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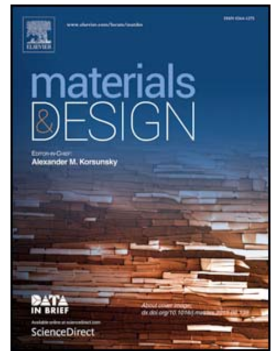

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The use of femtosecond laser ablation as novel tool for rapid micro-mechanical sample preparation

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Abstract

The focused ion beam technique has become a standard tool for micro-mechanical sample preparation in the last decade due to its high precision and general applicability in material removal. Besides disadvantages such as possible ion damage and high operation costs especially the characteristically small removal rates represent a bottleneck for this application. In contrast, femtosecond lasers provide material removal rates orders of magnitude higher, with small or ideally without thermal impact on the surrounding material. Hence, a combination of these two methods offers an ideal tool for time-efficient, micrometer-sized sample preparation. A prototype implementing this idea is presented here in combination with a case study. Cantilevers with a length of several hundred micrometers were machined into 25 μm, 50 μm and 100 μm thick, cold rolled tungsten foils. Scanning electron microscopy analyses reveal the influence of laser parameters and different scanning routines on the resulting sample quality and the effect of the laser pulse length (femtoseconds versus nanoseconds) on the ultra-fine grained microstructure. Finally, the performance for unprecedented rapid sample preparation is demonstrated with a sample array consisting of 100 cantilevers with a dimension of 420x60x25 μm^3 processed in only half an hour, opening completely new testing possibilities.

Keywords: Micro-mechanical testing, Femtosecond laser ablation, Nanosecond laser ablation, Sample preparation, Ultra-fine grained tungsten

1. Introduction

Mechanical experiments with specimens in the size regime between several hundred nanometers and some hundred micrometers become more and more important in order to achieve a better understanding of local mechanical properties and hence the mechanisms determining the materials' behaviour on these length scales [1–3]. Furthermore, the development and usage of small medical devices, micro-electro mechanical systems and nanocomposites increase the relevance of the knowledge of the materials' properties at these small dimensions [4, 5]. In addition, novel fundamental research approaches conduct micro-experiments, in order to e.g. validate multi-scale modelling approaches [6] or to determine the controlling mechanism of the brittle-to-ductile transition [7].

The state-of-the-art fabrication technique for the preparation of miniaturized mechanical samples is the focused ion beam (FIB) machining. Up to a sample size of few tens of micrometer the FIB technique offers an ideal tool in terms of variability and further provides high precision down to the sub-micrometer domain [8–10]. Utilizing this technique for micro-mechanics provided the basis for the development of various miniaturized testing concepts and sample geometries [11]. For example, for the fabrication of specimens in the micrometer range, starting from thin sheets [12] or bulk materials [13], it presents nowadays a standard tool. Nevertheless, due to the low removal rates it impedes the fabrication of an adequate number of samples when sufficient statistical information is required and therefore becomes a costly and time-consuming method. Hence, the sample preparation employing the FIB technique represents a bottleneck for micro-mechanical studies. A further disadvantage of the FIB is the so-called ion-damage, which describes ion-induced defects in the near-surface layer caused by ion implantation [14, 15].

Especially the pre-preparation of samples usually requires the removal of a large amount of material and therefore is a time critical step. Due to the depletion of the ion source, these time intensive rough cuts make up a significant part of the operation expenses for a FIB system. High currents further lead to a high ion beam dosage and hence a strong influence on the material [16].

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