Automated quality control for micro-technology components using a depth from focus approach

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Abstract

This paper describes an optical approach to verify the geometric accuracy of object surfaces structured by an excimer laser. Due to the restricted space in the excimer laser system a passive optical approach is chosen to be integrated in the system. Different optical techniques are compared. Their advantages and disadvantages for the use of integrating them in a laser system are discussed in the paper. The depth from focus approach is presented to create 3d models of surfaces structured by a laser and experimental results are shown. A prospective is given for implementing a control loop during runtime for the laser system.

1. Introduction

Fast growing micro-technology applications require reliable and cost efficient production methods for very small components, i.e. with dimensions in micrometer range or even below. An frequently used method to produce small components e.g. chassis is the structuring with UV-laser. A typical problem, particularly when structuring great regions with a laser, are webs arising at the boarder of the laser mask.

Therefore producing such components requires quality control in order to ensure geometrical accuracy. An integrated quality control reduces production time and costs.

Several measurement methods to inspect surfaces in micrometer range have been developed. They can be divided into tactile Systems, Scanning Probe Microscopes, Scanning Electron microscopes and optical systems [1]. Tactile systems acquire the depth map of selected points of an object by contact using e.g. a tactile ball. With Scanning Probe Microscopy the depth map of the object is obtained by physical interactions with the probe. Scanning electron microscopes use electron beams in vacuum for measuring. Optical systems use a lens system for measuring and can be further subdivided into active and passive techniques. Active techniques i.e. Speckle interferometry, confocal microscope use coherent light like laser beams for inspecting the depth map. Passive techniques instead use only a light microscope with camera and diffuse illumination.

This paper focuses on an automated quality control that can be integrated in UV laser systems. Due to limited space it is difficult to integrate a complex measurement method in the laser system. Therefore an passive optical approach was chosen to be integrated in the system.

Using a light microscope to verify the geometric accuracy of structured objects, two measuring modes can be distinguished. An monitoring mode during runtime of the laser and an offline mode. Monitoring at run time can be done during a laser pulse or between the pulses of the laser. An monitoring mode, measuring during the laser pulse was described by [6] where the light emitted from the burning metal of the object is used for specifying the distance. This monitoring method delivers only information of depth for the region of metal removal. The method can not be used in order to detect webs on the surface arising by moving the object to the new position between pulsing. Monitoring between the pulses is suitable used for implementing control loops of the laser system and the less time critical offline mode can be used for a final quality check of the structured components. These paper is focused on the monitoring process of the offline mode. A passive optical measurement system for this application has been developed and will be described in the following .

2 Passive optical measurement techniques

Several passive optical approaches have been developed. Among them the Stereo Image Analysis (SIA) approach.

2.1 Stereo image analysis

Depth map of an object is calculated based on two or even more images taken from different cameras. Camera parameters and position of the cameras have to be calibrated. Depth is calculated via triangulation of the corresponding points in the two images. A common problem are outliers where no corresponding points can be found. As a result of the different camera views it may occur that some parts of the object are observed only in one image, known as ”occlusion”. Depth estimation is not possible in such cases [2][3][7]. Depth estimation can only be done for points lying in focus of the lens. SIA requires therefore a as large as possible depth of focus. The used lense of the light microscope has a very small depth of focus. Finally, caused by the two cameras needed an integration in the system would be more complicated then using a single camera as described below. Therefore the SIA approach is not suited for the target application.

2.2 Depth from Defocus

With the Depth from Defocus method using only one camera, the depth estimation is done based on two images, one in focus and one in defocus with blurred areas [8][9]. With the grade of blur in the image taken the depth map can be estimated. According to [2] DD is less precise as SIA.

2.3 Depth from focus

More accurate depth maps as obtained from DD provides the Depth from Focus (DF) approach. Which requires a couple of images with different known settings for e.g. lens position or focal length and searches the setting with best focus measure for each pixel. The depth map can be calculated from the chosen settings. Due to the small depth of focus of a light microscope the DF approach can be easily applied to the described application.

An important advantage of the DF approach is the no existing correspondence resp. occlusion problems as known in SIA and the microscope do not have to be considered. Therefore, the DF approach is chosen for monitoring objects between being processed by the laser.

The laser system and integrated light microscope can be seen in figure 1.

3 Creating a depth map with the Depth from Focus approach

The DF approach exploits the fact that the distance between the camera and an object can be derived from a set of images taken at different camera parameter settings. The

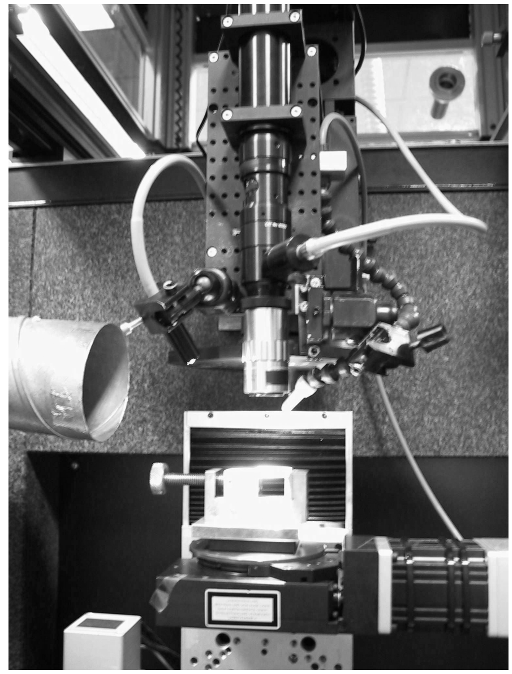

Figure 1. System

parameters which can be varied are object distance g, focal distance of the used lens system f, apex angle of the lens system α (figure 1).

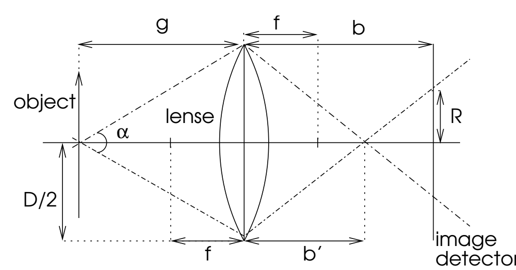

Figure 2. Optics model

Assumed is an abbe-ration free lens system and the projection is considered to be parallel due to the particular microscopes lens optic. With the lens formula

$$\frac{1}{b'} = \frac{1}{f} - \frac{1}{a} \tag{1}$$

and eq.

$$\frac{D/2}{b} = \frac{R}{b - b} \tag{2}$$

according to the theorem on intersecting lines we get for the radius of the blur circle:

$$R(g,f) = \frac{D}{2}(\frac{b}{f} - \frac{b}{g} - 1) \quad (3)$$

This equation describes the dependence of R of g and f with constant D and b for a given camera. The fact allowing the inspection of the deviation of a point from the focal plane can be described by the Point Spread Function(PSF). It describes the mapping of a point of the object to the image detector. Supposed the light intensity throughout the blur circle is considered to be uniform, the three dimensional PSF can be written as followed:

$$h(r,z) = \frac{\mathcal{I}}{\pi(z\tan\alpha)^2} P(\frac{r}{z\tan\alpha}) \quad (4)$$

(in cylinder coordinates) with

$$P(x) = \begin{cases} 1 & |x| <= 1 \\ 0 & \text{else} \end{cases}$$

Wherein $\mathcal{I}$ is the light intensity and α the apex angle of the lens system. The PSF describes a double cone whose top is located in the focal plane. The light intensity decreases with the power of two when increasing the distance. Thereby the in focus areas can be detected. For this application the object to lens distance was varied with a motorised micrometer lift table (see figure 3). Caused by the projection considered to be parallel, a change of the magnification can be neglected for a distance Δz between two observed levels. Several measures for the focus have been described. These are band-pass filtering, energy of image gradient, energy of image Laplacian [4][10] or the intensity of the image. For the application described in this paper the focus was measured by the variance within a window of size n*n. The value of focus is calculated for each pixel in each image of the image stack. Focus values of pixels located at the same position in an image are compared. The pixel nearest to the focal plane returns the maximum value. With information on the table position for a respective image on which this pixel lies, the depth at this location can be derived. These resolution in z-direction of the depth map depends on step size between two table positions Δz, characteristics of lens and camera system. Lateral resolution depends on lens, respectively the numerical aperture of the system and wave length of the used light (concerning to Raleigh) and in this case on the window size chosen to calculate the local variances.

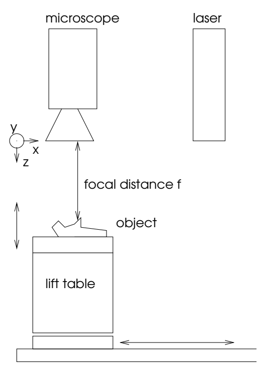

Figure 3. System setup

4 Optimisation of the Depth from focus approach

In order to increase the accuracy in z-direction an interpolation can be applied to find the position of the variance maximum over all images. Different approaches are described to approximate the devolution of the focus, e.g. a Gaussian normal distribution [5][11]. In this application the devolution is approximated by a polynom of second order. In order to get a first impression of the lateral distances of the object the 2D image of the texture map can be used. It shows the complete object in focus. Texture map is created using original source image values for the found maximum values.

5 Experimental results

Figure 4 shows three images of an image stack taken of a metal probe structured by an excimer laser using a rectangular mask geometry. The figure shows exemplary the difference of sharpness for a small region of the object. The probe has a rectangular hole with the dimensions $430\mu m * 300\mu m$ with different depths. The deepest hole is about $240\mu m$. In order to derive the depth map, 30 images of the probe were taken. The distance between two positions of the lift table Δz for each new image was 8.5 μm. Figure 5 shows the obtained shaded 3D model of the probe. The model with texture map is shown in figure 6. The reliability of the measurement when using a step size of $8.5\mu m$ was about 24 μm. Another metal probe is shown in figure 7. In this example a web as mentioned in the beginning of the paper can be seen. The size of the web depends on the speed of moving the laser mask to a new position and the frequency of the pulses. The size of the rectangular holes is about $340\mu m * 230\mu m$. The depth of the hole is about 60 μm. For modelling the probe 25 images were taken and the distance Δ z was about 3.4 μm. The reliability of the measurement using a step size of 3.4 μm was about 10 μm. Figure 8 shows the relief of the same probe. The textured model can be seen in figure 9.

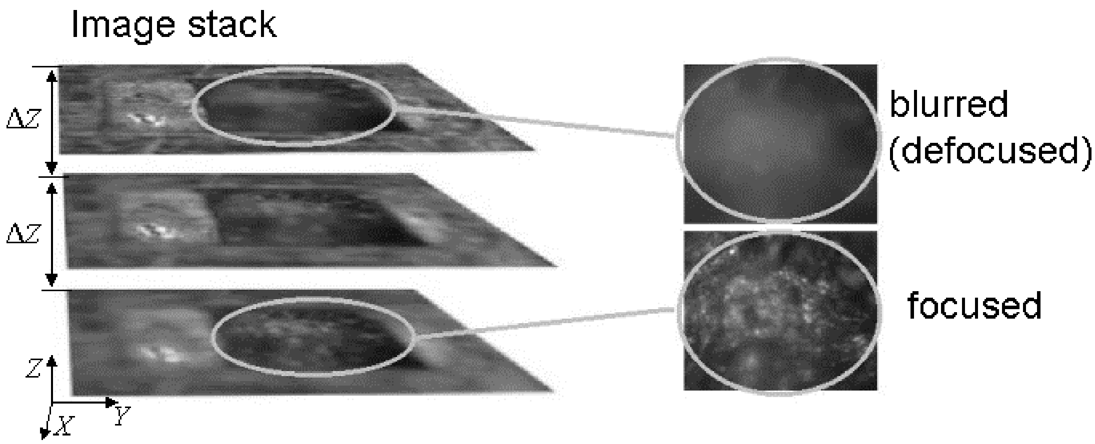

Figure 4. Input data: The variance is calculated for each pixel of each image. The maximal value (in z direction) represents the position nearest to the focal plane

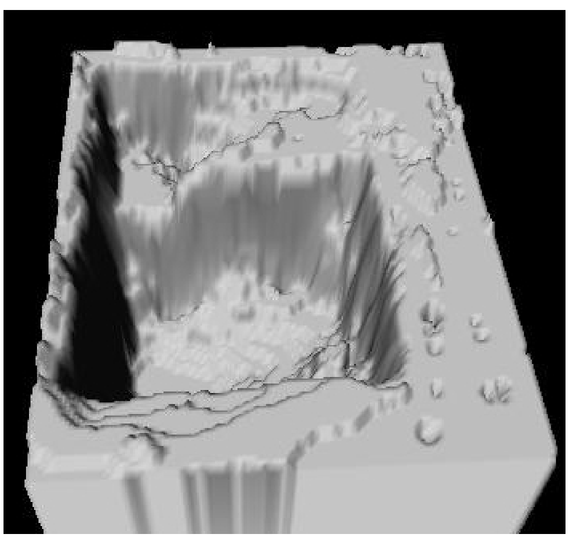

Figure 5. Shaded 3D model

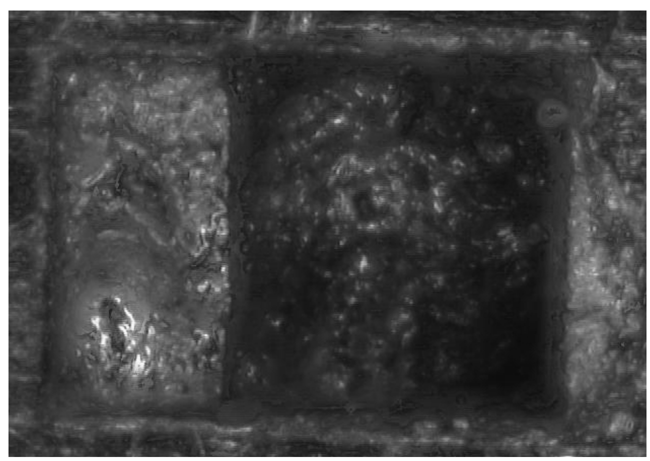

Figure 6. Texture map of the object

6 Conclusion and prospective

The DF approach is a simple and stable method. The mechanism can be easily integrated in a commercial laser system. For the given laser system the DF approach delivers sufficiently accurate results for the calculation of deviations of structured objects. The approach presented in this paper can be used for the quality control of structured objects after processing in the laser system. Further work focuses on a monitoring mode during runtime. In order to detect webs on the surfaces it is necessary to monitor the structuring process between the laser pulses as mentioned in the beginning. The amount of time for taking a couple of pictures and using a lift table as described in this paper is too large for such a time critical monitoring mode during runtime. For inspecting object surfaces during runtime an adapted DD approach should be implemented where only one image of the object has to be taken and knowledge of the material characteristics has to be integrated. This surface information could than be used to build an control loop for the laser. As discussed in the beginning the DD approach is less accurate then the DF approach presented in this paper. Therefore a final control step using the offline mode presented in this paper, seems still sensible in order to check the objects after processing.

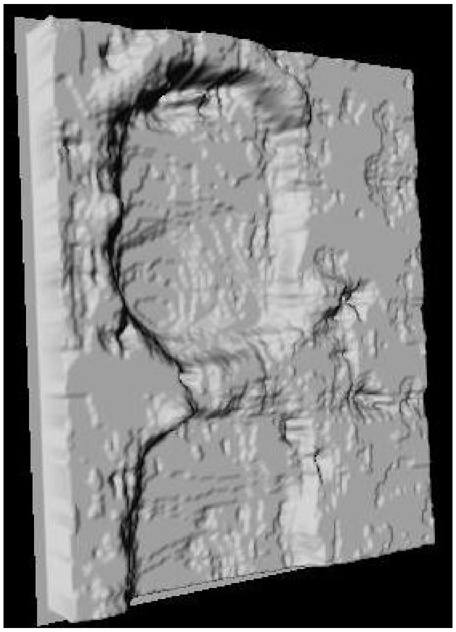

Figure 7. Shaded 3D model showing a web

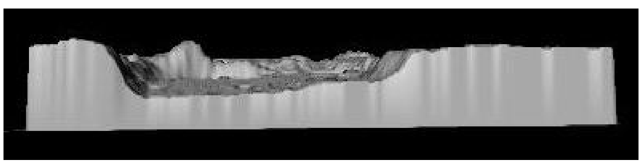

Figure 8. Relief of the shaded 3D model

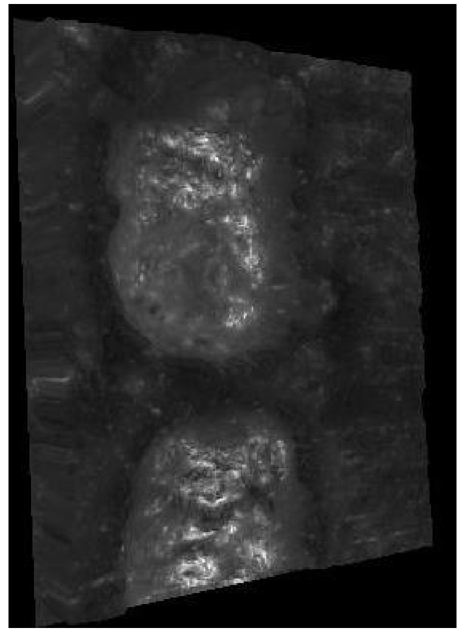

Figure 9. Textured 3D model with web

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