FEM Simulations to optimize a micro mirror array package for a wide operating temperature range

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ABSTRACT

The package of a Micro-Opto-Electro-Mechanical System (MOEMS), a Micro Mirror Array (MMA) based Spatial Light Modulator (SLM), has to stay stable over the full operation temperature range and throughout SLM lifetime in spite of the inevitably different coefficients of thermal expansion (CTE) of the various materials involved. Additionally, in our case the window not only protects the MMA from mechanical damage and corrosion but also serves an optical function as part of a beam combiner. Within the European Union funded Project REALHOLO we are therefore developing a packaging concept that accomplishes the desired optical functionality while meeting the challenge of precise alignment of the window relative to the micro mirrors in lateral direction, which is the motivating factor behind the FEM simulations presented here. The objective of this research is to stabilize the package when subjected to temperature changes by simulating its thermomechanical behaviour with Ansys Workbench™. A heatsink, a silicon crystal-based MEMS chip, and a window are glued together to form the package. Materials used for window and heatsink components, respectively, are chosen for a best possible CTE match. The significant parameters to be considered for package optimization are the misalignment between window and chip, the stress induced in the package, especially the glue, and the global deformation of the MMA surface. This paper discusses the challenges and possible solution based on a series of simulation findings.

Keywords: Finite Element Simulation, spatial light modulator, MEMS, micro mirror array, CTE, thermal expansion, Packaging, Ansys Workbench™

1. INTRODUCTION

Within the EU-funded project REALHOLO we are developing an innovative spatial light modulator (SLM) for holographic displays, see [2] and [3]. Micro-opto-electro-mechanical system (MOEMS) like this require sophisticated non-standard packaging schemes in order to fulfil various goals:

Obviously, the package has to provide the electrical interface, which in our case is quite challenging with its 144 digital high-speed LVDS (low voltage differential signal) input pairs with low error rate in close neighborhood to supply voltages and high-precision analog reference voltage(s) for thousands of DACs. As the micro mirrors are extremely sensitive to any mechanical contact, no cleaning would be possible. So the package needs to protect the MMA from dust as well as organic or corrosive contaminants and seal out moisture to avoid sticking. The optical interface requires a window with low reflection, low phase distortion, and high transparency in the visible range. It serves at the same time as a part of a beam combiner and therefore needs to be and stay precisely aligned to and in close proximity to MMA pixels while the global planarity of MMA needs to be very good and stable. Finally, chip cooling or temperature stabilization has to be provided and all packaging processes should be as close to room temperature as possible while they still can be done on regular industry packaging machines.

Together, these requirements are quite challenging to reach. Our basic concept, developed in earlier work, consists of a three layer stack comprising a heat slug, a silicon crystal-based MEMS (SLM) chip (21mm * 19.6mm), and a window (with beam combiner features) glued together plus a package substrate for electrical connection, see Figure 1. For the high accuracy window-to-chip attach, an UV curing epoxy of 5µm thickness is utilized, while a thermal curing epoxy is used to adhere the MEMS chip and substrate to the heat slug, as the non-transparent parts would not allow UV light for curing. There is an opening in the substrate to accommodate the MEMS chip. To attach the package to the system PCB we plan to use Z-ray connectors. Due to their high density and signal bandwidth they provide a wide design flexibility, from standard parts to full custom geometries.

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This is the ‘author’s version’ of this paper. See also:

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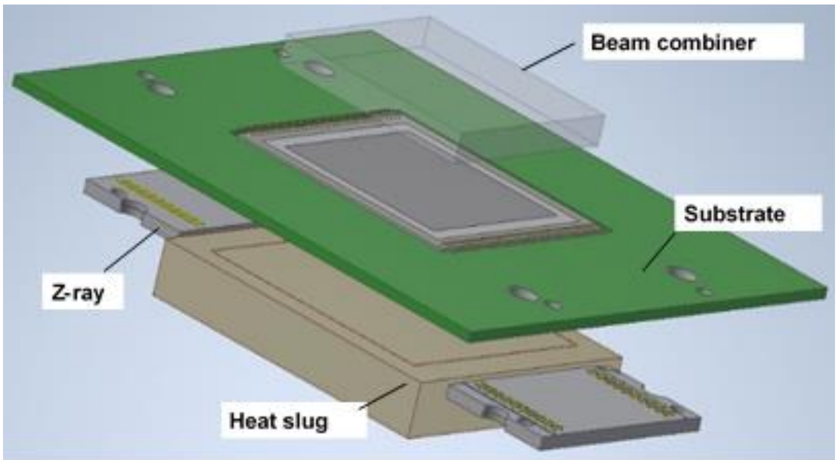

Figure 1: Package assembly consisting of beam combiner (transparent), MEMS (SLM) chip, heat slug, substrate and compression spring/Z-ray connectors

This paper focusses on the stability of the package over the full operation temperature range. This is very challenging due to the inevitably different coefficients of thermal expansion (CTE) of the various materials involved. This CTE mismatch between the components induces undesirable stresses and strains and thereby misalignment, which may adversely affect the performance and reliability of the SLM. In addition, the glues bonding the components together could creep under induced mechanical stress, potentially increasing the misalignment gradually. Understanding the performance of the package is therefore critical for successful device design, see [1].

The complicated package design and different material properties as well as the loading conditions made it almost impossible to study the mechanical behavior of MEMS package analytically. Therefore, FEM simulations are done to find a package concept that is as stable as possible over the full operating temperature range and SLM lifetime.

For a reliable and stable SLM performance, the project partners anticipate that the packaging needs to fulfil the specifications in Table 1.

Table 1: key SLM specifications

parameter	value
Placement accuracy of beam combiner during whole lifetime	≤ 0.3 µm
Global flatness change over operating temperature range	45 nm
Operating temperature range	-20 – 85°C
Gap height (MEMS surface to beam combiner window)	5µm – 10µm

For the FEM the SLM chip is modelled simply as single crystal silicon, as the MEMS is negligible in thickness and density. The material used for the beam combiner, which needs to be transparent, is Borofloat glass as it has the best CTE match to silicon that could be found. The heat slug is intended to be mechanically as stiff as possible and comes from the group of NiFe-alloys, which are optimized for low expansion. The so-called 'Alloy 42' provides the best CTE match to silicon/Borofloat glass. Low creep and outgassing are the most crucial requirements for the selection of glues. The material properties of all the package components used for simulations is shown in Table 2.

For a free expansion over ΔT of 63K (stress-free assembly at room temperature to maximum operating temperature), the beam combiner exhibits a mismatch of 270 nm with regard to silicon and the heat slug one of 1.4µm. For the beam combiner this eats up almost all of the misalignment spec, leaving too little for inevitable placement errors in the assembly process. The larger mismatch for the heat slug can cause the system to bend. In both cases it would also result in high shear stress levels within the adhesive. This could potentially lead to creep in the glue which would over time increase the misalignment further. Therefore, it is quite challenging to ensure precise alignment between these components, and we were looking for a package with low mismatch and stress.

Table 2: the mechanical material properties of the components involved in MEMS packaging

Components	Material	E-Modulus [GPa]	Poisson ratio	CTE (10-6/ K)
Beam combiner	Borofloat	65	0.2	3.2
Mems die	Si100	135	-	2.6
Heat sink	Alloy 42	145	0.25	4.7
UV curing epoxy	Master bond (UV22DC80-1)	2.9	0.3	32.5
Thermal curing epoxy	Addison clear wave	2	0.3	35
Molding compound	XKE-G8840	22	0.3	11
Substrate epoxy	QMI536NB	0.3	0.3	80
Substrate	I TERA MT40	21.09	0.234	12

The FEM models are simulated for the temperature range of 22°C to 85°C, corresponding to a temperature difference of 63°C. At 85°C, the relevant SLM parameters are extracted from the FEM results, especially the stress induced in the glues, the misalignment of beam combiner and micro mirrors, and the chip curvature change (z direction).

2. FIRST PACKAGE MODEL

The first package concept tries to minimize the stress in the beam combiner glue by stretching the silicon chip to the free expansion of the beam combiner using the influence of the heat slug. This should ensure a low risk of misalignment developing over time due to glue creep. The first package model is just a stack of only beam combiner, SLM chip and heat slug all glued together as shown in Figure 2 (left). The beam combiner and chip have thicknesses of 2 mm and 0.75 mm, respectively. The die bond adhesive is of 50µm thickness.

To reduce the FEM numerical effort only a quadrant model of the package is simulated. In this first model, the shear stress in beam combiner (BC) glue is evaluated while altering the thickness of the heat slug. An ideal thickness determined for the model is a heat slug of 3.7 mm thickness. In this case the stress in the BC glue is near zero (at all temperatures), implying long-term stability, see Figure 2.

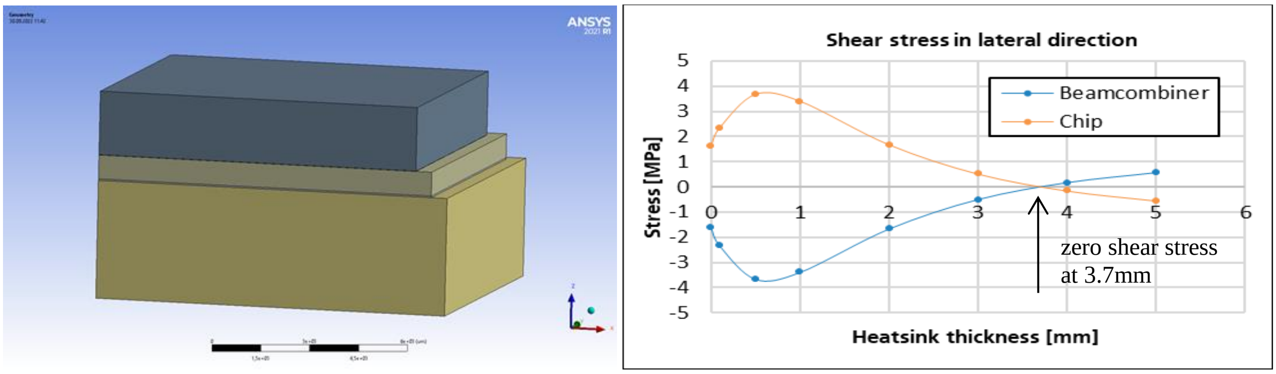

Figure 2: first packaging model (left), shear stress induced in BC glue in lateral direction for varying thickness of heat slug (right)

On the SLM chip, the active pixel area is 16mm x 14.4mm. In the quadrant model used in the simulations, the pixel area is 8mm x 7.2mm chip, and the locations along which the misalignment is evaluated is shown in Figure 3. The misalignment between the beam combiner and SLM chip is found by computing the difference in the lateral (y) deformation of these components along the y-dimension of MMA at two different x coordinates corresponding to the centre and edge of the pixel area, as shown in Figure 3.The maximum misalignment found in the first model is 63.3 nm and 37.7 nm respectively (Figure 4), meaning that the first goal of a small misalignment can indeed be reached by this concept. The criterion to have zero stress in BC glue is obviously not exactly optimizing the worst mismatch in the pixel area, but it is quite close.

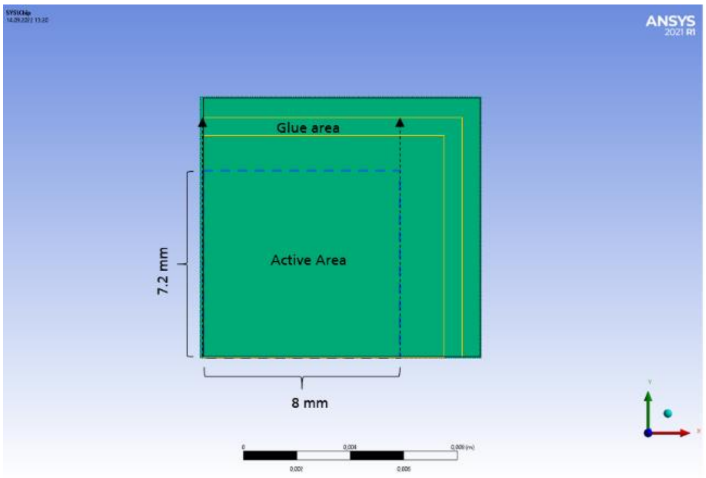

Figure 3: SLM chip with glue area (yellow lines), pixel/active area (blue dotted lines) and paths along the MMA where misalignment is extracted (black arrows)

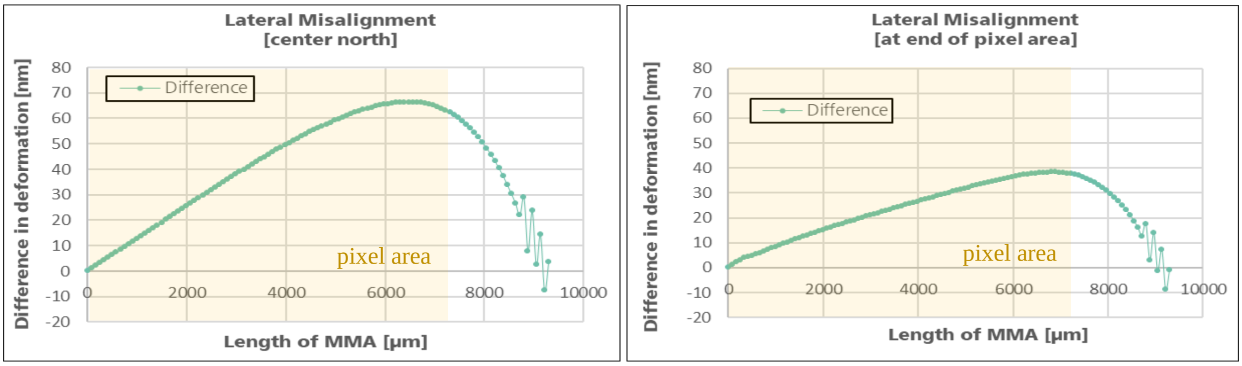

Figure 4: Misalignment between beam combiner and chip in lateral (y) direction along the y-direction of the MMA at center (in x direction) and at the edge of the pixel area at 85°C

The thermally induced stress in the SLM chip due to CTE mismatch ranges between 7 and 13 MPa, as shown in Figure 5 (right), which seems to be acceptable. Unfortunately however, the bow change at the pixel area of the SLM chip, shown in Figure 5 (left), is around 1.2µm, which hugely exceeds the specification and therefore this first approach is not usable.

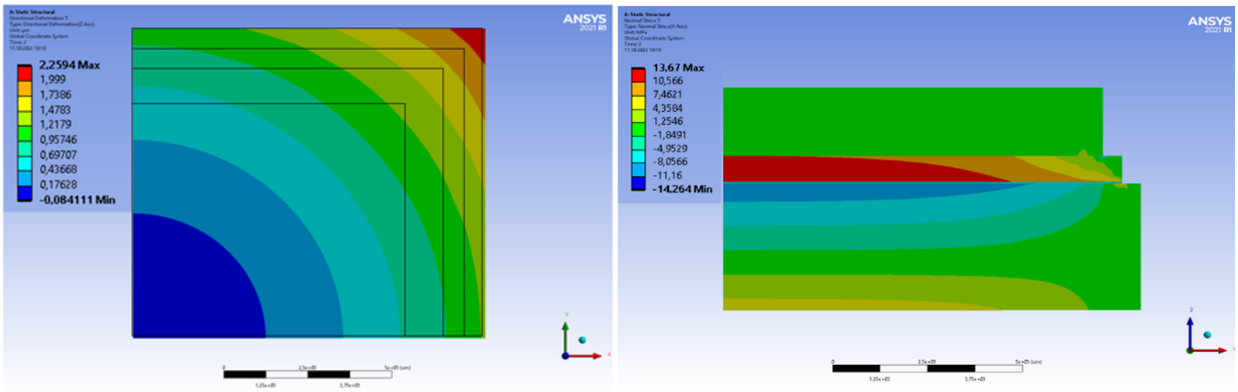

Figure 5: change in curvature of SLM chip for a ΔT of 63K (left), stress induced in the package (right)

3. FIRST PACKAGE MODEL WITH SUBSTRATE AND MOLD

Although it cannot be the final solution, the first package model is extended by including the substrate and molding to understand their impact on chip curvature and stresses caused by the CTE difference. The molding protects the bond wires and covers the edge of the SLM chip and part of the substrate as shown in Figure 6.

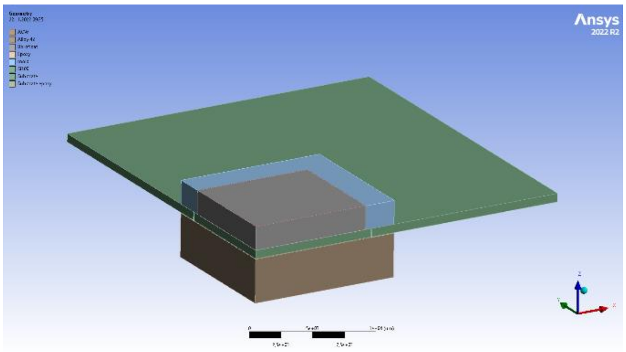

Figure 6: The first packaging model including substrate (green) and molding compound (light blue)

The substrate in the FEM model is 0.75mm, just as the SLM chip. This enables short bond wires due to chip and interposer being at the same level. The gap between the chip and the substrate is 100µm, which is small to enable short bond wires for good signal integrity and to prevent bond wire bending during transfer molding.

The bow change in the chip (z deformation) now is only 0.37µm (instead of the 1.2µm without substrate and mold), see Figure 7 (left), in principle a nice improvement.

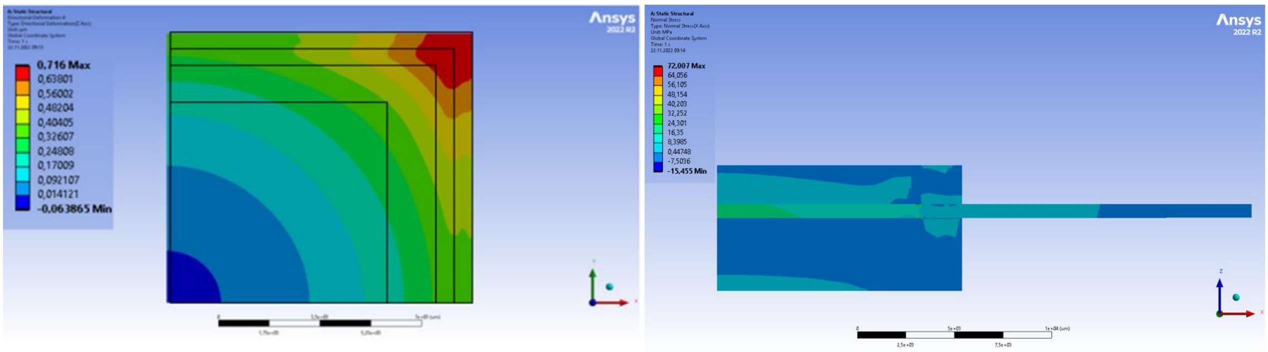

Figure 7: change in curvature of SLM chip for a ΔT of 63K (left), stress induced in the package (right) integrated with substrate and mold

The stresses extracted at the contact areas of the BC and the die bond glues at lateral positions are very small. The lateral misalignment along the pixel region between the SLM chip and beam combiner is shown in Figure 8. In both locations, the largest misalignment obtained in the pixel area is 29.5 nm and 37.6 nm, respectively which by itself is also an improvement.

On the other hand, the results clearly illustrate that the substrate and mold have a rather strong impact on the relevant parameters. Actually we had expected only a small influence of the mechanically rather weak substrate and mold material on the much stiffer heat slug, silicon, and window. While including the substrate and mold does improve the results of the simulations in the case of the simulations shown, we have strong concerns that the proposed heat slug is not robust enough to prevent bow variations in the SLM chip caused by external forces induced by z-ray connectors and their compressing screws as well as the mechanical mounting to a cooling system. These forces will depend a lot on the materials and geometry of the structures around the package and are quite difficult to model, so no simulations were done for this load case. They may also change a lot over time and with temperature, resulting in out-of-spec MMA curvature changes. Furthermore, the materials used for the substrate and mold may significantly creep, imposing the risk that the preceding results may not be very stable.

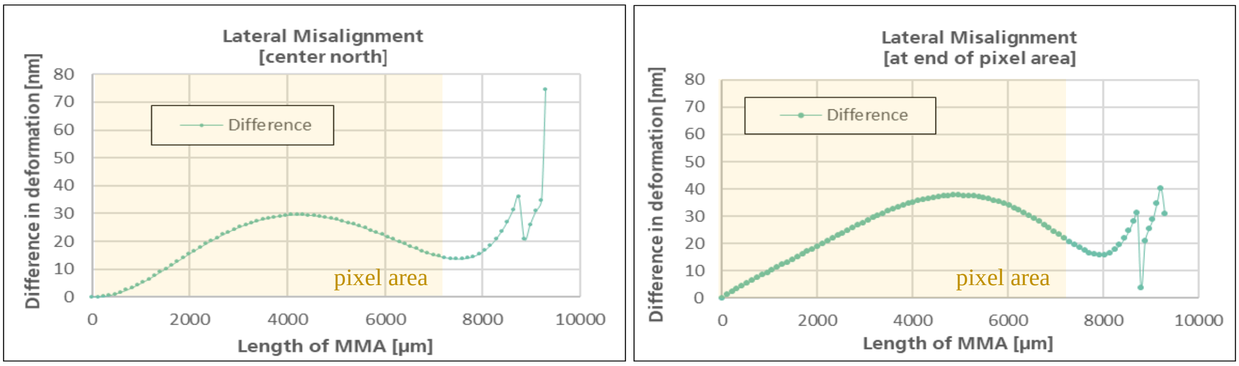

Figure 8: Misalignment between beam combiner and chip in lateral (y) direction along the length of MMA at center and at the edge of the pixel area for packaging model integrated with substrate and mold

Considering everything, the 3.7mm thick heat slug that minimizes the beam combiner glue stress seems to be not stiff enough to support the SLM with the required stability for the intended use case. We therefore check a significantly thicker and stiffer heat slug next.

4. PACKAGING MODEL WITH THICK HEAT SLUG

The packaging model with a heat slug of 10mm thickness is simulated. It is again extended by including the substrate and molding compound as in section 3, the proportions are shown in Figure 9.

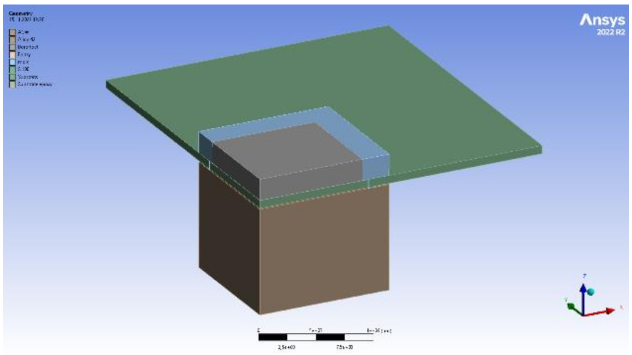

Figure 9: package model with thick heat slug, substrate and mold compound

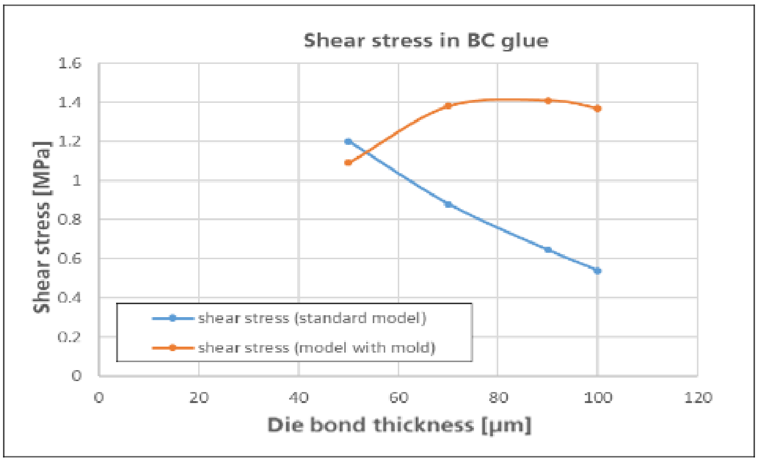

Figure 10: comparisons of stress in the BC glue for various die bond thicknesses

Furthermore, the simulations using the thick heat slug were extended by varying the die bond thickness for both the simple and extended models to possibly reduce the too-large influence of the heat slug on the SLM chip expansion and thus on the glue shear stress. In Figure 10 the blue curve shows that this would actually be possible. Unfortunately this does not work for the case including substrate and molding, as shown by the orange curve in Figure 10. The reasons for this are not fully understood, yet, but the direct contact of the mold and BC sides may be a reason.

More important, the bow change in the SLM chip can now be as low as 110 nm, as shown in the left graph of Figure 11, and the difference for the models with and without substrate and molding is small. Thus the thick heat slug improves the stability significantly, best of all for the smaller die bond thicknesses (50µm and 70µm).

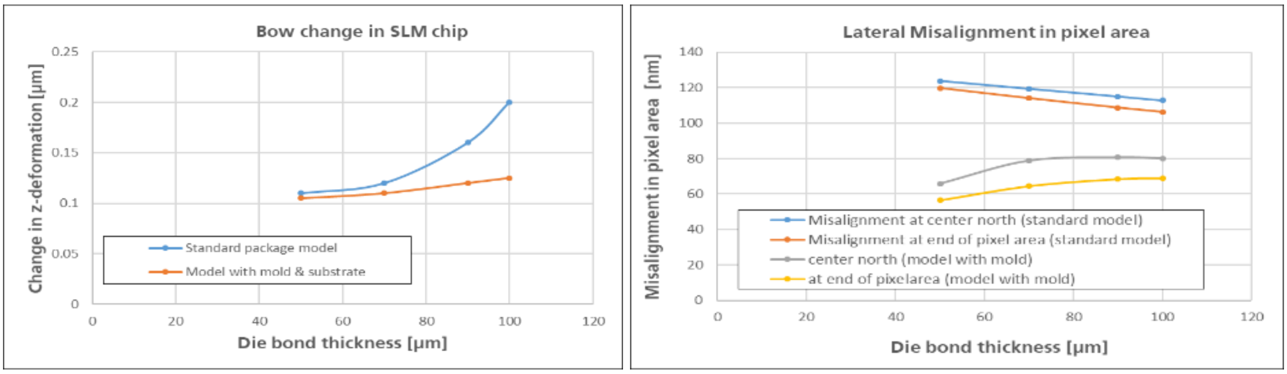

Figure 11: comparisons of bow change in SLM chip (left), and lateral misalignment (right) for various die bond thicknesses

The stress evaluated for both the glues in lateral direction is 1.0MPa in BC glue and 2.0MPa in the die bond for a 50µm die bond thickness. This stress, that the adhesives have to withstand, is much lower than the stress it should be able to withstand according to the manufacturer's specification, so we think that we actually can accept this stress level and heat slug thickness.

The maximum misalignment in the pixel area is around 120nm without and around 60nm with substrate and mold, as shown in the right graph of Figure 11. This seems to be an acceptable difference allowing the hope that the package with the thick heat slug will be stable enough even with external varying forces. The simulated misalignment does eat up a substantial part of the specification, but on the other hand still leaves acceptable margin for the initial placement accuracy.

5. CONCLUSIONS

Developing an SLM package fulfilling the requirements of a MMA for holographic applications proves to be quite challenging. A package featuring a 10mm thick heat slug, beam combiner window, substrate, and mold offers acceptably low shear stress in the glue layers. It allows only a moderate influence from substrate and mold on the relevant package parameters, promising good resistance against external forces. The change in SLM bow over the full operating temperature range unfortunately is still larger than the target value, and an even thicker heat slug does not seem to be practical. Investigations are currently being done to find whether the amount of bow change found in the simulations might still be acceptable. If this is not the case, a possible remedy would be to stabilize the actual SLM temperature to a narrower range than the ambient operating temperature range. This could be done using a peltier element.

6. SUMMARY

Microelectromechanical Systems (MEMS) require sophisticated packaging schemes in order to achieve the required performance. The demand for well-designed package is very challenging to ensure the long-term stability and reliability of the devices. In the European Union funded Project REALHOLO we are currently developing a packaging concept that is as stable as possible within the entire operating temperature range and throughout SLM lifetime despite the inevitably different coefficients of thermal expansion (CTE) of the various materials involved. For that purpose, FEM thermo-mechanical simulations are carried out comparing different package concepts regarding their resulting package stress, mismatch between chip, and beam combiner and SLM curvature. This paper describes a packaging concept with thick and stiff heat slug meeting the challenges together with detailed simulations.

7. ACKNOWLEDGEMENTS

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