Die attach technology to reduce die stresses in MEMS pressure sensors

Karumbu Meyyappan
CALCE EPSC
University of Maryland
College Park, MD 20742
karumbu@wam.umd.edu

Patrick McCluskey
CALCE EPSC
University of Maryland
College Park, MD 20742
mcclupa@calce.umd.edu

LiangYu Chen
NASA GRC
21000 Brookpark Road, MS 77-1,
Cleveland
OH-44135
Liangyu.Chen@grc.nasa.gov

ABSTRACT

The MEMS device chip (SiC die) carries the mechanically active, Piezoresistive MEMS sensors. The thermomechanical stresses, arising due to the high temperature excursions, can result in undesirable thermomechanical forces on the diaphragm, causing loss of precision of the sensor. This paper describes a new die attach technology, which can help attenuate the stresses in the mechanically active portion (part containing the sensor) of the die. The die attach is used to partially attach the die (non-active portions) to the substrate. Non-linear finite element analysis was performed to determine the peeling, shear stresses and the von Mises stresses, in the SiC device, the pressure sensor and the die attach, for temperature cycling from 20°C to 600°C. The analysis has been performed for various attach widths. The stresses are seen to reduce in the mechanically active parts of the die. The effect of the substrate material has also been studied in the paper.

BACKGROUND

Electronic devices and sensors which can operate in harsh environments (~600°C) are necessary for many space and aeronautic applications such as space missions to the inner solar system and emission control sensors/electronics located in an aeronautical engine environment. SiC semiconductor electronics and MEMS (Micro-Electro-Mechanical System) pressure sensors fabricated at NASA GRC have been demonstrated operable at temperatures as high as 600°C [1]. However, these materials and technologies need to be more systematically evaluated (especially mechanically) for long-term operation at higher temperatures.

After wafer-level packaging, a MEMS device chip (die) is typically attached (mounted) to a packaging substrate using epoxy, glass, solder, or eutectics and the substrate is sealed to a stainless steel case. Unique materials are required for die attachment at temperatures above 500°C. For such high temperatures, gold thick film is necessary [2, 3]. The signals are routed from the top of the sensor chip to the conducting tracks in the substrate using wirebonds. The materials and components chosen must be evaluated for their reliability at high temperatures of 500°C - 600°C.

The Piezoresistive MEMS sensors have been extensively used for both dynamic (acoustic) and static pressure measurements. These sensors, mounted on the diaphragm in the die, sense the mechanical deformation on the diaphragm and convert them to equivalent pressure readings. Therefore, these sensors are very sensitive to any form of external forces on the diaphragm. The mismatch of the coefficients of thermal expansion (CTE) between the substrate, die attaching materials and the die material introduces high thermomechanical stresses in the attach layers. These thermomechanical stresses can result in undesirable thermomechanical forces on the diaphragm, causing loss of precision of the sensor. Very often, these unwanted MEMS thermal responses are not reproducible with respect to both time and environmental temperature. Thus, packaging technology is a critical factor determining the reliability of packaged MEMS devices.

Two pressure sensor designs were analyzed earlier [4, 5], one containing a regular SiC die while the other design was a pressure sensor, modeled as a square die with a central thin diaphragm (a hollow cylindrical area etched from the back of the die) using finite element analysis. This paper describes a new die attach technology, which can help attenuate the stresses in the mechanically active portion (part containing the sensor) of the die. The die attach is used to partially attach the die (non-active portions) to the substrate. Non-linear finite element analysis was performed to determine the peeling, shear stresses and the von Mises stresses, in the SiC device for temperature cycling from 20°C to 600°C. The effect of substrate materials has also been studied.

OPTIMIZATION OF DIE ATTACH STRESSES

A different thermal stress-free die-attach method, lateral stress attenuation die attach, was proposed for MEMS packaging [6]. This stress reduction die-attach structure requires that the die be partially attached to the substrate through the backside area of the non-mechanically active (non sensor) portion of the die, rather than fully attaching the die to the substrate. The main purpose behind this practice is to reduce the stresses at mechanically active (unattached) areas of MEMS chips. This could partially eliminate the need to match the CTE's among the various layers. This low stress die-attach technology is especially suitable for applications in high temperature MEMS packaging for which thermal stress is a critical concern for both (packaged) device performance and reliability.

Figure 1 shows the schematics of the structure with the partially covered die-attach. The die is attached to ceramic substrate using gold (Au) thick-film at 600^{o}C so the die-attach assembly is assumed to be thermo-mechanically relaxed at the attaching temperature. The die is essentially 2 mm x 1 mm x 0.29 mm while the attach width varies from 0.25 mm to 1 mm in steps of 0.25 mm. The attach thickness is 30 microns. The substrate is chosen to be 4 x 4 mm.

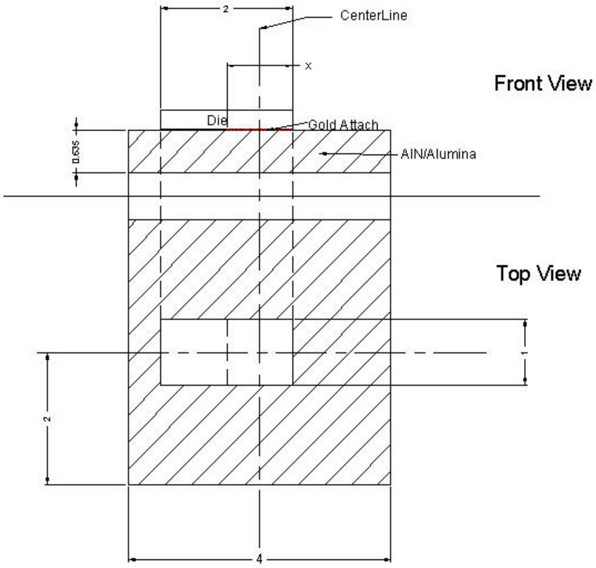


Figure 1

The x shown in Figure 1 is varied from 0.25 to 1.0 mm in steps of 0.25 mm. Considering symmetry, only half of the structure has been modeled. Figure 2 shows an image of the mesh and the die attach layer. The SiC die and the Al_2O_3/AlN substrates have been assumed to be linear elastic between room temperature and 600^{o}C while non-linear material properties have been assigned to the die attach. The temperature dependent properties for the SiC die, Au attach and Al_2O_3/AlN substrate are reported in an earlier work [7]. The sensor has been subjected to a load cycle of 20 - 600°C.

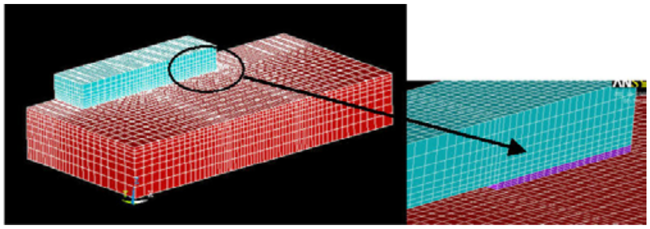


Figure 2

RESULTS AND DISCUSSION

A stress and displacement analysis was performed on the pressure sensor with the diaphragm. Two different substrates materials, AlN and Al_2O_3, were chosen for the study.

Effect of Substrate Material

The effect of substrate would be more pronounced in the attach layer adjacent to the substrate. Hence, a layer of nodes, shown in Figure 3, was chosen to study the effect of substrate.

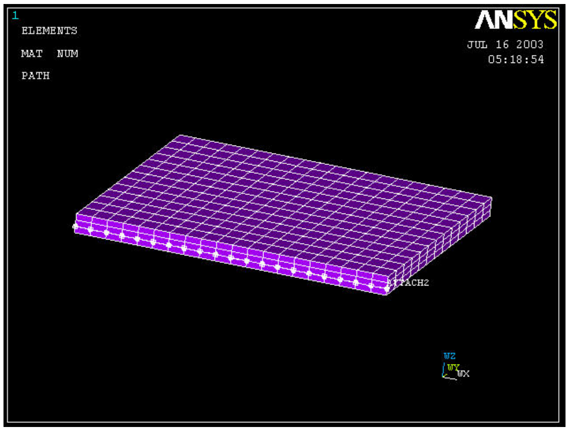
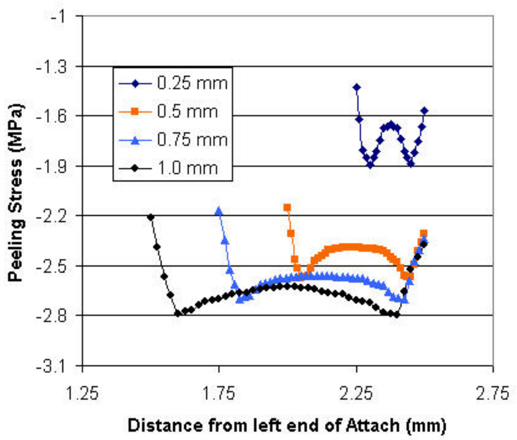
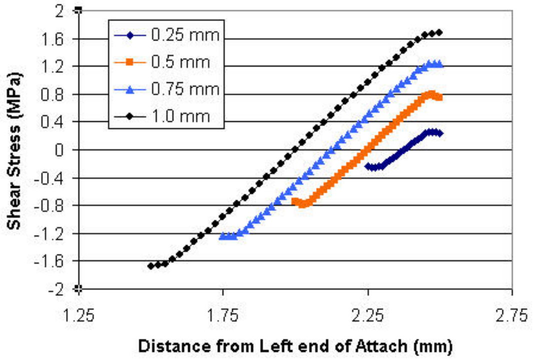


Figure 3 Layer of nodes chosen in the Attach layer

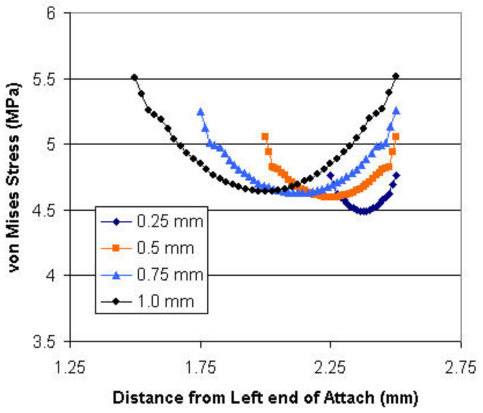
Figure 4 and Figure 5 shows the Peeling, Shear and von Mises stresses for a layer of nodes shown in Figure 3. The reduced thermal expansion mismatch between AlN and SiC layers when compared to Al_2O_3 and SiC layers results in lower stresses in the AlN based assembly. For simplicity, only the results from the AlN based substrate will be reported henceforth in the paper.



(a) Peeling Stresses

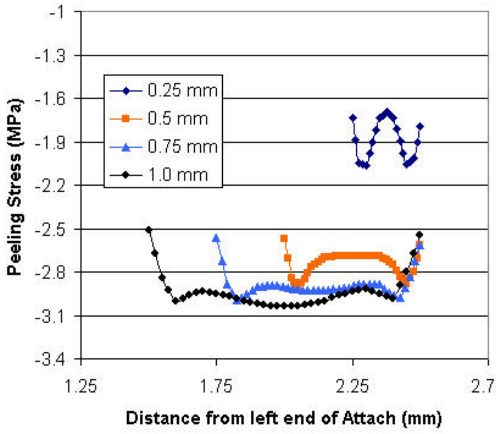


(b) Shear Stresses

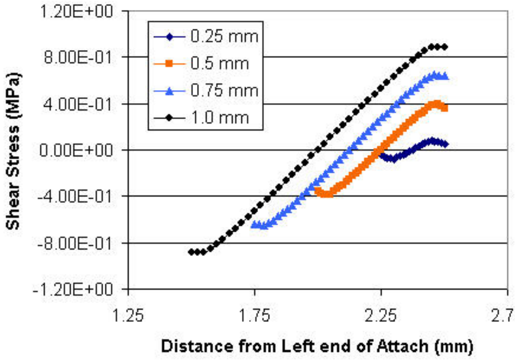


(c) von Mises Stresses

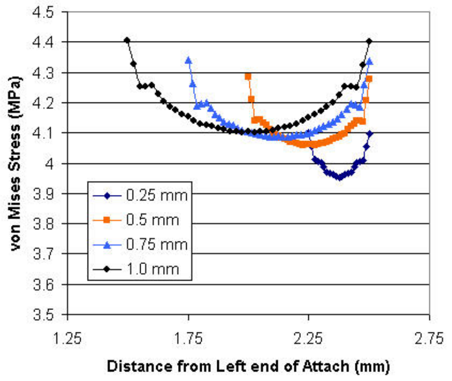
Figure 4 Stresses in the attach layers (Al2O3 Substrate)



(a) Peeling Stresses



(b) Shear Stresses



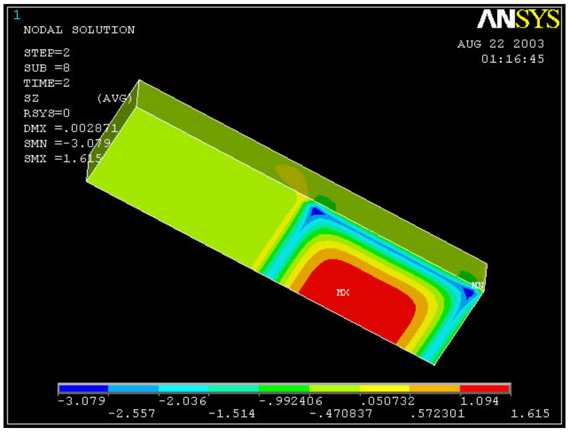
(c) von Mises Stresses

Figure 5 Stresses in the attach layers (AlN Substrate)

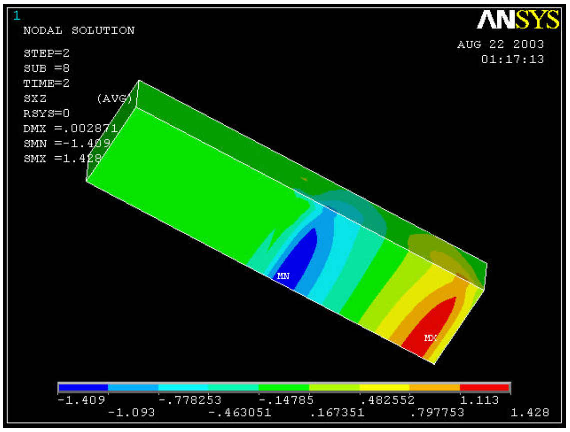
Stress Attenuation

Also, the graphs shown in Figure 4 and Figure 5, clearly show that as the attach width becomes smaller the stresses in the attach layer also reduces. Also, the graphs show that the die area under high stresses is more as the attach width gets larger.

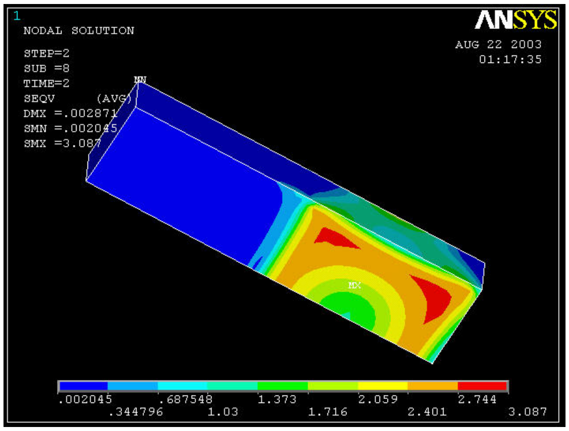
Figure 6 show the Peeling, Shear and von Mises stresses in the bottom of the die for the 1 mm wide attach. All stresses on both the top and bottom of the die attenuate rapidly towards the free end of the die. The stresses in unattached area of the die is low, thus protecting the mechanically active components built in this device area.



(a) Peeling Stresses



(b) Shear Stresses



(c) von Mises Stresses

Figure 6 Stress Distribution in the bottom of the die (1 mm wide attach)

CONCLUSION

A lateral stress attenuation concept is introduced by partially attaching the substrate to the backside area of the non-mechanically active portion of the die. In all the designs, the attach is assumed to be perfectly bonded to the substrate and the die. In addition, the boundary conditions permit no slip. FEA simulations indicate that this die-attach structure allows the stresses generated by thermal expansion mismatch at the die/attach/substrate bonding area to attenuate rapidly along this lateral distance. Such an assembly could reduce the stresses at mechanically active areas of MEMS chips. The study also reveals that AlN substrate is preferable when compared to the Al_2O_3 substrate.

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