LTCC - Packaging of a Laser Optical System for Harsh Environments

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***Abstract*—The ceramic multilayer technology "Low Temperature Cofired Ceramics" (LTCC) provides, thanks to its 3D structuring ability, the alternative key technology for the cost efficient packaging of miniaturized laser components. The goal of the development was therefore, to create an ultra-compact platform usable as carrier for laser optical components in the middle and high power range (≤ 50 W). To achieve this aim, an actively cooled edge emitting laser diode will be coupled to a glass fiber in a hermetically sealable package based on the LTCC-technology. Based on simulative and experimental investigations a ceramic integrated 3D-channel structure was developed for cooling an 8 W laser diode emitter (12 W power dissipation). The development of the LTCC active cooling structure components and the experimental results will be presented within the paper. The alignment of the optical elements on the bench was done by a high-precision jet soldering process and enables for an efficient optical coupling of the laser diode to the glass fiber.**

***Keywords*—LTCC, laser optics, packaging, hermetic sealing**

I. Introduction

Integration platforms for laser optical modules are typically machined metallic and highly heat conductive components upon which the optical bench is installed. However, demands for increasing miniaturization and rising power density for small volumes are still open challenges for highly integrated laser components [1].

Due the 3D structuring ability in combination with a high reliability and its outstanding thermal matching to silicon the LTCC technology provide a cost-efficient packaging platform for photonics and sensory applications [2], [3]. Recent developments of LTCC modules for photonics applications demonstrate the suitability as a packaging alternative for low power VCSEL emitter. The VCSEL emitter was assembled via Flip-Chip-Technology on the LTCC module to inject the emitted laser beam into the additionally integrated LTCC fiber optic cable [4]. The development of LTCC-packaging platforms for semiconductor laser diode for the fiber coupling by additional coupling elements (focus lens) is demonstrated in the applied research. The necessary precise assembly and the missing hermetic sealing had a disadvantageous effect on the set-up [5]. Furthermore laser diodes were coupled with glass fibers integrated on LTCC and hermetically sealed. Though the passive alignment of the laser diode to the glass fiber resulted in a low coupling efficiency [6]. In addition the suitability of integrated cooling channels were demonstrated for laser diodes of low power (> 1 W) [7].

In summary, promising approaches for laser optical modules are existing for the integration into LTCC System platforms. The aim of the study was to bundle the benefits of the ceramic multilayer technologies like structuring, reliability, multi-functionality for a miniaturized packaging for laser diodes in the middle power range.

II. Module Design

The technical solution was based on the principle of mechanical and functional structuring of green tapes of LTCC as well as subsequently stacking, laminating and sintering to a monolithic ceramic device. Based on a single emitter of middle power (8 W optic power, 12 W thermal power loss) and a multimode-transport fiber a principle layout of the optics for the free-jet fiber coupling with a FAC (fast axis collimator) and a SAC (slow axis collimator) three lens system was designed. The circuit design should combine the aim to miniaturize the package by embedding the wiring into the LTCC multilayer and to integrate the ability for a hermetic sealing. To cool the laser diode emitter an effective active cooling system, which should be easily integrated into the LTCC device was designed and simulated.

An LTCC frame around the package and an optical window which will be joined on the front side allows the integration of the fiber optic on the package and create the conditions for a finally hermetic sealed package. The 3D LTCC module design for the laser packaging is pictured in Fig. 1.

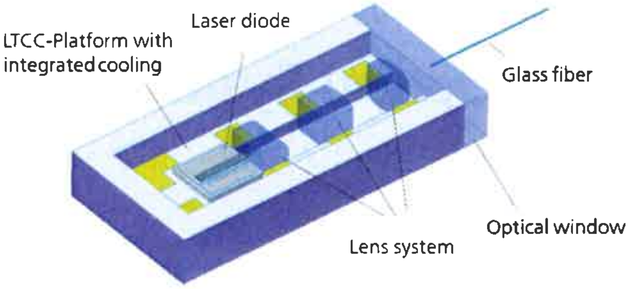

Fig. 1: Module design laser optical LTCC device

III. ACTIVE COOLING

High operating temperatures in combination with moisture and oxygen could lead to the degradation of the semiconductor laser diode. During operating of the powerful laser diode the thermal power loss of up to 12 W per emitter should be dissipated. Therefor the usage of a passive cooling system in LTCC is not sufficient. To dissipate the heat efficiently, channel structures were integrated into the LTCC layer by punching and stacking of the LTCC green tapes (see section B). The laser diode should be cooled down to 30° C on the backside of its heat spreader in operation with the help of the integrated active cooling structure in LTCC.

A. Simulation

FEM-based ANSYS simulations were used to analyze the cooling behavior of the punched LTCC cooling channels. To avoid corrosion a very thin LTCC layer (90 µm thickness) in the interface between laser diode and the cooling structure was intended and simulated. Tab. 1 shows the materials which taken into account of the simulation investigation

Table 1: Material properties used in simulation.

Material	Heat capacity [J*Kg^{-1} K^{-1}]	Heat conduction [W*m^{-1} K^{-1}]
Silicon	702	150
LTCC 951	989	3
Conductive adhesive	700	8
SAC305 – soldering material	283	56
Aluminiumnitrid	738	170
DuPont 6141 Ag Via paste	0.237	289

Fig. 2 shows the cross section of the heat simulation of the laser diode joined with SAC soldering material on the LTCC setup at 12 W thermal power loss. The inlet pressure and temperature of the cooling fluid was defined to 0.5 bar and 23° C. The simulation results showed that the heat from the working laser diode (pigmented in red) is not conducted well to the cooling areas in deep blue and the diode remained in hot state (ca. 130° C). This is particularly because even the thin LTCC interface layer causes a heat built-up because of its relatively bad heat conduction (see Table 1). Additional integrated thermal vias in the LTCC top layer result in a partial heat conduction into the first nearby cooling structure layers which results in a temperature reduction of 30° C to 100 °C on the backside of the heat spreader of the simulated laser diode (see Fig. 2).

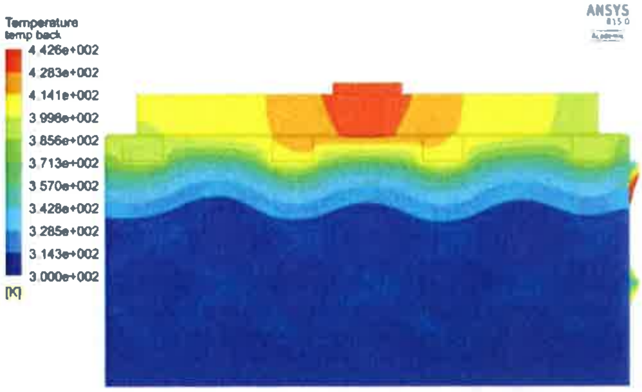

Fig. 2: Detail of the simulation of the laser diode in operation (20 W thermal power loss) and the connected cooling channel with thermal vias in the interface layer

To achieve the requested temperature conditions under load a hybrid setup for the miniaturized platform was strongly needed. The combination of the LTCC device with an aluminum nitride (AlN) substrate linked the structuring behavior and the thermal conduction of ceramic material in an optimal way for this application to achieve the ideal heat conduction to the cooling fluid. Since the coolant was in direct contact with the AlN interface layer, the low thermal conductivity of the LTCC cooler body material does not adversely affect the thermal performance of the device.

B. Manufacturing

Fig. 3 shows the sintered LTCC structures of the active cooling picture with a top and a cross-section view. By the alternating structuring the cooling fluid fulfills a laminar flow (see also Fig. 2). To manufacture the structures, 1 mm small holes were punched into the LTCC green tapes next to each other to get slotted holes, which were stacked with an offset on top of each other in an 11.5 mm to 11.6 mm wide structure field. The openings enabled a large contact area between the interfacing AlN layer, which carries the laser diode, and the cooling fluid. No more additional thermal vias were integrated. As mentioned before an AlN substrate was joined onto a designated LTCC frame of the cooling structure. To allow the assembly and soldering of the laser diode and a temperature sensor, a silver-palladium (AgPd) paste was screen printed on the AlN substrate. The paste is an in-house development and also usable for heavy wire bonding with aluminum wires.

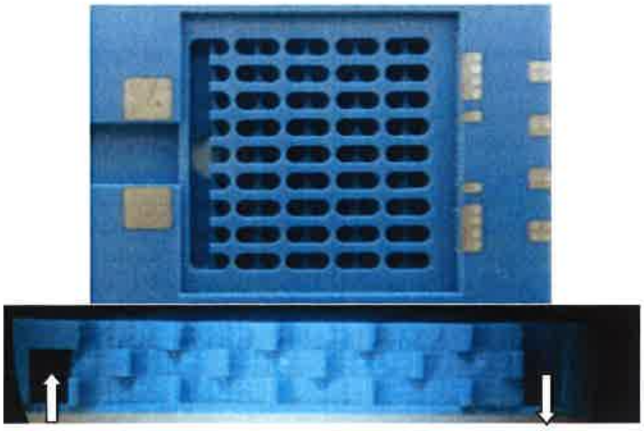

Fig 3: Top-View (above) and Cross section of the realized and patented punched cooling structure for the active cooling of in LTCC (arrows visualize inlet and outlet)

The AlN substrate was afterwards joined in the frame with a high temperature adhesive which is acting nearly gastight. In future the joining should with be realized with glass paste to ensure the hermetic sealing of LTCC platform. On the backside of the cooling structure a brass block was glued to integrate the hose connections (AlN interlayer and hose connection: see Fig. 6).

C. Characterization

For the characterization of the active cooling a thick film heater in the size of laser diode was printed on the AlN substrate with AgPd-paste to test and simulate the laser emitter under load. The heater had to be place on the front of the interface, which restrains the optimal cooling of the laser diode in comparison to a positioning in the middle of the cooling system.

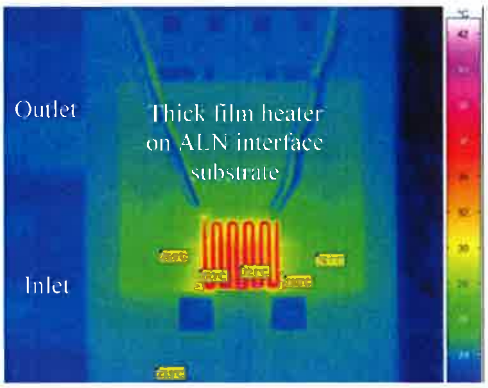

Fig. 4: Infrared camera picture of a printed thick film heater at 12 W power on ALN simulating an assembled laser diode which is cooled by the active cooling structure at 23 °C fluid temperature and 0.3 bar fluid pressure

Nevertheless the cooling characteristic of the active cooling system was measured with an infrared camera up to 26 W (see Fig. 4). The average value of the 4 mm x 4.5 mm heater was therefor analyzed with a field measurement (see diagram Fig. 5). At 12 W power of the heater and 23 °C coolant temperature (0.3 bar fluid pressure) the heater showed an average temperature of 32 °C. In comparison, the uncooled heater showed an average temperature of 270 °C at 12 W.

This measuring result corresponds to a thermal resistance of 0.70 K/W for the cooling system and fulfill the requirements. That means the designated laser diode in combination with the developed ceramic active cooling system could operate without needing a cost-expensive pre-cooling of the induced coolant. By the use of a pre-cooling system for the cooling fluid a more powerful laser diode could be applied. With a 20 °C pre-cooled fluid, the thermal resistance sank to 0.52 K/W.

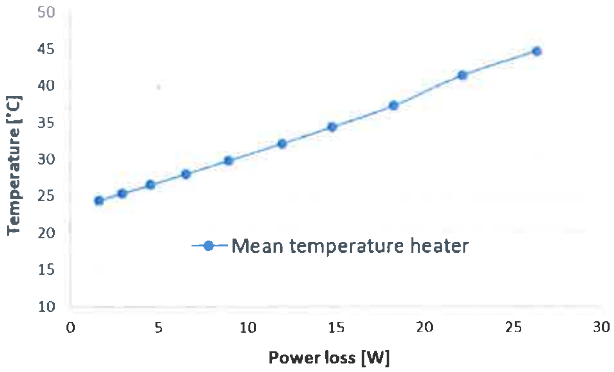

Fig. 5: Cooling behavior of the active cooling simulated with heater at 23 °C coolant temperature and 0.3 bar fluid pressure

The temperature monitoring of the running laser diode should be conducted with an assembled temperature sensor closely to the emitter on the AlN interface layer.

IV. Final Modul and Assembly

The final LTCC module device became an overall dimension of 17.5 mm to 30 mm. Additional to the already descripted devices a cavity with solder pads were integrated in front of the laser diode emitter to allow the assembly of the optical bench with SAC and FAC lenses which should ensure the fiber coupling of the laser beam (see Fig. 1 and 6).

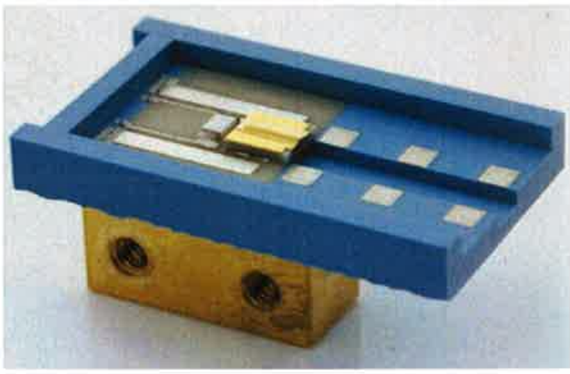

Fig. 6: Final LTCC-platform with integrated and wire bonded AlN-substrate, soldered laser diode and temperature sensor as well as fluidic connections on the backside plus frame for the hermetic sealing on the topside

Fig. 6 also shows the assembled and soldered laser diode and temperature sensor on the AlN interface substrate, which was soldered with SAC solder material. To realize the contacts to the outer connections, the printed AgPd-pads on the AlN layer were bonded by ultrasonic heavy-wire bonding with aluminum wires (see also fig. 6).

V. Hermetic packaging

To demonstrate the hermetic sealing of the packaging platform an additional LTCC multilayer frame was integrated on the LTCC basic module before sintering to get a monolithic packaging body (see fig. 6). For the future work the frames should be added by in-mould labelling of LTCC material on the LTCC laminates to avoid loss of material by multilayer processing [8]. Based on the introduced platform a fused silica optical window will be placed on the front side to seal the overall packaging. The glass fiber is therefor spliced and aligned on the outer side of the window (see fig. 7). For the first demonstration of the LTCC-platform the window will be stuck with adhesive on the front. In the next step of development the window will soldered on the front of the package to ensure the hermetic seal. The packaging can finally sealed off with a joined lid on top of the LTCC frame and an optical window. Final reliability tests (thermal, shock, vibration up to 1000 h or 1000 cycles) should demonstrate a maximum degradation of the coupling efficiency of < 2 % of the laser optical module.

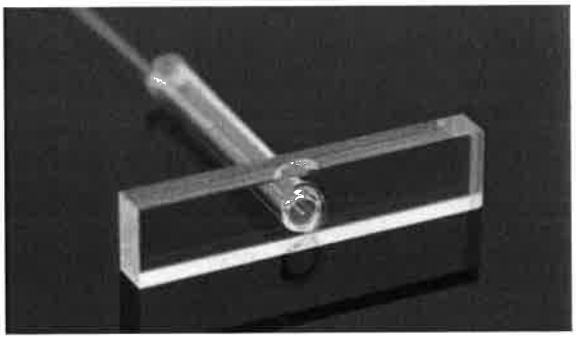

Fig. 7: Fused silica window with spliced glass fiber for the assembly on the front side of the LTCC package

VI. Conclusion

The contribution demonstrates the ability of using LTCC multilayer ceramic substrates to create a smart packaging for laser-optical applications. The developed LTCC based platform allows a maximum amount of miniaturization and enables, thanks to the active heat sink and to its implemented condition monitoring sensors, the generation of middle laser powers (< 50 W). This presented laser optical systems is also characterized by its intended superior robustness under harsh environments, which is owed to the excellent thermomechanical matching of the ceramic base material to the semiconductor laser diode and to the possibility of realizing a real hermetic packaging. Final development steps should contain the assembly of the optical bench and the optical window as well as the evidence of the hermetical sealing of the package.

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