HECTIC—Improved SiC Sensor Technology for Harsh Environment and Yield Optimization Strategy for Hermetic Laser Assisted Bonding

G. Spinola Durante, A. Hoogerwerf, R. Jose James, K. Krasnopolski, M. Fretz, S. Ischer, M. Despont, O. Dubochet, M.-A. Dubois, S. Mohrdiek

Last year, CSEM technology development has shown its potential for SiC MEMS pressure sensor manufacturing for harsh environments. Towards achieving a high TRL required by the industry, both challenging front-end and back-end process steps needed to be improved in quality and long-term reliability. In this respect, at the front-end level, effort was made to reduce the level of electrical noise in SiC MEMS contacts. A second step was taken to upgrade the SiC etching equipment to improve overheating issues, etching uniformity and productivity. At the back-end level, a new clamping fixture enabling chip edge temperature measurement, together with a thermal multi-physics model developed in Comsol®, was implemented to improve the yield of the laser-based (LADB) hermetic sealing of the SiC back-plate. At last, approaches are investigated to overcome the degradation mechanisms observed at 600°C in air for 500h [1].

Silicon carbide (SiC) has excellent chemical and thermal characteristics to make it the material of choice for sensing in harsh environments. CSEM has therefore developed SiC pressure sensors that can operate at temperatures of up to 650°C[1,2]. The promising results of this development have led us to continue working on maturing these sensors aiming to achieve a Technology Readiness Level of 4 (TRL 4) that is sufficiently high to attract the interest of the industry.

The issues to be addressed to mature the technology are the following:

- Improve quality of ohmic contacts to SiC for realizing low-noise piezo-resistance in the MEMS pressure sensor.
- Upgrade equipment for Deep Reactive Ion Etching (DRIE) of SiC to achieve a more robust etching process.
- Improve our understanding of the Laser Assisted Bonding (LADB) process to increase its yield.
- Avoid degrading mechanisms after 500 hours at 600°C in air.

The cause of the electrical noise in the ohmic contacts was investigated and it was found that gas diffusion that occurred during the wafer fabrication degraded the contacts, as can be seen by the dark voids in the Focused Ion Beam (FIB) made cross-section of the contacts shown in Figure 1. Modifications were made in the fabrication process flow to prevent the gas diffusion from taking place. As a result, the electrical noise of the contacts was reduced by two orders of magnitude.

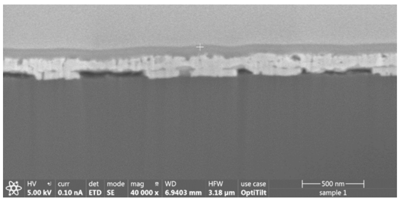

Figure 1: FIB-made cross section of a noisy electrical contact to SiC.

The DRIE etching of SiC improved with the purchase of a Plasma-Therm Corial 210IL DRIE etcher. Especially the improved clamping mechanism of this machine allows a better cooling of the wafer during etching and allows a better resistance to thermally induced wafer bow. A selectivity of 100:1 with respect to the etch mask material has been achieved.

At the back-end level, a process with highly localized heat and minimal damage to the chips, to achieve low-stress, hermetic and reliable laser assisted bonding (LADB) is performed. To improve process yield, more insight in the thermal field is necessary. Therefore, a new clamping fixture has been developed to enable laser bonding (Figure 2), while closely monitoring with a thin-wire thermocouple (0.25 mm diameter) the chip edge temperature. A test showed that the SiC chip edge reached ~300°C within 3 seconds of laser exposure. This is expected due to SiC substrate absorbing ~20% of laser power and confirmed by Au80Sn20 preform melting when placed on top of the SiC chip.

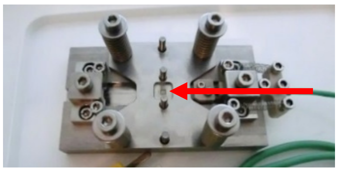

Figure 2: Fixture to apply pressure on SiC chip for LADB hermetic sealing. The arrow shows direction of the hidden thin-wire thermocouple.

Simulations also enable to estimate temperatures directly in the bonding metal ring, where no other method can be applied. The simulation model temperature field will be calibrated with the experimental values from the fixture thermocouples (Figure 2). In Figure 3 non-calibrated simulation results are shown, featuring only laser power absorbed in the metal ring [3].

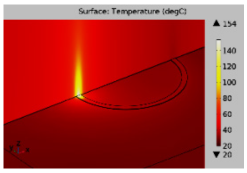

Figure 3: Cross-section of Comsol thermal model (non-calibrated) to show laser induced temperatures on the sealing ring and on the SiC chip.

As an outlook on the long-term reliability in air up to 650°C improvement activity, CSEM is focusing on different potential solution areas: high-quality protection coatings, dedicated diffusion barriers and accelerated testing strategy.

[1] G. Spinola Durante, *et al.*, "HECTIC2—SiC-based MEMS Pressure Sensor Development", CSEM Scientific and Technical Report (2018), p. 18.

[2] A. Hoogerwerf, *et al.*, "Silicon carbide pressure sensors for harsh environments", Transducers 19, Berlin (DE), 2019.

[3] G. Spinola Durante, *et al.*, "Laser Assisted Bonding (LADB) Thermal Modeling with COMSOL Multiphysics®" Comsol Conference in Cambridge (UK), Poster presentation, 2019.