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Solderjet Bumping as a versatile tool for the integration of piezoelectric deformable mirrors

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Abstract

A deformable mirror (DM) is a device that aims to compensate laser-induced mirror deformation and thermal lensing in the optical system. The mounting of membrane based DM with screen-printed actuators is crucial, as stress may deform the membrane and change their characteristics (shape, piezoelectric deflection, natural frequency). We present the laser-based Solderjet Bumping (SJB) technique to assemble mounts for piezoelectric-activated DM. The discussed polymer-free joining offers advantages, such as improved temporal stability and low outgassing, over adhesive bonding. We evaluate the optimum number of solder joints with respect to resonance behavior by finite elements analysis and experimental measurements. Long-term evaluation over a period of more than four years shows no significant change of resonance behavior. Thus, we prove the SJB bonding technique to be stable for dynamic applications over several years, and consider it a versatile tool for integration of DM.

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1. Introduction

Mounting is crucial to performance of piezoelectric actuated membrane mirrors as mount-induced moments and constraints change the mirror's characteristics such as flatness, piezoelectric stroke, and resonance behavior. Such deformable mirrors (DM) must have a high quality optical surface and offer large piezoelectric stroke. Further, their dynamic properties must be reliable. Only if these requirements are fulfilled, can DM be applied to compensate for wavefront aberrations in optical systems. The large stroke of DM relies on thin membranes with large aspect ratios; typical diameters of several tens of millimeters and thicknesses below 0.5 mm.

Unimorph deformable mirrors can be applied to compensate for atmospheric wavefront aberrations (Feinleib *et al.*, 1974; Steinhaus *et al.*, 1979; Ma *et al.*, 2013) as well as aberrations in laser systems (Aleksandrov *et al.*, 2007; Cheriaux *et al.*, 2007; Zhi-Jun *et al.*, 2009), e.g. thermal lensing (Primmerman *et al.*, 1976; Aleksandrov *et al.*, 2005). Unimorph mirrors with 214 actuators have been proposed by Ma *et al.* (2013) for atmospheric applications. Furthermore, thermal-piezoelectric deformable

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mirrors (TPDM) with piezoelectric and thermal actuators as well as integrated sensors requiring 89 reliable contacts have been introduced for the compensation of thermal lensing by Reinlein *et al.* (2014).

The mirror's dynamic properties need to be reliable as current control strategies use the dynamic behavior of the actuated mirror membrane in order to improve the control performance in terms of control rate and deviation. It is therefore beneficial to identify a reliable technology for mounting and electrical contacting of DMs. Different approaches are worth discussing: clamping or material fit bonding such as adhesive bonding or soldering.

Clamping is a basic principle that relies on form and force fit joining using retainers, e.g. spring clips, snap rings, threaded retaining rings (Yoder, 2004). It could be realized by pressing the membrane's front surface against the flat surface of the mount either by a retaining ring, a flange type retainer, or by screws or springs on the rear surface. The point or line contact of such mountings might lead to potentially large contact stresses that could impair the functionality of the system due to surface deformation. Elastomeric mounting provides a means of distributing such preloading forces but introduces organic materials to the system.

Compared to mechanical clamping material fit joining allows further miniaturization of the joint and the minimization of mount-induced stresses. Bonding techniques using polymeric adhesives or soldering by metallic solder alloys can provide such material fit joints. Both processes could produce extensive plane or point-shaped joining areas. Localized joints minimize stress but decrease mechanical stiffness and may therefore change the dynamic behavior of the assembly. Adhesive bonding seems quite obvious as it is a simple and inexpensive technique. Unfortunately it has certain drawbacks: low thermal conductivity of the adhesive, shrinkage, reduced long-term stability, moisture induced degradation, and eventually outgassing. Solder joints provide a higher thermal conductivity, higher mechanical strength, and improved stability over time with respect to environmental influences. The all in-organic bonding materials prevent outgassing and offer significant advantages for many fields of application. Soldering, however, requires a solderable metallization on both components and the thermal reflow of the solder alloy. Laser-based soldering is well suited for the joining of optical components made of fragile and brittle materials such as glasses, ceramics, and optical crystals due to its localized and minimized input of thermal energy. In particular the limited heating of the local soldering is a key advantage over high temperature processing of a global reflow of the assembly. Such a reflow process could lead to significant deformation or disruption of the LTCC (Low Temperature Cofired Ceramics) membrane and depolarization of the piezoelectric elements.

We therefore propose a laser-based soldering technique, Solderjet Bumping (SJB), for mounting and packaging of deformable mirrors for both the attachment of the mirror membrane to a mount and the electrical contacting of the piezoelectric actuators to a printed circuit board. It is based on prior work for mounting of optical elements, e.g. lenses (Burkhardt *et al.*, 2015a) and unimorph deformable mirrors (Reinlein *et al.*, 2013). It simplifies the manufacturing process and the localized heating during soldering is beneficial for a low stress mounting of sensitive components such as the used mirror membranes. SJB bonds have been characterized with respect to their thermal and dimensional stability of assemblies joined by SJB, bridging large gaps of about 100 µm between the components. They exhibit a length change of ~25 nm and a tilt of ~1 arcsec when subjected to a temperature variation from 10°C to 40°C over a year, supporting the claim of long term stability (Lorenz et al., 2015). We have also demonstrated the stress relaxation in solder joints by photoelasticity measurements of optical path difference (Burkhardt *et al.*, 2015b). However, the capability of the SJB technique to influence DM dynamic properties, and the long-term stability of soldered DM mounts have never been addressed.

This study examines DM mounting and actuator contacting by SJB. The aim of this work is the determination of the necessary number of discrete solder joints in order to obtain membrane characteristics comparable to a fixed mount by analysis of their resonance behavior. Moreover, three pilot samples were set up to analyze the resonance behavior at the optimum number of solder joints in order to detect mounting-induced moments and constraints. In addition, we evaluate the long-term stability of SJB bonds by resonance measurements over a period of more than four years.

2. Experimental setup and procedures

2.1. Laser-based Solderjet Bumping

Joining, packaging, and assembly of sensitive optical components benefit from flux-free bonding techniques that prevent contamination of surfaces. Precisely controlled heating, e.g. laser-based, and solder reflow lead to minimized areas of thermal influence and are thus advantageous for high-precision joining. The localized heating avoids thermal dealignment during assembly and enables the sequential build-up of systems. Different techniques of heating solder alloys by laser irradiation are proposed using either thin film solder layers (Banse *et al.*, 2005), solder pastes (Stauffer *et al.*, 2005), solder preforms heated at the joint (Hoult *et al.*, 2003), or the jetting of laser-molten solder droplets (Beckert *et al.*, 2010). Furthermore Stein *et al.* (2014) extend the use of this principle to high temperature joining/brazing using Cu89Sn11 alloy preforms and a novel ceramic nozzle type. A contact-free alternative, the Pick&Align soldering technique, has been suggested by Faidel *et al.* (2012) using integrated resistive layers.

The proposed SJB technique allows for a flux-free and contact-free bonding of optical components. In contrast to thin film soldering techniques, it is possible to bond materials with lower demands to surface quality – especially with respect to surface