Assessment of ORDYL SY 355 dry film for RF MEMS 0-level packaging

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***Abstract* — RF MEMS must be protected by a suitable package. A simple and cheap solution is to use quartz caps bonded by a polymer. This work reports on the use of ORDYL SY 355, a photosensitive dry film. The caps fabrication and bonding process were developed and tests were performed to define performance. Shear tests demonstrated good adhesion to the substrate and water immersion the sealing capability. Caps bonded on CPW and microstrip lines demonstrated negligible or very low impact on the RF performance in the 0-30GHz tested frequency band. Preliminary tests on capped RF MEMS switches indicated good performance of both capacitive and ohmic contact switches. Yield of ohmic switches resulted more sensitive to process conditions requiring a more accurate control.**

I. INTRODUCTION

The realization of a protective package is a must for the reliable operation of RF MEMS, avoiding the dangerous effects of dust and contaminants, as well as providing mechanical protection to the sensitive moving parts and a stable atmosphere to operate in. Many solutions have been proposed for both wafer-to-wafer and die-to-die capping. The use of intermediate adhesive polymers [1] to bond silicon or dielectric caps to the device wafer is a relatively simple and cheap solution that allows for low temperature processing. The main drawback is that the seal is not fully hermetic, as contaminants can diffuse trough the polymer. Photosensitive dry films can be applied by hot roll lamination [2] thus reducing the problem of uniform surface coverage presented by spinned liquid polymers, particularly in the case of substrates with cavities and holes. PerMX 3000, an epoxy based photosensitive dry film, was successfully used by FBK [3] for both cap to die and wafer to wafer capping but it is no more commercially available and other dry films are under investigation. Similar epoxy based materials, like TMMF, are commercially available but in order to obtain a good sealing over not flat surfaces high bonding force is required. For this reason a softer material would be preferable.

The use of ORDYL SY 300 [4], an acrylic based permanent dry film photoresist, was reported for microfluidic and MEMS wafer-to-wafer bonding [5]. Even if no evidence of its use for RF-MEMS was found in the literature, it was taken into consideration because it can be bonded at relatively low pressures thus requiring a reasonable low bonding force on 6 inch wafers, and it is fully polymerized at only 150°C. Moreover it is quite cheaper than other available dry films.

55 µm thick (ORDYL SY 355) sealing rings of different dimensions were realized on quartz substrates and diced caps were bonded on flat surfaces to test adhesion, on CPW lines to test insertion loss and water leak resistance and finally on RF MEMS switches to test the impact of this capping on their functionality.

II. EXPERIMENTAL AND RESULTS

To optimize the cap fabrication process a dedicated lithography mask was designed with different caps dimensions having sealing rings of internal width ranging from 480x480 µm to 3900x3500 µm and line width of 50, 100 and 150 µm.

Many tests were performed with a RLM 419p Dry Resist Laminator to define the process parameters. 55 µm thick dry film was laminated over 150 mm, 600 µm thick quartz wafers after the substrates were cleaned and exposed to oxygen plasma to improve adhesion. Good results were obtained heating the lamination rollers at 105°C, using a lamination speed of 1 m/min and an applied force of 8 kg.

To define the structures the wafers were exposed in a Karl Süss MA6 mask aligner using different energies. After removal of the protective film, the resist was baked at 85°C to crosslink the exposed polymer, developed in a proprietary mixture of solvents containing xylenes, 2-butoxyethyl acetate, and ethylenbenzene and then rinsed in isopropyl alcohol. The resolution of ORDYL SY 355 is not high but adequate for the purpose. According to the datasheet [4] employing 55 µm thick resist laminated over oxidized silicon wafers it is possible to obtain 60 µm lines spaced almost 50 µm at an exposure energy of 100 mJ/cm^2 or 40 µm lines spaced at least 70 µm at 200 mJ/cm^2 .

On quartz wafers using 600 mJ/cm^2 exposure energy the obtained lines are close to the nominal width (for either 50 and 150 µm width) but when the separation between sealing and scribing lines is less than 50 microns, a few microns thick resist residues are found between them, due to light interference phenomena. Reducing the exposure energy reduces the amount of residues but the lines became thinner. At 250 mJ/cm^2 no residues remain in between but the resist has a sloped profile with the resist top more than 10 microns narrower than the nominal value.

Fig. 1 Fractured sealing ring residues on Au substrate after removing the cap during the shear test.

This problem can be solved at design level, increasing the minimum distance between the lines and thus avoiding residues formation. For sealing ring design this is not a critical aspect because the quartz caps are diced by using a diamond blade 200 µm wide and it is possible to reduce the width of scribing lines in order to have enough free space in between. Thickness uniformity on wafer was quite good with standard deviation better than 2% and sealing rings surface very flat. The caps used for single dies capping were singulated by dicing the wafers with a diamond blade. A 6 minute bake at 85°C was required to increase polymer adhesion, avoiding detaching of small parts during dicing.

For a preliminary assessment of the optimum bonding process conditions single caps were bonded on flat surfaces, either gold or silicon oxide, by a Semi auto TRESKY T3000 FC3 die bonder. Different combinations of temperature, applied force and time were experimented and shear tests were performed to measure the bonding strength. The obtained shear stress ranged from 10 to 25 MPa, lower than PerMX, but adequate for the requirements. The strength obtained on oxidized substrates are only slightly higher than the one on gold substrate, probably because the fractures occurred mainly inside the polymer with residues remaining on both caps and substrates indicating a good adhesion of polymer on both surfaces. The ORDYL SY 355 behaviour during shear test appeared more elastic than in case of PerMX. The polymer was elastically compressed as a spring, the fracture was brittle and the caps jumped away quite far while in the case of PerMX the caps were simply moved laterally by the test blade.

Fig 1 reports a picture of a fractured sealing ring after the cap was removed by the shear test.

To test the sealing capability, caps were bonded above CPW lines consisting of 3 µm thick Au lines and soaked in water for 1 hour. On some samples bonded with a pressure of 1.4 MPa small water bubbles penetrated inside the cavity and optical inspection showed the presence of micro channels along a few of the Au line edges. Increasing the bonding pressure eliminated the problem. On samples bonded at 2.9 MPa ORDYL SY 355 filled completely all the cavities between the Au central line and the lateral ground and no water leaked inside. To obtain the same results with PerMX bonded caps it was necessary to apply a pressure of 20 MPa.

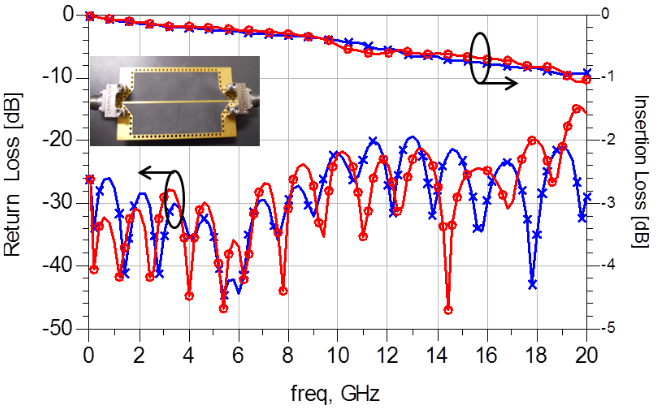

Fig. 2 Comparison between the RF performance of a 5 cm long microstrip (crossed-blue curve) and of an identical microstrip line covered by an 4 cm long ORDYL SY 355 layer (circled-red curve).

Considering the preliminary test results the following procedure was defined and used to bond the caps over MEMS devices: the MEMS die is loaded on the bonder chuck having a temperature of 40 °C, the cap is picked by a vacuum tip, aligned to the RF MEMS and then pushed on the device in order to obtain a contact pressure of about 3 MPa. The chuck temperature is then quickly increased and maintained at 100°C for 30 min. For complete polymerization of the resist the temperature is further increased at 150°C and kept for 30 min. After cooling at 40 °C the applied force is removed.

In order to evaluate the loss introduced by the dry resist and the quartz cap, two RF test structures were measured. The first one is a 50 Ohm microstrip line, (5cm long) covered with 4 cm long ORDYL SY 355 layer and connected to 0-27GHz SMA end launch connectors. The comparison between the RF performance of the microstrip line with and without ORDYL SY 355 is presented in Fig. 2. The almost negligible impact caused by the presence of the polymer indicates good RF properties (low tangent delta).

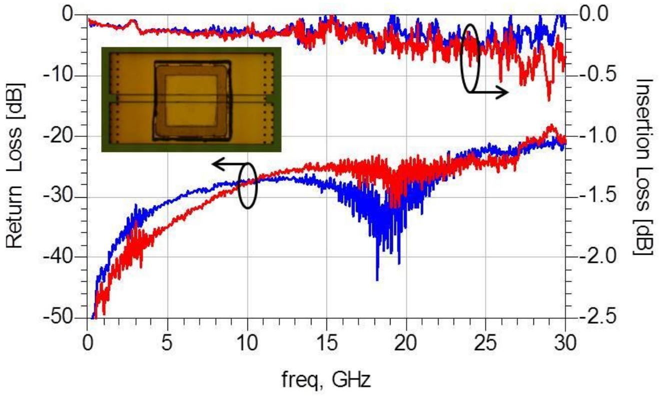

Fig. 3 Comparison of the RF performance of 2 mm long 50 Ohm CPW line with (red curve) and without (blue curve) a Quartz Cap, sealed by ORDYL SY 355.

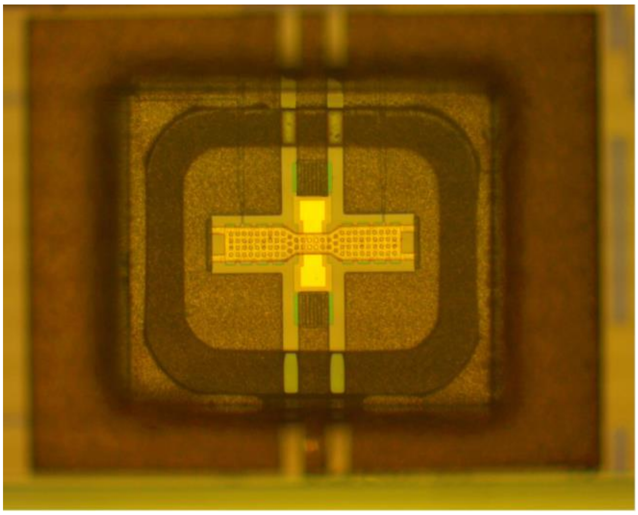

Fig. 4 Picture of a quartz cap bonded over a capacitive shunt switch with a 100 µm wide ORDYL SY 355 sealing ring.

The second test structure is a 2 mm long 50 Ohm coplanar line (G/W/G=65/110/65 µm realized on HR Silicon substrate) with a 800x800 µm quartz cap bonded on top by using a 150 µm wide sealing ring. Fig. 3 shows the comparison of the RF performance of the naked line and the capped line in the 0-30 GHz frequency range. Note that up to 25 GHz the performance is the same, indicating that the cap has almost no influence on the RF characteristics.

The quartz caps were then bonded on RF MEMS switches [6] to test the impact of capping on their functionality. Fig 4 shows a picture of a quartz cap having a sealing ring 100 µm wide with 800 x 600 µm internal dimensions bonded over a clamped-clamped shunt switch. The change of capacitance, measured at a frequency of 1 MHz, versus the applied bias voltage both before and after capping is reported in the CV curve of fig 5.

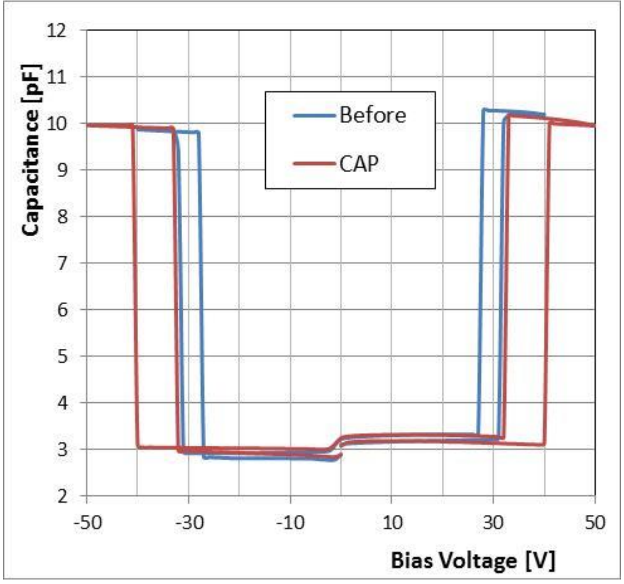

Fig. 5 CV measurements on the switch of fig 4 before (blue curve) and after (red curve) capping.

The on/off capacitances was not significantly modified by the capping process while, as already experimented using PerMX 3000, the actuation voltage increased from 32 to 41 V presumably due to the tensile stress induced in the switch.

To check the influence of the capping process on ohmic contacts, quartz cap having a sealing ring 150 µm wide with 1000 x 1000 µm internal dimensions were bonded over SP4T switches consisting of 4 cantilever ohmic switches as shown in Fig. 6. The actuation voltage and the DC line resistance of each of the four lines composing the devices were measured before and after capping. The line resistance included the switch contact resistance, the resistance of the metal lines as well as the connecting cables and measuring tips contact resistance.

Good devices were produced having a total line resistance close to 3 Ω both before and after capping. As in the case of the same kind of cantilevers capped using PerMX the actuation voltage was reduced from about 80V to about 70V. Optical profilometer measurements showed that the thermal treatment of the capping process reduced the upward bending of the cantilever beams, presumably due to modification of internal stress gradient, and as a result the actuation voltage decreased.

Fig. 7 shows the comparison between the RF performance of the MEMS SP4T switches with and without cap in the 0-10 GHz frequency band. The Quartz cap does not modify the switch insertion loss whereas it introduces a slight variation of its impedance, that can however be taken into account in simulation.

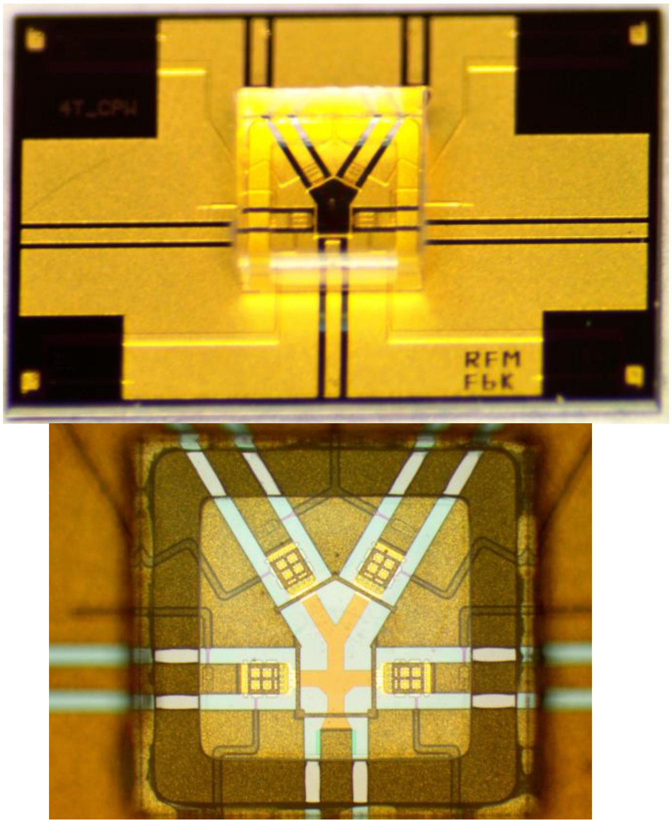

Fig. 6 Quartz cap bonded over an ohmic cantilever SP4T switch by using a 55 µm thick and 150 µm wide sealing ring.

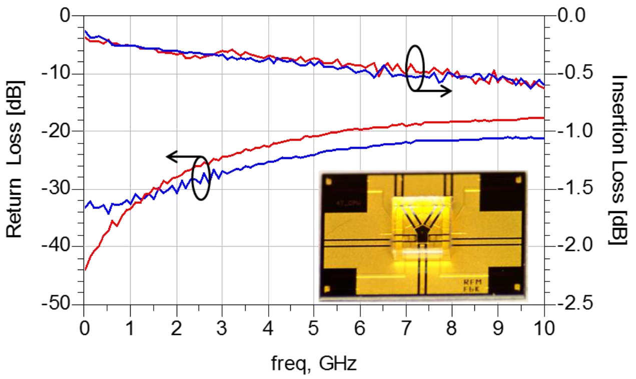

Fig. 7 Comparison between the RF performance of the SP4T switch of Fig.6 with (blue curve) and without (red curve) cap.

Ohmic devices resulted more sensitive to process conditions with respect to capacitive ones. On some switches, the on-state resistance increased after capping. By repeating the resistance measurements a few times (i.e. actuating the switches and forcing a small measuring current of 0.1 mA) the line resistance returned low in most cases. A possible explanation is contamination of contact surfaces during the capping process although this may not be the only cause. By using an appropriate procedure in order to minimize solvents residues and controlling the atmosphere in the bonding area, by blowing dry nitrogen, the yield increased. Long term reliability tests still have to be performed.

III. CONCLUSIONS

The development of a RF-MEMS capping process by using quartz caps and intermediate ORDYL SY 355 dry film photoresist as bonding and sealing ring is under development at FBK. This kind of cap is not fully hermetic but protects sensitive RF MEMS structures against dust and contamination and provides mechanical protection during wafer dicing and handling. After optimization of the dry film lamination, photolithography and cap to die bonding process, single caps were produced and bonded on test structures. Good adhesion of the bonded caps on both gold and silicon oxide substrates, waterproof sealing of signal lines and no additional insertion losses were demonstrated.

Preliminary results on capped RF MEMS devices indicated no loss of functionality but a shift of the actuation voltage, attributed to modifications of the switch internal stress. Electrostatic actuated, clamped-clamped capacitive contact switches showed no change in the on/off capacitance behaviour after capping. Ohmic contact switches having the same line resistance before and after capping were demonstrated as well. Ohmic switches resulted however more sensitive to process parameters, and on some devices the contact resistance increased after capping. Careful control of contaminants reduced the problem and increased the yield. The obtained results are promising and long term reliability test are planned as well as the transfer of the process to wafer scale by wafer to wafer bonding

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