Solderjet Bumping technique used to manufacture a compact and robust green solid-state laser

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ABSTRACT

Solder-joining using metallic solder alloys is an alternative to adhesive bonding. Laser-based soldering processes are especially well suited for the joining of optical components made of fragile and brittle materials such as glasses, ceramics and optical crystals due to a localized and minimized input of thermal energy. The Solderjet Bumping technique is used to assemble a miniaturized laser resonator in order to obtain higher robustness, wider thermal conductivity performance, higher vacuum and radiation compatibility, and better heat and long term stability compared with identical glued devices. The resulting assembled compact and robust green diode-pumped solid-state laser is part of the future Raman Laser Spectrometer designed for the Exomars European Space Agency (ESA) space mission 2018.

Keywords: Solderjet Bumping, laser based soldering, adhesive-free, micro-packaging, Raman Laser Spectrometer (RLS), micro-assembly, diode-pumped solid-state laser resonator, ESA Exomars

1. INTRODUCTION

The use of compact and miniaturized lasers capable to operate under extreme conditions has become one of the main goals for the laser manufacturers that develop devices for industry, space, medicine and military applications [1]. Such devices use to demand high output power with a high thermal, wavelength and beam stability by minimizing the size and weight via replacing optical clamping methods with different sort of adhesives. Nevertheless organic adhesives used in extreme applications could suffer slow and constant deterioration, resulting in optical components displacements, laser spectrum degeneration, efficiency losses or even failure.

Solderjet bumping technology is used to manufacture a compact and robust green Diode-Pumped Solid-State Laser (DPSSL) to be used for the next Raman Spectroscopy ESA Exomars mission 2018. The assembled laser is able to overcome all the adhesive induced issues and is adequate to achieve all the stringent specifications need for space applications and Raman laser spectrometry applications, as described by Rull et al. [1].

This laser-based soldering technique offers a local and minimized input of thermal energy and thus allows the components joining with very high position accuracy even for fragile and sensitive optical components such as the

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second harmonic generation crystals. Components need a wettable surface metallization which is provided by physical vapor deposition.

2. SOLDERJET BUMPING

Solder-joining using metallic solder alloys is an alternative to adhesive bonding. Laser-based soldering processes are especially well suited for the joining of optical components made of fragile and brittle materials such as glasses, ceramics and optical crystals, due to a localized and minimized input of thermal energy. Different techniques of heating solder alloys by laser irradiation are proposed using either thin film solder layers [3], Pick&Align resistance soldering technique [4] and [5] or the jetting of laser-molten solder droplets [6]. This so called Solderjet Bumping is a technique adapted from flip chip processing of semiconductor devices also allowing for the flux-free and contact-free processing of optical components and 3D-packaging. It uses spherical solder preforms of various soft solder alloys (e. g. tin-based lead-free solders, low melting indium alloys or high melting eutectic gold-tin, gold-silicon or gold-germanium solders) in a diameter range of 60 µm to 760 µm. The solder spheres are transferred from a reservoir to a placement capillary with a conical tip and an inner diameter that is slightly smaller than the diameter of the spheres. After positioning the capillary next to the joining geometry using an articulating robot or a gantry system, the solder alloy is molten by an infrared laser pulse and jetted out of the capillary by the applied nitrogen pressure. The jetting of liquid solder volumes provides a very good thermal contact of the alloy with the components and allows for the joining within complex 3D-integrated geometries. The bond head of the Solderjet Bumper integrates solder volume feeding, reflow and application of liquid solder droplets in a compact device and allows for highly automated and flexible use (Figure 1).

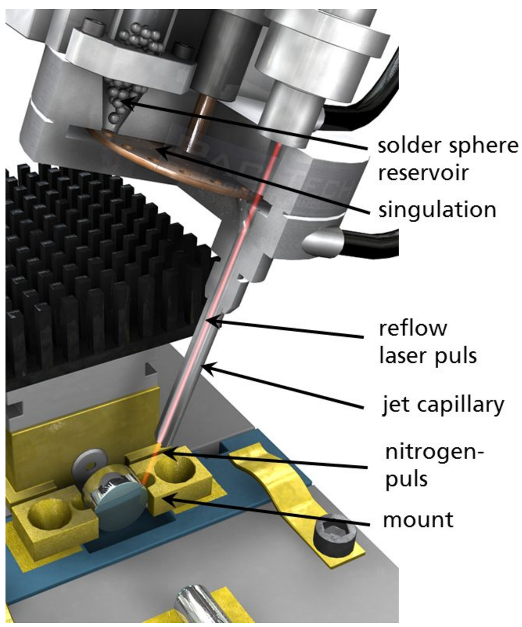

Figure 1: Schematic drawing of the Solderjet bond head able to solder droplets with 6 degrees of freedom (DOF).

The formation of a metallic solder joint using components made of non-metallic materials with Solderjet Bumping requires a wettable metallization layer applied to the components. Such surfaces can be provided by thin film (e. g. physical vapor deposition) or thick film (e. g. screen printing of metal pastes) processes. Sputtered three layer systems using titanium adhesion layer, a platinum diffusion barrier and a noble gold finish preventing oxidization and acting as a wetting surface, provide superb conditions for wetting of liquid solder droplets.

Typical photonic applications of Solderjet Bumping are described in the literature [6]. Sub-micron accuracy in placement of components, direct fiber coupling by soldering of polarization maintaining fibers and the hermetic sealing of an endoscopic tip is demonstrated. Further examples show the mounting of sensitive micro-optical components such as gradient-index lenses and fibers. The assembly of a multi-beam deflection array for next-generation lithography (Figure 2) outlines the features of this soldering technique with respect to vacuum compatibility and very high component placement accuracy [7]. Silicon-based micro-structured MEMS devices for the deflection of multiple electron beams are precisely attached to ceramic carrier substrates utilizing both mechanical fixation and electrical contacting by the solder joint [8].

Figure 2: Examples of solderjet bumping assemblies: left, lens mount geometry soldered with cold soldering technique [9]; right, wavelength division multiplexing device for optical measurements [7].

The use of the Solderjet Bumping technique in the assembly of high-power lasers modules is reported in [10]. A variety of components from Fast-Axis-Collimator-lens (FAC) with very high accuracy demands to micro-structured beam splitting/combining units and beam shaping micro-lenses are mounted to a ceramics based Direct Copper Bond substrate (DCB).

3. ASSEMBLY EXPERIMENTAL DETAILS

For the diode-pumped solid-state laser for the ESA Exomars mission, the laser optical components are soldered on an aluminum nitride (AlN) ceramic substrate with copper for the heat-dissipative elements and Kovar pads used to reduce the thermal mismatch between the AlN substrate and the rest of the components. Two different redundant laser channels have to be assembled for the mission purposes. Each channel includes a laser diode 808 nm, a couple of micro-lenses, an active medium laser crystal, second harmonic generator and a resonator mirror unit. The resonator mirror and the second harmonic generation crystal are mounted on a half sphere shape sub-mount to allow a highly precise tip/tilt alignment. The design also includes folding mirrors, a polarization coupling cube, a pinhole and a spliced fiber onto the output lens to guarantee a coaxial output beams (Figure 3).

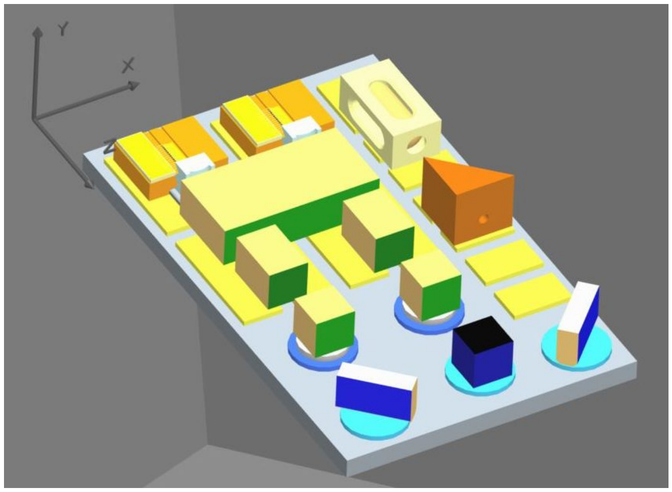

Figure 3: Exomars design of laser components soldered on an AIN ceramic of approximately 300 mm^2.

Prior to the alignment and joining of the elements, all the components are metallized applying wettable surfaces by using DC magnetron sputtering Ti/Pt/Au. The first element to be soldered is the active medium laser crystal; after being metalized, an array of AuSn Solderjet Bumps (melting point 280 °C) is applied on the surface to be soldered and later assembled by means of Fineplacer (multi-purpose bonder that offers a high placement accuracy). Although the solderjet technology proved to be better for soldering materials with different Coefficient of Thermal Expansion (CTE), the fine placer will assure a better operational laser cooling for this component. Subsequently, the diodes are placed in front of the crystal and soldered with SAC396 (melting point 217 °C) to the copper pads.

The rest of the optical components are soldered with different SAC305 solderjet bumps depending on the accuracy needed for each assembly [11]. The micro-lenses are aligned by a pneumatically-actuated gripper allowing 6 DOF, and soldered over the Kovar pad with the solderjet machine by two 300 µm bumps placed on each side of the micro-lens. Afterwards, the second-harmonic generation crystal and the output coupler are aligned and soldered, both with a half sphere submount allowing accurate tip/tilt alignment and avoiding any translational movement in order to guarantee a soldering accuracy of a few arcseconds. The rest of the components (being less critical) are soldered over the pads using a 400 µm solderjet bumps.

Finally, the laser is inserted inside a copper housing (Figure 4) specially designed and modeled[1] for the mission purpose that will be hermetically sealed to ensure a leak smaller than 10^{-8} mbar*l/s by using the same cold soldering technique. Moreover, the housing is designed with an output Mini-AVIM[2] connector (Figure 5) with a spherical lens that has to be soldered to the housing for the same hermeticity reasons. Also, the sphere has to be precisely assembled with SAC305 alloy to assure that the laser beam is coupled correctly to the output fiber.

1 Designs and Finite-Element-Method (FEM) analysis performed by LIDAX Ingeniería (Spain).
2 Manufactured for the mission purposes by Diamond SA (Switzerland).

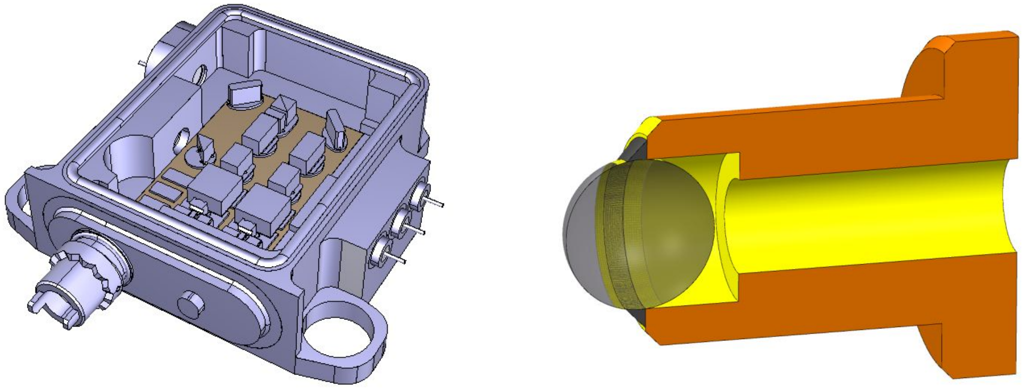

Figure 4: Left, design of the hermetically sealed housing by means of Solderjet technique (designs and simulations performed by LIDAX). Right, detail of the precisely assembled spherical fused silica lens into the stainless steel Mini-AVIM fiber connector, by means of cold soldering technique.

Figure 5: Example of Mini-AVIM connector specially designed for harsh environment as space applications. The Mini-AVIM combines two leading edge technologies: the AVIM MILstyle ratchet system and the base construction of Diamond Micro Interface (DMI) connector [12].

4. RESULTS AND DISCUSSION

Both adhesives and soldering techniques have been tested to assemble the laser unit for the Exomars ESA mission 2018. Different space-suitable adhesives have been studied (masterbond UV22, Masterbond EP21TDCHT-LOB, etc) to asses a better candidate, however none of them were free of gradual misalignments and instabilities over time. These misalignments have been observed during characterization time, making evaluation of a stable and repetitive laser emission impossible. Only the soldered assembled lasers by solderjet technology have been able to pass the stringent required specifications, being stable and constant over time.

The main tests performed on such lasers (at National Institute of Aerospace Technology INTA), able to be used in extreme conditions, are vibration, shock and thermal conditions. Through the mechanical characterization tests, the components have been proved to hold shear forces of 60 to 65 N, this shear strength being enough to withstand a shock of more than 10^6 g and able to handle the wide range of specified vibrational requirements for space devices. Even more, the assembled laser prototypes (Figure 6, left) were able to withstand the thermal environment requirements with a nonoperational temperature range from -60 °C to +70 °C and operational range between 15 to 45 °C (due to the strict wavelength stability requirement of a few picometers needed for Raman spectroscopy). Moreover, the devices were tested through radiation (proton and gamma radiation), vacuum and several burning and on-off cycles.

The main requirements have been demonstrated before and after the different performed tests at constant temperature. The wavelength stability has been maintained, better than ±0.005 nm, the full width half maximum (FWHM) under 0.03 nm (Figure 6, right), a TEM00 spot has been stable in time and the required output power has been constant at 50 mW, below a power consumption of 2 W (although the laser module can provide >500 mW with a power consumption of around 4.5 W).

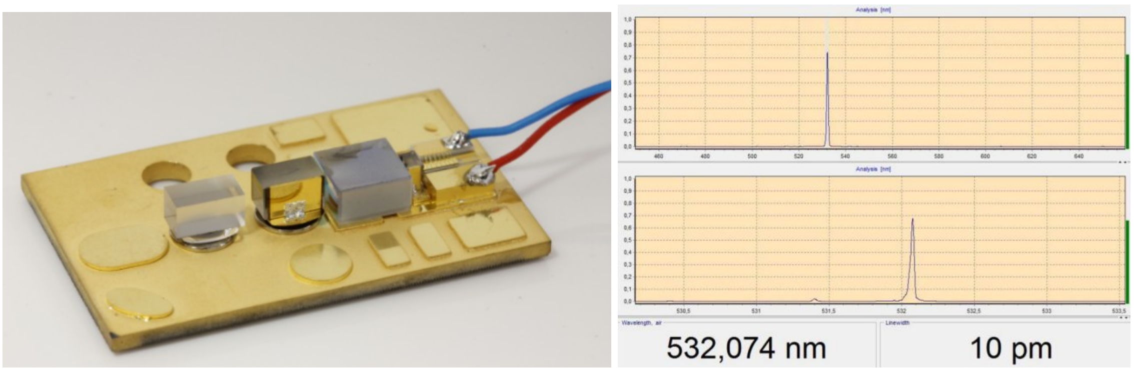

Figure 5: Left, soldered Exomars one laser channel resonator. Right, wavelength laser emission example.

5. CONCLUSIONS

A compact and miniaturized adhesive-free green laser for extreme conditions application has been achieved for the first time, applying laser-induced Solderjet bumping technology to fix the optical components in order to improve robustness and repeatability. This technology could be used in a wide range of applications that require similar characteristics as could be industry, medicine or military applications. Thanks to the 6 DOF SolderJet set-up, a wide range of geometries can be assembled to cover relevant design needs.

6. ACKNOWLEDGEMENTS

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