Laser Trimming of Silicon Micro Mirror Devices by Ultra Short Pulse Lasers

B. Keiper[1], M. Weber[1], J. Hänel[1], T. Petsch[1], J. Mehner[2], C. Kaufmann[3]
[1]3D-Micromac AG, Max-Planck-Straße 22b, Chemnitz
[2]Fraunhofer Institut for Reliability and Microintegration, Department Micro Devices and Equipment
[3]Chemnitz University of Technology, Center for Microtechnologies

1 Introduction

Laser-trimming of microstructures is a promising approach to overcome manufacturing tolerances and to tune sensors and actuators for certain operating conditions. A joint research project between 3D-Macromac AG and the Chemnitz Center for Microtechnologies investigates new technologies for wafer level stiffness and frequency tuning of silicon microstructures by ultra short laser pulse tuning. Goal of the development work is to establish a novel technology which allows for in-line measurement of mechanical properties and laser treatment in order to calibrate performance parameter of MEMS. Particular features of laser trimming will be demonstrated on Micro Mirror Devices (MMDs) which are widely used for image projection applications Fig. 1.

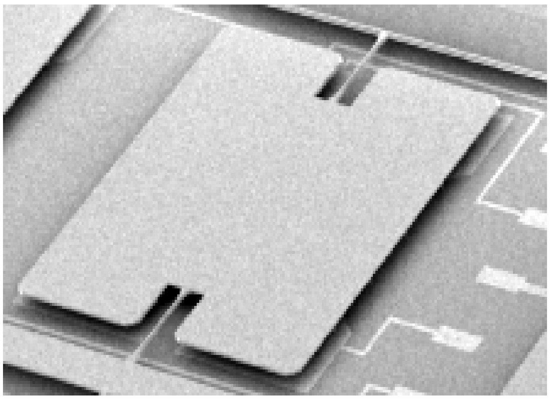

Fig. 1 SEM photography of a Micro Mirror Device.

Advanced optical projection systems (e.g. head-up displays for cars) require micro mirror cells where the resonance frequency lies in a narrow spectral range of about 1% what can hardly be realized in manufacturing facilities. The new idea is to tune the stiffness or inertial mass of micro devices by laser thinning or laser cutting processes. Fig. 2 shows our general approach schematically. Challenging issues for the project are how to prevent contamination by emitted particles and how to reduce surface damage or warp due to laser treatment.

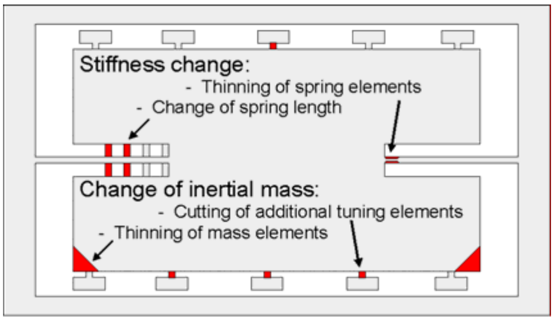

Fig. 2 Possible options for resonant frequency tuning.

2 Laser Trimming Techniques

Tuning of MEMS can be accomplished with extremely high precision by laser ablation. However, when utilizing a conventional long-pulse laser, processing is accompanied by the deposition of heat in the material. Due to the excitation of phonons in superficial regions of the sample, melting occurs and molten material evaporates from the sample. This process is associated with the formation of a heat-affected zone possessing much elevated temperatures. The spatial extent of such zones depends on material parameters including thermal conductivity and laser parameters such as wavelength and pulse duration.

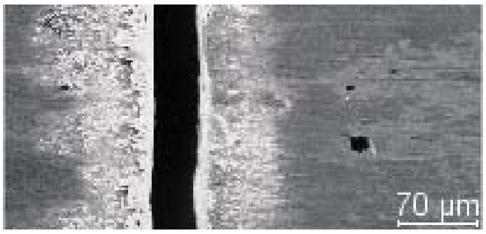

Fig. 3 Extended heat-affected zones on both sides of a ns-laser cut trench.

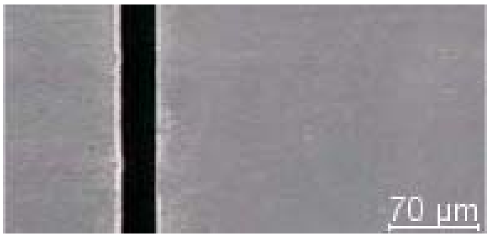

Fig. 4 Virtually absent heat-affected zones adjacent to fs-laser cut trench.

By contrast, ultra-short laser pulses interact thermally with solid matter by the generation of a highly excited electron-hole plasma. Since the extraordinarily high energy contained in the ultra-short laser pulses (several gigawatts per pulse) is directly coupled into the electronic structure and no phonons become excited, a heat-affected zone is almost completely absent and no melting or splashing of droplets is observed. The ablation energy is almost completely carried with the plasma expanding away from the sample (Fig. 4). For this rationale, trimming of MMDs with ultra-short laser pulses is to be preferred over the usage of long-pulse laser radiation.

Fig. 5 Femtosecond Workstation

Yet another problem consists in the generation of debris, since the wafer containing the MMDs has to become further processed and e.g. upon bonding, superficial particles or an increased roughness are highly problematic. When processed under ambient pressure, ablated material has a mean free path of less than a few hundreds of micrometers. Two approaches have been validated capable of resolving this issue: processing under a rapidly flowing gas (a crossjet nozzle was placed close to ablation spot) and micromachining inside a vacuum chamber. While in the former setup, particles continued to condense on the sample (the spatial distribution, however, was no longer symmetric around the ablation location), processing in vacuum proved to give much better results.

Fig. 6 Picosecond Workstation PS-1064

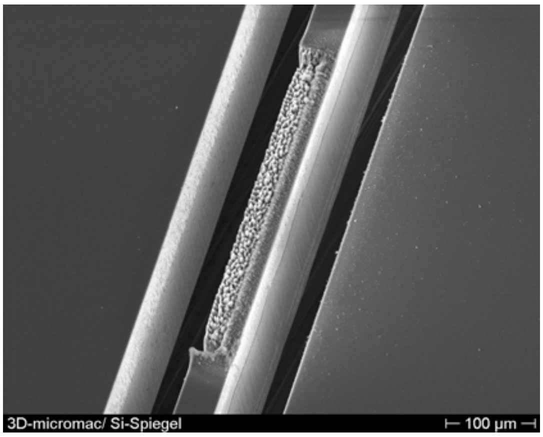

Fig. 7 Processed spring bar of a MMD.

A thinned spring bar is depicted in Fig. 7 and 8. The examples shown have been micromachined with a femtosecond-laser workstation developed by 3D-Micromac AG. At a wavelength of 775 nm and a pulse width of ~ 150 fs, processing was performed using a 50 mm objective resulting in a minimum focus diameter of 7.5 µm. Thinning has accomplished by scanning the beam sixty times at a parallel offset of 1 µm.

The Center for Microtechnologies (ZfM) and 3D-Micromac AG have successfully developed and tested strategies for laser trimming of microstructures. Aim of the collaboration is to investigate achievable accuracy and efficiency as well as developing new laser systems and equipment for in-line laser treatment of MEMS.

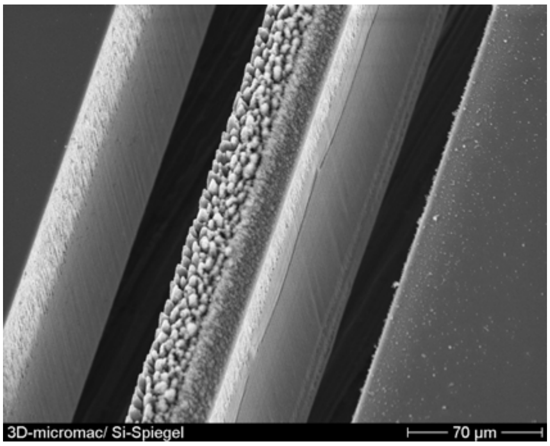

Fig. 8 Femtosecond-laser machined spring bar of a MMD (enlarged section of Fig. 4).