Temporary 0-level MEMS packaging using a heat decomposable sealing ring

L. Bogaerts*a, A. Phommahaxay*a, C. Gerets*a, P. Jaenen*a, R. Van Hoofo, S. Severia, J. De Costera, R. Beernaertb, S. Rudrab, P. Soussan*a and A. Witvrouwa

aimec, Kapeldreef 105, 3001 Leuven, Belgium
bUGent Cmst, Technologypark building 914, 9052 Zwijnaarde, Belgium

Abstract

This paper reports on a novel temporary 0-level packaging process for MEMS (Micro Electro Mechanical Systems), in particular MEMS for optical applications. In this process protective caps, with a heat decomposable and photo-patternable polymer sealing ring, are placed by flip-chip on the MEMS wafer. The resulting temporary packages are gross leak tight, fulfil the MIL spec for shear testing and respect the thermal budget of Al-coated SiGe micro-mirrors. After debonding the cap, the SiGe mirrors are unharmed.

1. Introduction

Freestanding MEM (Micro Electro Mechanical) devices are very fragile, making it impossible to use standard packaging techniques. Steps such as wafer dicing, die handling, assembly and wire bonding can seriously damage the device functionality if the MEM devices are not properly protected at the wafer-level with a chip or thin film cap during the dicing and assembly process. Normally it is possible to leave this protective package on during higher level packaging steps. For optical applications, it might however be necessary to remove the wafer-level cap to allow the interaction with light. These applications often also have thermal budget restrictions. Imec already reported on the temporary packaging of SiGe micro-mirrors using SU-8 spacers and glass caps laminated with UV-sensitive tape [1]. Here we show an alternative approach for which the MEMS wafer does not need any extra spacer processing.

* Lieve Bogaerts. Tel.: +32 16 288 787; fax: +32 16 281 097.
E-mail address: bogaertl@imec.be

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2. Technology and processing

This paragraph discusses the fabrication, bonding and removal of the protective temporary caps in detail. The complete process flow is shown in Fig. 1. First, the micro-mirrors are released at the wafer level. Next, a temporary cap with a patterned heat decomposable polymer spacer ring is bonded to the device wafer, enabling dicing of the wafer and assembly of the die. After wire bonding, the cap can be removed by applying heat. Next we will discuss the temporary bonding material in detail.

![Fig. 1. Process flow: release micro-mirrors, temporary capping, dicing and assembly to PCB, decapping](image)

2.1. Unity 2203P

Since we focus on the development of a temporary packaging process for Al-coated SiGe-based micro-mirrors and diffractive gratings, the temporary glue has to fulfil some specifications. Besides a minimum thickness of 10μm to avoid contact with the MEM structures, the glue should be easy removable without residues or without damaging the fragile structures. Processing and de-capping has to be done at a temperature lower than 200ºC. Indeed, low processing temperatures are a prerequisite in order to avoid degradation of the reflectivity of the Al coating on the mirrors. As a dicing step is implemented in the process flow, the glue also has to be waterproof. In this work a heat decomposable and photo-patternable bond material, namely Unity 2203P from Promerus [2], has been used as temporary bonding material. First the spin curve (as shown in Fig. 2), exposure and baking conditions had to been defined and optimized. A stable film thickness of 11μm can be obtained with a spinspeed of 1000 rpm for 30 sec. The development bake was found to be a very critical process step determining the ring dimensions. For example, Fig. 3 demonstrates the very different Unity 2203P ring profiles for 2 different development bake temperatures.

![Fig. 2. Spin curve: thickness vs. spinspeed](image)  ![Fig. 3. Profile for development-bake temp.](image)  ![Fig. 4 Unity 2203P spacer ring](image)

*Fig. 2. Spin curve: thickness vs. spinspeed  Fig. 3. Profile for development-bake temp.  Fig. 4 Unity 2203P spacer ring*
Unity 2203P residues can be removed by an O₂-plasma descum step. Fig. 4 is a picture of the final Unity 2203P spacer ring. For this work, a ring width of 430μm was used (see paragraph 2.2). This leads to a total contact area of the Unity 2203P of 16.24mm² for 1 cap. The caps themselves are diced to the dimensions of 11.5mm x 8.6mm. The Unity material has also been characterized by TGA. This analysis justified the use of 120°C as bonding temperature and 200°C as debonding temperature.

### 2.2. Die to Wafer (D2W) assembly and reliability

D2W bonding is performed on a flip-chip bonder (FC150 from Suss Microtec). The optimized thermo-compression profile uses a temperature of 120°C for the cap and 80°C for the base wafer for 5min, while applying a force of 0.28MPa. The temperature of the base (MEMS) wafer can also be lowered to 40°C, but this reduces the shear strength. 40°C is the minimum temperature that can be used due to tool limitations. Applying a force of 2.8MPa results in samples with a higher shear force but these packages are not leak tight. This is probably due to the squeezing out of the Unity 2203P. Fig. 5 depicts the shear force vs. bonding temperature of the device for both 0.28MPa as 2.8MPa bonding pressure.

All shear tested samples have a shear force which is higher than the shear force required by the MIL-STD-833, method 2019.5 (>2.5kgf if the area > 4mm²). Besides shear testing, also gross leak tests have been performed to check reliability. Samples processed with different ring widths and the optimized bonding conditions show a yield of 86% after gross leak testing (Fig. 6). However, all assemblies (100%) survived dicing as required for the temporary packaging process flow. Gross leak testing, performed according MIL-STD-883D, method 1014.9, is a more severe testing method as compared to dicing.

Due to design constraints, the spacing for the Unity 2203P ring on the MEMS device wafer during assembly is limited to 440μm or less. The final ring width has been optimized with respect to these mask design constraints and reliability. Very narrow polymer rings result in assemblies that are not gross leak tight and with a very low shear strength. Wide rings will harm the released micro-mirrors. The chosen ring width is thus 430μm. Fig. 6 illustrates the shear strength vs. ring width using a 0.28MPa bonding pressure.
2.3. Decapping

After capping all released micro-mirrors with temporary caps according to the optimized bonding conditions, as described in paragraph 2.2 (see Fig. 7), the device wafers are diced and assembly of the dies to a PCB or first level package with wire bonding can take place. Finally, the caps have to be removed again to allow the device operation. The debonding of the cap is also done on the flip-chip tool, allowing a slow separation of the cap and MEMS wafer during heating. A debonding profile has been optimized on a FineTech flip chip bonder. The cap is held at 200°C, while the base wafer is kept at 40°C, resulting in a release of the cap after +/- 50sec. The Unity 2203P sealing rings thermally decompose, leaving little residues in the patterned area. The micro-mirrors were found to be unharmed (Fig. 8). The blue dots indicate the measurement points for the laser Doppler vibrometer.

![Fig. 7. Temporary capping](image1)
![Fig. 8. Unharmed mirrors after decapping](image2)
![Fig. 9. Tilt angle as a function of applied dc voltage](image3)

2.4. Optical measurements

In order to demonstrate the applicability of the process flow, optical measurements have been done on the device wafers before capping and after debonding. Fig. 9 shows the measured tilt angle as a function of the applied bias voltage (optical equivalent of C-V characteristic) as measured using a laser Doppler vibrometer. Two curves are shown for each mirror, measured before capping and after de-capping. Taking the inaccuracy of the laser Doppler vibrometer into account (±0.15mrad), as well as a small horizontal offset between the two sets of measurements (attributed to charging), no significant difference in the tilt angles is observed. This implies that the micro-mirrors are unharmed after the full temporary packaging process.

3. Conclusion

A temporary 0-level MEMS packaging process, using the photo-patternable and heat decomposable polymer Unity 2203P from Promerus, has been shown to successfully protect MEMS wafers for optical applications during dicing and assembly. The process has been demonstrated on wafers with freestanding Al-coated SiGe micro-mirrors. The micro-mirrors are still functional after removing the temporary cap. No extra processing on the fragile MEMS wafer is required.

References
