MEMS Mirror in Hermetic Package for Enhanced Performances

Marco Del Sarto
STMicroelectronics
Cornaredo, Italy
marco.delsarto@st.com

Luca Maggi
STMicroelectronics
Agrate, Italy
luca.maggi@st.com

Amedeo Maierna
STMicroelectronics
Cornaredo, Italy
amedeo.maierna@st.com

Mark Shaw
STMicroelectronics
Agrate, Italy
mark.shaw@st.com

Roberto Carminati
STMicroelectronics
Cornaredo, Italy
roberto.carminati@st.com

Gianluca Mendicino
STMicroelectronics
Cornaredo, Italy
gianluca.mendicino@st.com

Davide Rotta
CamGraPhIC srl
Pisa, Italy
Davide.Rotta@camgraphic-technology.com

Marco Chiesa
CamGraPhIC srl
Pisa, Italy
Marco.Chiesa@camgraphic-technology.com

Aina Serrano Rodrigo
CamGraPhIC srl
Pisa, Italy
Aina.Serrano.Rodrigo@camgraphic-technology.com

Antonella Bogoni
Sant'Anna School of Adavanced Studies
Pisa, Italy
antonella.bogoni@santannapisa.it

***Abstract*—Ceramic substrate coupled to metal lid has been selected for realizing hermetic package for MEMS mirror. The component passed the fine and gross leak tests and show good performance with improved Q-factor**

Keywords—MEMS mirror, hermetic package

I. Introduction (*Heading 1*)

New emerging applications in consumer electronics, Augmented Reality (AR), Virtual Reality (VR) and in automotive field for autonomous driving are asking for new optical components with enhanced features [1]. Laser Beam Scanning (LBS) using MEMS mirror is suitable for addressing these requirements. By the way there is the need to overcome the current performances, mainly limited by the fact that MEMS mirror is operating in open air environment. MEMS mirror enclosed in hermetic package could enhance their performance, especially the Q-factor and the voltage required for maximum angle of deflection

In the present paper the design of hermetic package and method of realization are described. The experimental results are shown and the enhancement in performances, especially about Q-factor are presented.

Package design and structure are presented in section II, the method of realization is explained in section III, section IV shows the characterization results of the new component, section V summarizes the conclusion.

II. Package Design and Structure

A. Package Design

It's well known [2] that an issue of spurious reflections occurs in every optical package. The known solution is to tilt the cap so that the spurious reflections are no more parallel to the light reflected by the mirror. the effect is schematically presented in Fig. 1 and Fig. 2

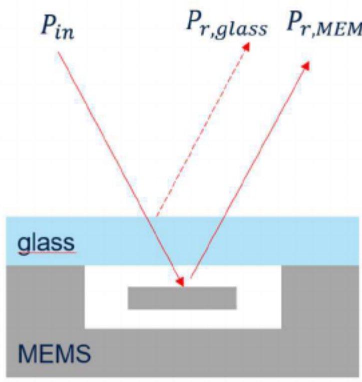

Fig. 1. Spurious image

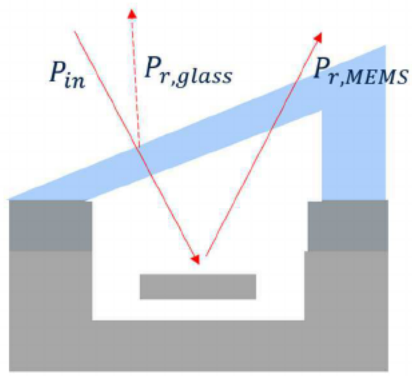

Fig. 2. Ghost image avoided by tilt cap

We simulated the effectiveness of this solution using a optical software [3]. Simulation results are presented in Fig. 3 where is clearly visible that the intensity of ghost image, created by spurious reflection, is negligible compared to light reflected by mirror.

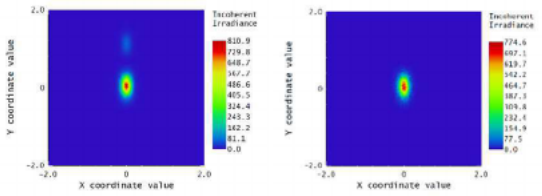

Fig. 3. Optical simulation of flat cap (on the left) and of tilted cap (on the right). The ghost image is clearly vsible on the left, while it completely disapperas on the right

For the investigation about the performance in hermetic package, two different mirrors have been selected- Both are activated by piezoelectric actuation [4], but they are characterized by different size, targeting possible different applications. The MEMS die 1 is 4 x 2.4 x 0.67 mm^3, with mirror diameter = 1.1 mm, the MEMS die 2 is 5.5 x 5 x 0.9 mm^3, with mirror diameter = 3 mm. Representation of the two dice are presented in Fig. 4 and Fig. 5.

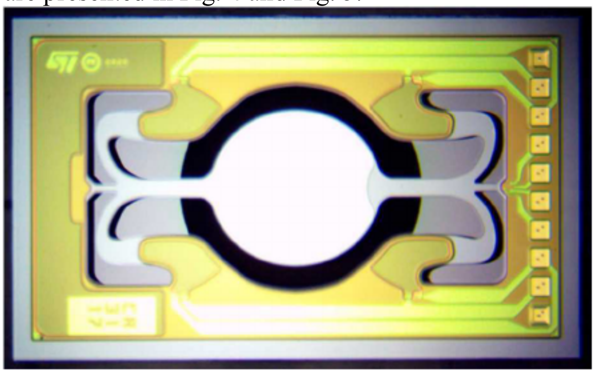

Fig. 4. MEMS mirror 1

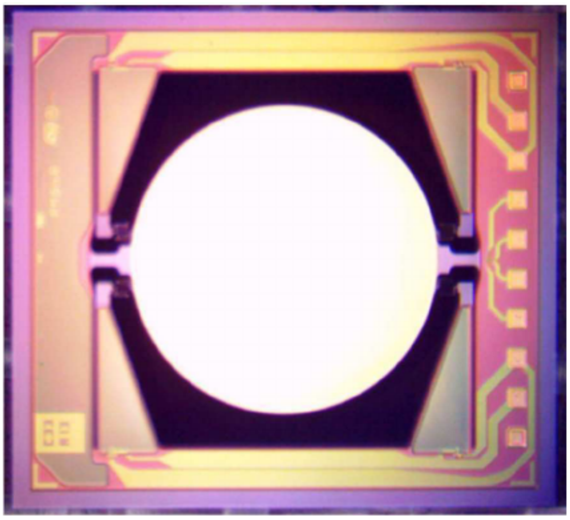

Fig. 5. MEMS mirror 2

A unique package, suitable for accommodating both the dice, has been developed.

B. *Package Structure*

Package is based on ceramic carrier- coupled to metal lid, suitable for soldering operations. Ceramic base is 2 layer substrate with size 8 x 7.24 x 0.5 mm^3. On the top surface of ceramic base, a solder ring is realized. The lid is made of kovar, plated with NiAu. The optical glass is sintered to the metallic case. Lid size is 7.30 x 6.58 x 3.10 (the highest side) mm^3. Soldering between lid and ceramic is performed using a ring shaped preform. The selected alloy is SAC305 (Sn 96.5% Ag 3% Cu 0.5%). For this alloy, liquidus and solid temperature are respectively 220 °C and 217 °C.

Complete package structure is presented in Fig. 6

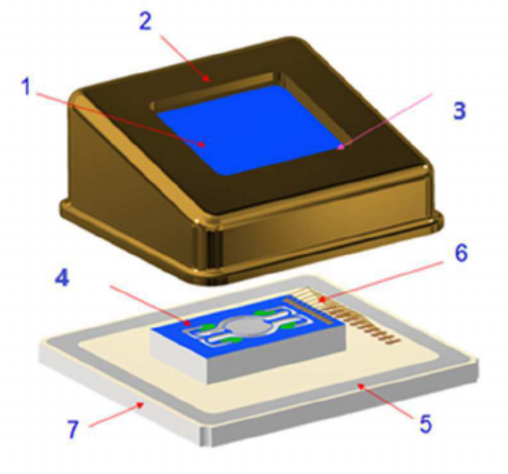

Fig. 6. Strucutre of the pacakge

TABLE I. PACKAGE ELEMENTS

lement ID	Description
1	Optical window
2	Metal lid
3	Material for sintering the window
4	Die
5	Solder preform
6	Wire bonding
7	Ceramic substrate

III. PACKAGING PROCESS

The dice have been attached to the ceramic substrate using a conductive epoxy resin which shows excellent stability up to 300 °C and is compatible with NASA outgassing limits [5]. Dedicated pick-up tools with a gimbal have been designed to avoid damaging the MEMS and improve the attachment parallelism. Particular care has been dedicated to avoiding the contamination of the metals by resin bleeding, where necessary the attached devices have been cleaned with Ar plasma. Both dice withstand a non-destructive shear test with a maximum applied force of 10 kgf performed according to MIL-STD-883-2 standards, Method 2019.10 [6].

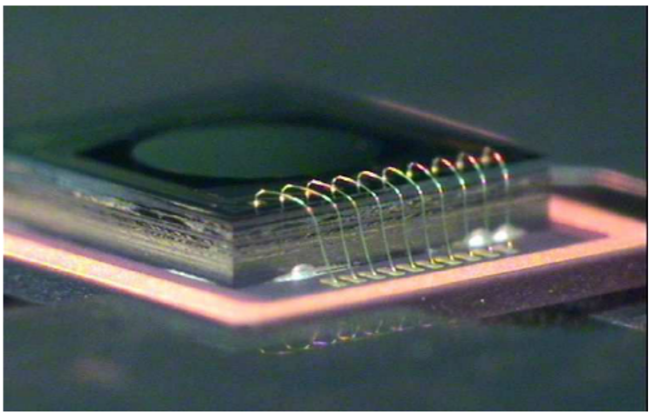

Figure 7 - Die attach and wire bonding of a MEMS mirror

The electrical connections are realized by automatic ball bonding using 20 µm gold wire. An automated routine to process batches of 9 packages has been developed. In order to ensure a safe clearance from the lid, the loop shape has been controlled with a height kept in the 200-250 µm range. Pull tests have been performed according to MIL-STD-883-2 standards, Method 2011.10 [7] on devices annealed with the same thermal profile used to solder the lid. The measured breaking force is 4.04 gf or higher, i.e. well above the threshold limit. Fig. 7 shows a MEMS mirror 2, attached and bonded to the ceramic substrate.

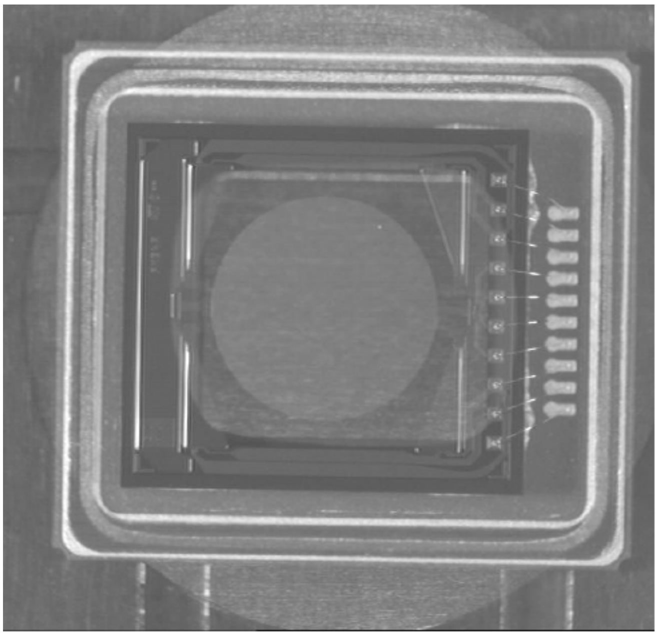

Figure 8 – Vision assisted alignment of the lid to the package + preform

The solder preform and the lid have been aligned to the package ring by vision-assisted pattern recognition (Fig. 8), using specially designed tools. The lid is then pressed on top of the preform (Fig. 9), with the package heated, to promote some tacking and avoid displacements of the lid before the soldering process.

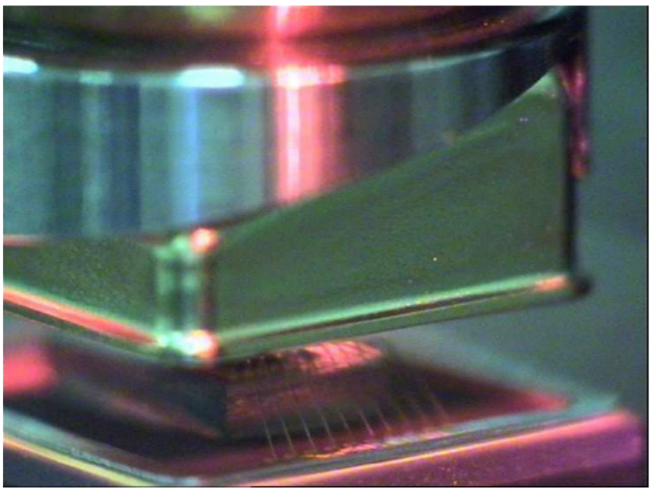

Figure 9 - Placement of the lid on top of the preform

The assemblies have been transferred to a reflow oven in N_2 atmosphere using a silicon wafer as a substrate. The temperature profile is shown in Fig. 10: First the temperature is raised to 150 °C and the system is vacuum pumped below 5 Pa for 30 minutes so that any volatile residue can outgas from the epoxy. After refilling the chamber with nitrogen, the temperature is raised to 200 °C and formic acid is fluxed into the chamber to reduce any oxides. The peak temperature of the reflow process is 250 °C. During the solidification phase it is important to avoid pressure changes in the chamber, which may cause displacements of the lid and adversely affect the solder joint. For this reason, the cooling is performed with a limited N_2 flux although this can result in a longer time above liquidus (TAL).

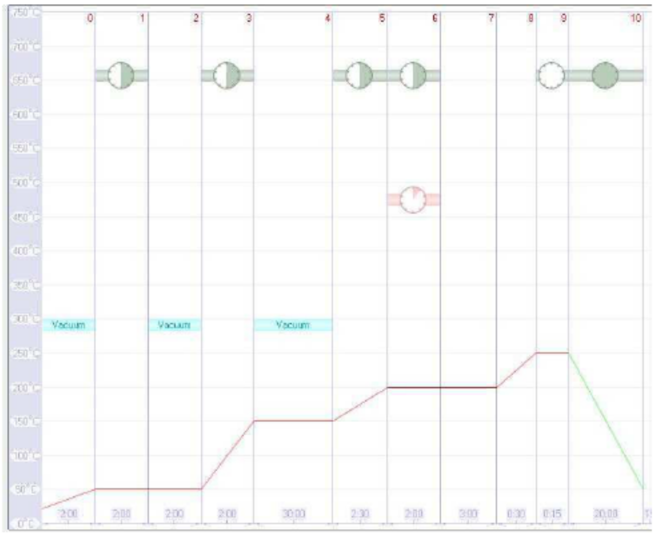

Figure 10 - Temperature profile of the solder reflow process

IV. CHARACTERIZATION

Parts passed the fine and gross leak test[8], exhibiting a leak rate < 1.5 E-8 atm cc/s. Then the package has been mounted on a board suitable for characterization, shown in Fig. 7.

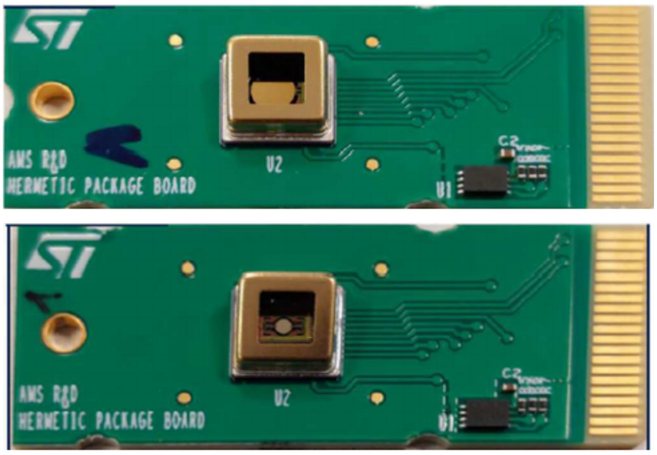

Fig. 7. Characterization board

A measurement station has been used for collecting mirror opening angle in different operating conditions. The setup is composed by a laser, a camera, a projection screen, a function generator and an oscilloscope, as reported in Figure 1. Laser light hits the mirror surface through a dedicated aperture in the projection screen. The projected line is acquired using a camera. By processing the collected picture, it is possible to extract the line length and to obtain the opening angle of the device.

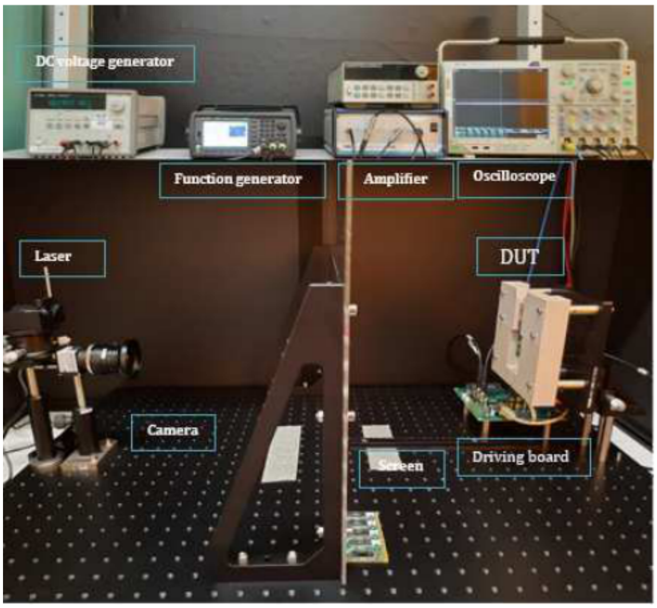

Figure 11 Measurement station picture

The performance of those devices has been evaluated by analyzing the frequency response function (FRF) of the functional mode. The FRF has been obtained by collecting the opening angle at different frequency values around its resonance and at fixed voltage. The measurements have been performed with an automated setup developed for this purpose. Hermetic and not hermetic packages have been compared for MEMS mirror. Effectiveness of the package solution with soldered tilted cap has been proved with two MEMS mirror layouts.

The performance enhancement has been tested on MEMS mirror 1. A performance comparison has been done considering two different samples: one in a hermetic package and one in open air. As visible in Fig. 8, the hermetic package can provide an improvement in quality factor and consequently decrease in the voltage required to achieve the maximum deflection angle. In particular, the device actuated in the hermetic package shows a performance improvement up to 40%.

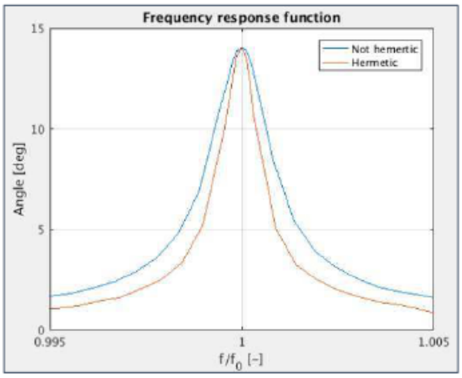

Fig. 8. Frequency response function comparison of MEMS mirror 1

Several mirror 1 samples have been tested. As visible from graph in Figure 9, still some the spread is visible in the performances,

The packages are sealed at 1 bar in nitrogen atmosphere at 250 °C, that means that at room temperature the *internal pressure is 0.5 – 0.6 bar. The root cause of the reported spread is linked to air ingression in sealed package, that follows an exponential decay law [9]. So, even if the threshold of leak test is passed (< 1.5 E-8 atm cc/s), there is air ingression in the package in few weeks. For guaranteeing that pressure inside the package remains low we have to select parts with leak rate around E-10 atm cc/s. this value assures that air ingression takes more than 10 years for filling the volume.

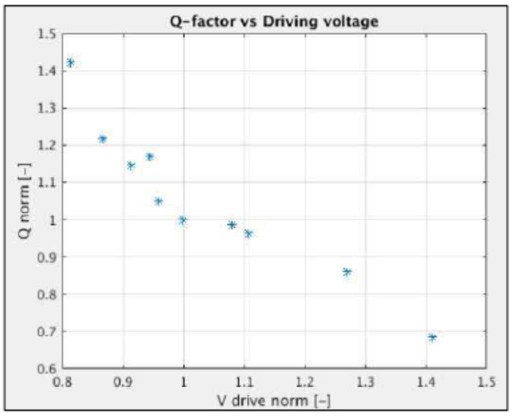

Fig. 9. Driving voltage versus quality factor for different Mirror 1 samples

Mirror design 2 has been tested in hermetic package with pressure level equivalent to the ambient one. The frequency response functions collected display a very similar trend, As visible from the graph in Fig. 9. Therefore, the performances in the hermetic and not hermetic one are comparable.

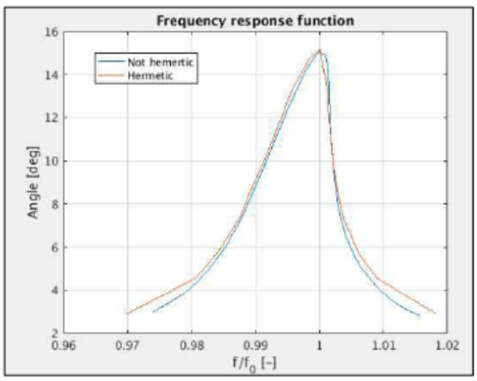

Fig. 10. Frequency response function comparison of MEMS mirror 2

This test confirms that the MEMS mirror 2 can be actuated in a protected environment also at pressure level comparable to the ambient one. In this condition, an effective barrier can be used to protect the device from environmental elements.

V. CONCLUSION

Package approach has been proved to be suitable for obtaining hermetic packaging of MEMS mirrors. Experimental results show an improvement with respect to the case of MEMS mirrors working at open air. The enhancement in performances is in line with expectations and pave the way to the use of LBS for new emerging applications.

VI. AKNOWLEDGMENT

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REFERENCES

[1] Urey H., Wine D. W., Osborn T. D.,"Optical performance requirements for MEMS-scanner based microdisplays",Proc. SPIE Vol.4178,pp 176-185 (2000)

[2] U. Hofmann, C. Eisermann, H.-J. Quenzer, J. Janes, C. Schroeder, O. Schwarzelbach, B. Jensen, L. Ratzmann, T. Giese, F. Senger, J. Hagge, M. Weiss, B. Wagner, and W. Benecke "MEMS scanning laser projection based on high-Q vacuum packaged 2D-resonators", Proc. SPIE 7930, MOEMS and Miniaturized Systems X, 79300R (14 February 2011)

[3] ZEMAX Optic Studio, www.zemax.com

[4] N. Boni, R. Carminati, G. Mendicino and M. Merli, "Quasi-static PZT actuated MEMS mirror with 4x3mm2 reflective area and high robustness," in Proc. SPIE 11697, MOEMS and Miniaturized Systems XX, 1169708, 2021.

[5] https://outgassing.nasa.gov/

[6] MIL-STD-883-2 method 2019.10 (2018).

[7] MIL-STD-883-2 method 2011.10 (2018).

[8] MIL-STD-883-1 method 1014.17 (2018).

[9] L. Fang and L. A. Menk, "On Gas Ingression of Hermetic Packages," in *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 9, no. 6, pp. 1038-1044, June 2019, doi: 10.1109/TCPMT.2019.2915164.