Low-Temperature Photosesitive Film-Type Permx Polymer Zero-Level Packaging Technique for RF Applications

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Abstract. This paper presents a film type PerMX polymer-based low temperature zero-level packaging technique for RF devices. PerMX polymer capping technique was developed in two different types that are PerMX ring and PerMX membrane, SU8 ring and PerMX membrane. The height of the implemented cap is 100 μm having 50 μm thick sealing ring and 50 μm thick membrane and the implemented dimensions are 1.4×1.1 mm^2, 2.1×2.1 mm2 and 5.1×5.1 mm^2. The electrical characterization of microstrip line on PerMX is also presented. Also, the effect of the PerMX package on coplanar was found to be negligible insertion loss change of the packaged transmission line while its return loss is better than 20 dB at the measured frequency range.

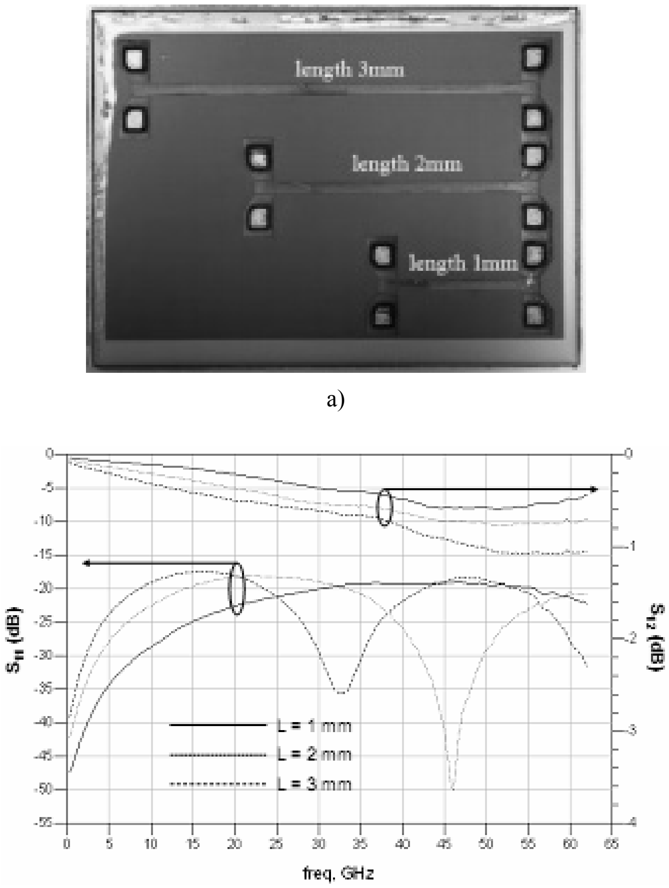
Index Terms: Packaging, Polymer, PerMX, RF.

1. Introduction

MEMS packaging is considered as an essential technology because MEMS contains movable fragile parts such as membrane or spring. One big approach for wafer-scale zero-level package is an adhesive-bonding of a cover wafer that contains cavities on its surface over a wafer containing active devices. As a capping material, pyrex glass and silicon have been mainly chosen because of their manufacturability [1, 2]. For RF devices packaging, a relatively high cavity should be considered to minimize the effect of packaging material to the packaged devices. Hence, additional processes like glass wet-etching and deep Si etching are needed.

Polymer cap packaging technique is being attractive due to its small size capability, enhanced manufacturability compared with the conventional packaging techniques. Furthermore, it has negligible effect on the package RF devices owing to its low dielectric constant. SU8 [3] or BCB [4] polymers have been implemented as a packaging cap. In general, the polymer capping has been realized by sacrificial etching [3] or polymer cap transfer technique [5]. We reported BCB cap transfer packaging technique that uses BCB caps bonding at 250 °C. It could be a significant problem for some RF MEMS devices.

In this paper, low-temperature packaging technique based on the film type PerMX polymer is presented. It is first noted that micropstrip line on PerMX has insertion loss of 0.1 dB/mm at 10 GHz and return loss of less than 15 dB up to 70 GHz as shown in Fig. 1. Also, the influence of the PerMX cap on the packaged device will be presented.



a)

b)

Fig. 1. Microstrip line on PerMX (a) and measured S-parameters (b).

2. PerMX Packaging

The basic PerMX packaging process is shown in Fig. 2; (a) PerMX sealing ring patterning (b) Lamination PerMX film on the patterned sealing ring (c) Exposure and PEB (Post-Expose Bake) (d) Development and hard bake. It should be noted that at step (a), the PerMX ring can be replaced by other polymers such as

SU8 or BCB that are often used for microwave devices and packaging. The thickness of PerMx at step (a) and (b) is 50 μm. The process condition of PerMX is presented in Table 1. PerMX sheet is first laminated on a substrate at 65°C and then it is soft-baked at 95°C for 4 minutes. The PerMX is patterned by a conventional photolithography process.

Exposure energy was 400 mJ and it is developed using PGMEA after 10 minutes PEB. Finally, it is hard-baked for 30 minutes. The maximum process temperature is 150°C.

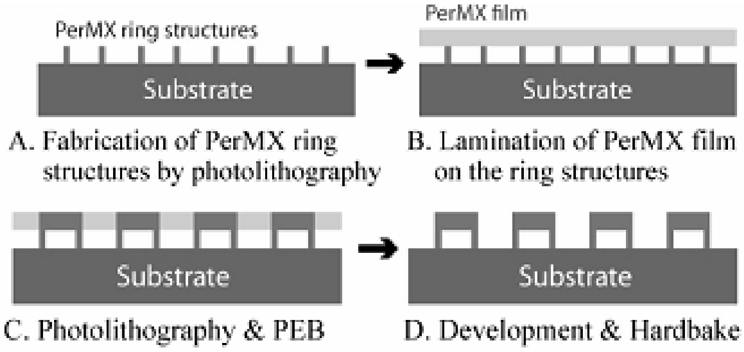
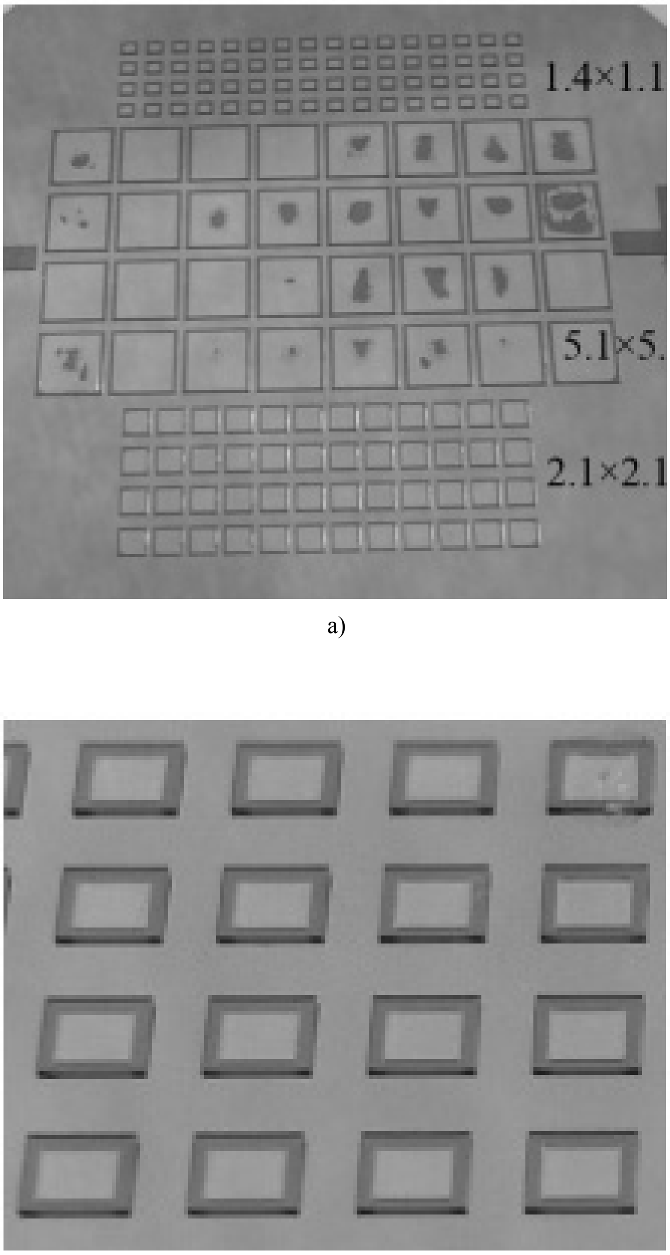


Fig. 2. PerMX packaging process.

Table 1. PerMX 3050 process conditions

Step	Conditions
Lamination	Hot roll @ 65°C
Soft bake	4 minutes @ 95°C
Expose	400 mJ
PEB	10 minutes @ 60°C
Develop	PGMEA, 5 minutes
Hard bake	30 minutes @ 150°C

Fig. 3 shows the result of wafer-level PerMX packaging using 3 inches Si substrate. The sizes of test packaging caps are 1.4 × 1.1 mm^2, 2.1×2.1 mm^2, and 5.1×5.1 mm^2. As seen in Fig. 3, some of the largest ones were not successfully implementedbecause of the high aspect ratio of the membrane. Themeasured profiles of the PerMX caps are shown in Fig. 4. Theheight of the caps was 100 μm because both sealing ring and membrane were 50 μm. The maximum deflection of the PerMX cap was approximately 6.2 μm for 5.1×5.1 mm^2 at itscenter due to the residual stress effect. It should be noted that the deflection should be considered at the design step becauseit could affect the performance of the packaged device. It willbe mentioned later at discussion section.



a)

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Fig. 3. PerMX packaging results; (a) whole wafer (b) the smallest size PerMX caps.

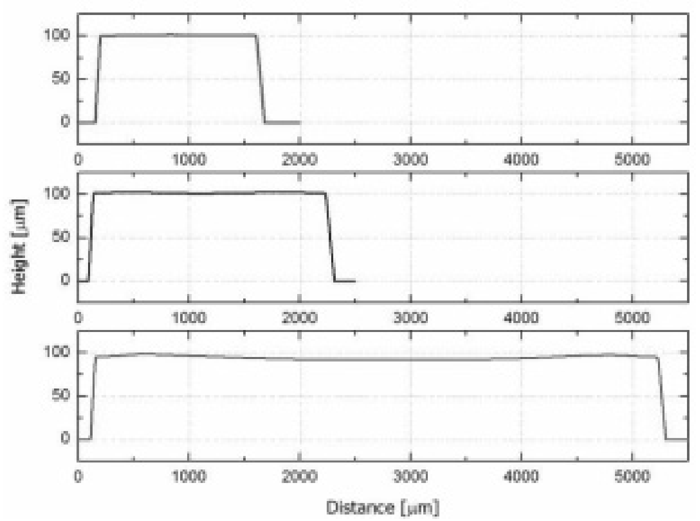


Fig. 4. Measured PerMX cap profiles.

3. RF Measurement and Discussion

To estimate the PerMX packaging effect on transmission line, a 50 Ω coplanar on HRS (High Resistivity Silicon) was measured before and after packaging. Fig. 5 shows the PerMX packaged test coplanar line. The insertion loss change was negligible up to 67 GHz while the return loss is better than 20 dB at the whole range as shown in Fig. 6. It is noted that the proposed PerMX packaging has a competent RF performance with our earlier BCB film one although it has slightly poor material properties as mentioned earlier. It resulted from its bigger cavity depth that is one of the critical parameter of packaging influence that will be investigated later.

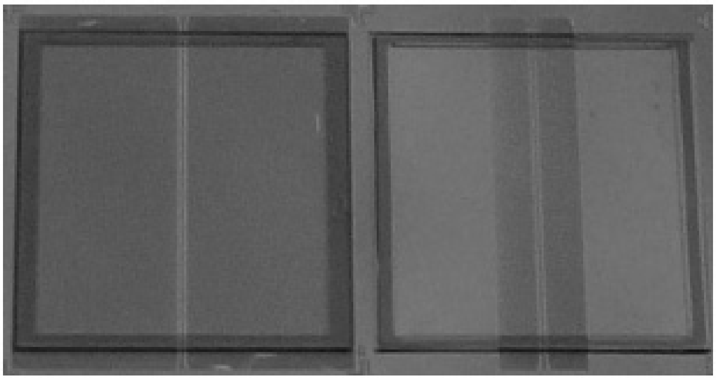
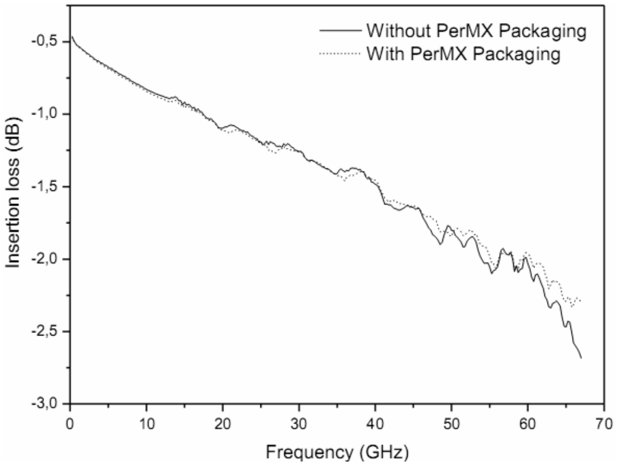
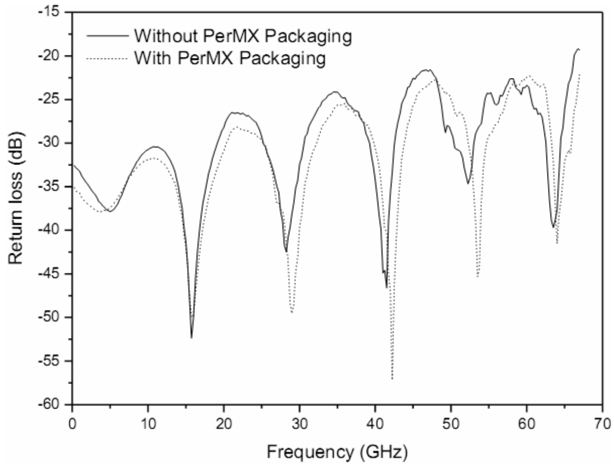


Fig. 5. PerMX polymer capped CPW.



a) Insertion loss S12



b) Return loss S22

Fig. 6. Measured S-parameter before and after PerMX packaging.

From here, the influence of the packaging cap materials will be investigated in terms of characteristic impedance Z_c and effective dielectric constant ε_{reff} of the packaged CPW. For comparison, Si capping and PerMX capping were chosen for a 50 ohm coplanar line packaging. The dielectric constants are 12 for Si and 3 for PerMX respectively. It is assumed that the I/O interfaces at bonding area are suitably designed to be 50 ohm. The packaging cap thicknesses are determined to be 100 µm and 50 µm for Si and PerMX due to technological constraints. Also, analytical expression from conformal mapping method that assumes a quasi-TEM mode of propagation along the line will be applied to find Z_c and ε_{reff} of the packaged CPW. Additionally, the partial capacitance technique in which the line capacitance of CPW is presented as a sum of partial capacitances is applied [6]. Fig. 7 shows the characteristic impedance and effective dielectric constant of unpackaged and packaged coplanar line. The unpackaged coplanar has characteristic impedance of 50.3 Ω and effective dielectric constant of 6.4537. Silicon capping makes the uncapped CPW impedance 40.5 Ω at 10 μm cavity depth and 46.4 Ω at 50 μm one, while PerMX capping has 48.7 Ω and 50.3 Ω at each depth. It is noted that silicon cap must have high cavity depth to minimize its influence on the packaged device due to its relatively high dielectric constant. It needs more than 50 μm cavity depth to reach the impedance of the unpackaged coplanar line. Also, it can be said that Si cap and PerMX cap result in impedance change per cavity depth of 0.1475 Ω/μm and 0.04 Ω/μm respectively. As seen in Fig. 8, the effective dielectric constant of Si capped CPW is higher than that of PerMX capped one; Si packaged CPW has 9.9603 at 10 μm cavity height and 7.5914 at 50 μm one and PerMX packaging one has 6.8844 and 6.4537 at the same cavity heights.

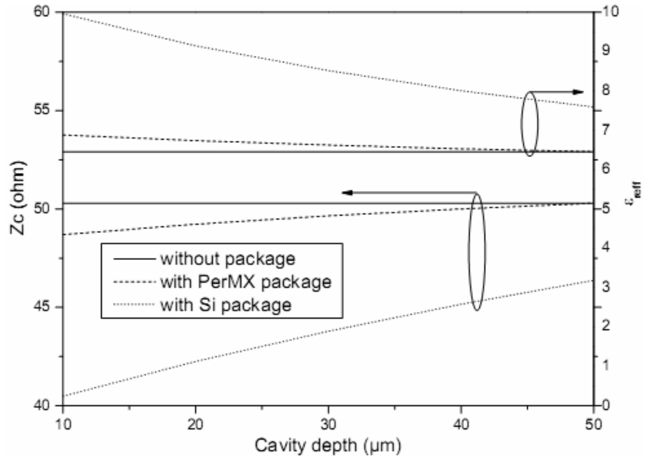


Fig. 7. Characteristic impedance and effective dielectric constant of unpackaged and packaged coplanar line.

4. Conclusion

A low-temperature PerMX film-type polymer zero-level packaging technique has been proposed. The electrical parameters of PerMX were extracted from the measured S-parameter of microstrip line. PerMX showed slightly higher loss tangent than BCB, while the effective dielectric constant of these two materials had almost same value of 2.4. Polymer capping is attracting an increasing interest because its negligible package influence on the packaged devices. For this purpose, the polymer packaging caps are manufactured by the release of SU8 cap and wafer-level transfer of BCB cap. The technological difficulties of the methods were overcome by laminating PerMX film on the packaged device at low temperature. Therefore, the film type PerMX can provide more efficient approach for polymer thin-film packaging. The developed package was applied to CPW line on a Si substrate to evaluate its influence. The measured results of PerMX film packaged CPW lines have shown that the insertion loss change was negligible up to 67 GHz while the return loss is better than 20 dB at the whole range. In addition, analytical calculation based on partial capacitance technique was presented to theoretically show the effect of the packaging material to the packaged coplanar line. It is clearly proven that the polymer cap has better performance than the conventional ones thanks to its low dielectric constant. Finally, it can be said that the proposed PerMX polymer film packaging technique can be an excellent candidate for RF devices.

Acknowledgement. The authors wish to acknowledge the technical staffs of IEMN. This work was supported by European funding FEDER (Fonds Europeen de DEveloppement Regional).

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