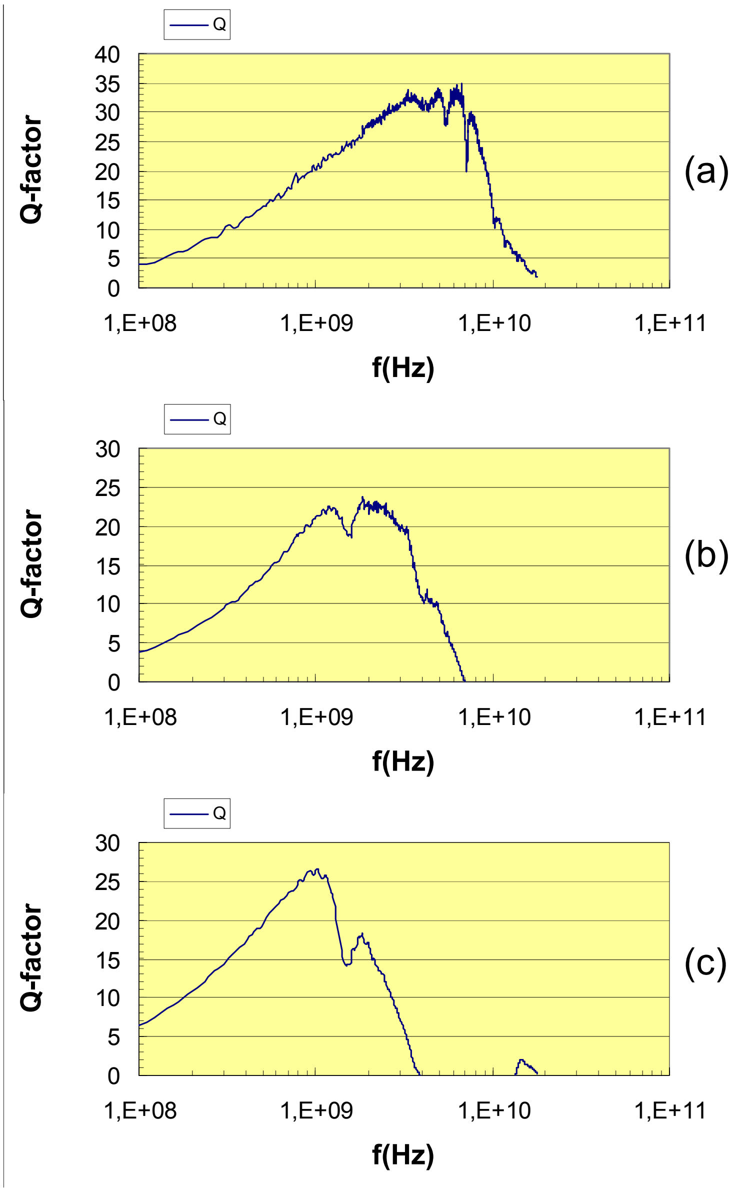

Figure 15. Example of RF measurement of (a) a 1-turn coil, (b) a 3-turn coil with a small overlapping zone (3.1), and (c) a 5-turn coil with a small overlapping zone (5.1).

Section 5 - FUTURE WORK

The plan for the continuation of the project is to await the analysis of the coil RF results. A choice has then to be made regarding the passive device for the planned system in package integration demonstrator. It has also been decided to fabricate a prototype RFID antenna-design for WP3A.

From a technological stand point there are various things to further explore, e.g. resist lift off-process for metal layers, electroless plating, and minimum electrode widths and separations. The geometry should also be improved in order to reduce the metallized area needed, as shown in Figure 16.

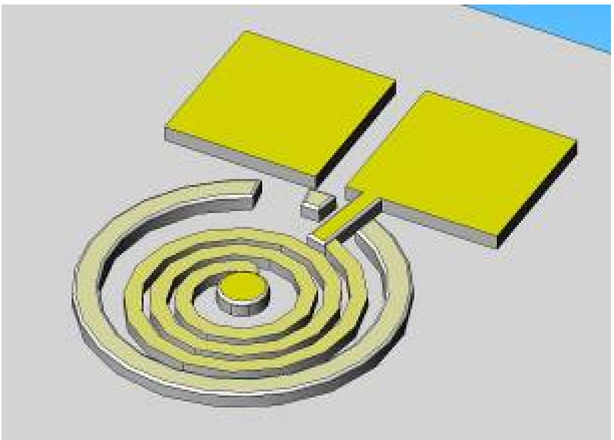

Figure 16. Improved geometry for reducing overall metallized area.

Section 6 - TIMETABLE

This work has been performed during January 2005 and June 2004.

Section 7 - RESOURCES DEPLOYED

Approximately 4 man months has been deployed. David Bergman, Mikael Dudas, Mikael Jonsson, Mikael Olsson, and Simon Uhrberg have contributed to this work.