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Research paper

Lateral performance evaluation of laser micromachining by high precision optical metrology and image analysis

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ABSTRACT

Today several techniques are available for micro-manufacturing. Yet, it is difficult to assess the precision and lateral X,Y accuracy of these techniques. The available accuracy information is usually based on specifications given by machine suppliers. This information is based on in-house laboratory tests performed by dedicated machine operators and within an adapted environment. In practice, the accuracy is likely to vary due to environmental conditions, materials and operator skills. In order to check the specifications in realistic environments the EUMINAfab infrastructure consortium initiated a set of independent high precision onsite verification tests on different laser micromachining installations. In addition to providing performance verification, it gave the participating partners real capability information of their equipment and possibilities to improve machining performance to a higher level. In this study a comprehensive verification test was designed and carried out by using a high precision metrology method for 2D measurements based on subpixel resolution image analysis. This methodology improved our knowledge of the capabilities of three laser micromachining installations, and showed that specifications at single micron levels are hard to obtain.

1. Introduction

Over the past decade micro-manufacturing has developed into many areas [1–4]. Today micro-machined components are key elements in many micro-mechanical/electronic and optical devices with a wide range of application in different fields such as biomedicine [5,6], micro-electronics [7], and telecommunication [8–10]. In micro-manufacturing, the critical dimensions of a product often require a very high precision in absolute measures. A small deviation from the nominal design in micro-machined components can cause the final product to fail. Thus there is a need to understand the correlation between the micromachining process and the micro-manufactured products as many parameters may affect the precision at micrometer level. This requires a thorough study of all possible errors such as tool, installation, process, operator and environmentally induced errors. Yet, it is common practice to simply trust the machine's specification provided by the manufacturer. But in practice the absolute performance of the machines may be critically different from the manufacturer's specifications due to conditions not considered by the manufacturer's in-house test conditions. Therefore a precise objective verification test which accurately reveals the absolute performance of the micromachining equipment is considered as a great help to machine users, to assess the real performance of their equipment.

So far, a precise objective verification test for general performance evaluation of micromachining installations has been a challenge because of the limited number of ultraprecise submicrometer metrology techniques covering the accessible XY range of the laser micromachining equipment. In addition to our initial tests [11], there are few studies related to performance evaluation of laser micromachining [12,13]. Most of these studies were done in terms of investigating specific error sources and not the general performance of the equipment [14]. To provide the machine's capability information, our study is performed as a comprehensive verification test, designed and carried out by using an optical 2D ultra-precision metrology system. Combined with high performance subpixel image metrology techniques, which were developed and adapted to the images of the manufactured components, we have established more knowledge about the XY accuracy

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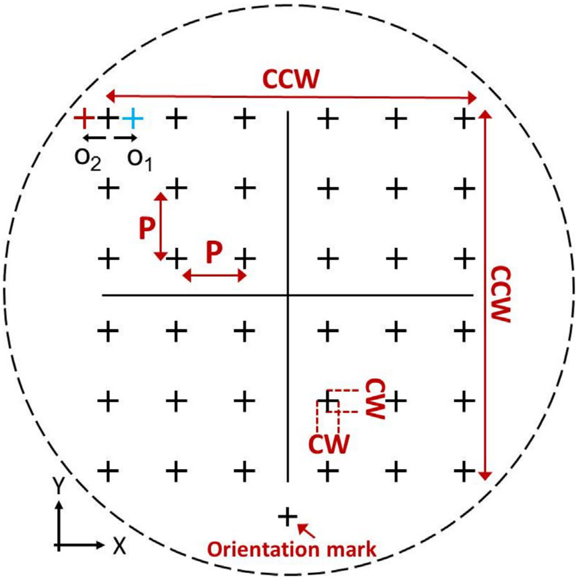

Fig 1. Dimension labels of laser machining pattern..

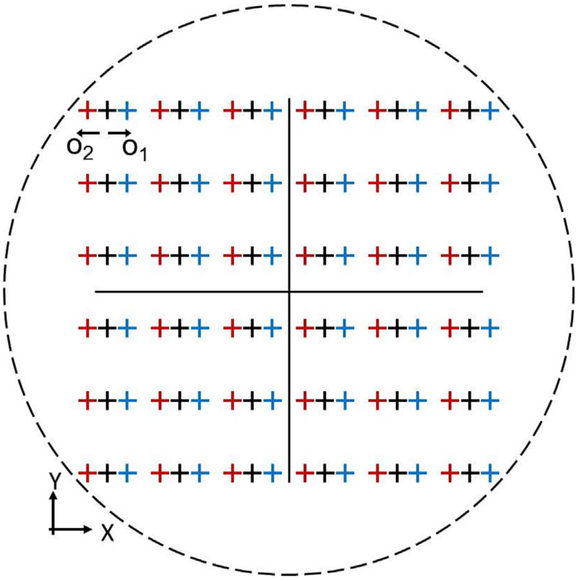

Fig. 3. Pattern repetition for laser machining.

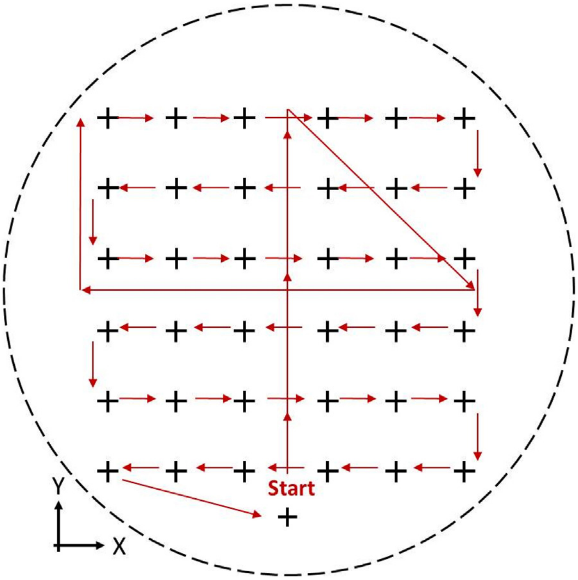

Fig. 2. Laser beam trajectory used in the process.

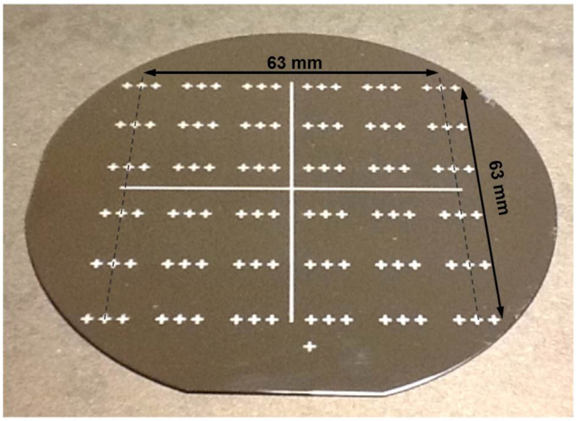

Fig. 4. A laser micro-machined wafer.

of the studied equipment. In contrast to traditional performance tests, being made in a limited number of points of the non-loaded machine as advised by SS-ISO 320-1, our study was carried out in typical operating conditions of real materials and applied at multiple points covering most of the accessible XY range of the laser micromachining equipment. This methodology was used to reveal the machining accuracy, pseudo-repeatability and reproducibility of each installation. In total the absolute performances of three laser micromachining installations are evaluated. The results also include the large range axis straightness of the machines.

1.1. *Laser beam machining*

Laser Beam Machining (LBM) is one of the micromachining processes which is used in making geometrically complex micro components. In this process, a laser beam is focused on the workpiece surface. Depending on the wavelength λ and pulse duration the focused beam melts or dissociate atoms or molecules and vaporizes the material and creates the desired structure and pattern at the surface [15]. In LBM the thermal and optical properties of the material have a stronger impact than the mechanical properties. Therefore, LBM can be applied for a wide range of materials including difficult-to-cut materials such as silicon [16,17]. The X,Y position of the laser beam, on the sample surface to be treated, is set by a beam delivery system based on Galvano-mirror control of the beam or in direct beam applications by mechanical translation of the sample holder. For a thorough description of the fundamentals of laser micromachining the reader is referred to reference [15].

In this study the absolute X,Y positioning performance of two picosecond installations, operating at λ 355 nm, and one nanosecond installation, λ 193 nm, was investigated.

2. Experimental

The lateral X,Y performance evaluation of the three laser micromachines was done in four steps;

First, a nominal pattern was designed and agreed on with the machine operators. The design makes use of a large portion of the writeable area of the machine. In the second step the laser machining was done in a predefined trajectory using the machine's typical running conditions and process parameters set by the operator. The third step is carried out on an ultra-precision optical coordi-

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