Optik 164 (2018) 488–497

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

# Spot image ablated by femtosecond laser segmentation and feature clustering after dimension reduction reconstruction

Fu-bin Wang[a,c], Yang Liu[a,*], Chen Wu[b], Xian-zhong Chen[b], Kai Zeng[a]

[a] School of Electrical Engineering, North China University of Science and Technology, Tangshan, Hebei, 063210, PR China
[b] School of Automation Engineering, University of Science & Technology Beijing, Beijing, 100083, PR China
[c] Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, Canada

ARTICLE INFO

*Article history:*
Received 5 February 2018
Accepted 9 March 2018

*Keywords:*
Femtosecond laser
plasma spot
image segmentation
manifold learning
feature dimension reduction

ABSTRACT

When monocrystalline silicon material is ablated by femtosecond laser, plasma derived luminescence also occurs. By collecting plasma spot image and analyzing the feature of spot image, which can be used for the classification of laser ablation power and the parameters optimization of ablation process. Considering that the contrast between edge and background area of plasma spot is not obvious and the signal to noise ratio is lower, we analyzes the segmentation efficiency for dim spot target by comparing the traditional Otsu (maximum class square error method) and PCA(Principal Component Analysis). The experimental study shows that the extracted multiple geometric features of spot image segmented by PCA method are more consistent; however, the ablation transition zone and part halo are segmented into target by traditional Otsu, which leads to the larger dispersion among extracted geometric features of spot, and it is also not beneficial for feature analysis and recognition of ablation process parameters. Further, the brightness of spot image under different ablation power was extracted, combining with pixel area, perimeter, long and short axis and long and short axis ratio of spot image, a six-dimensional feature matrix is built to classify the laser ablation power. Because of the large amount of data collected plasma spot sequence image, the manifold learning algorithm is used to reduce the dimension of feature matrix. Each spot image with 10mW, 20mW and 50mW ablation power is selected respectively 100 frames to build the six-dimensional feature matrix, three manifold learning algorithms are used in contrast to realize matrix dimensionality reduction and scatter plot reconstruction, then the feature distributions of spot image ablated by three kinds of ablation power are observed in three-dimensional space and two-dimensional plane, we find that the clustering effect for decreased dimension feature points using LPP(Locality preserving projections) algorithm and LLTSA(Linear Local Tangent Space Alignment) are better, they can be used to classify the spot image under different ablation power.



## 1. Introduction

Femtosecond laser micromachining ablation technology is widely used to process on the surface of opaque material or in transparent material, and various microscale structures can be obtained by high ablation energy of laser beams. Compared with ordinary laser processing, femtosecond laser processing has the advantages of high precision, low thermal effect and low

* Corresponding author.
*E-mail address:* liu1130377088@163.com (Y. Liu).

https://doi.org/10.1016/j.ijleo.2018.03.027
0030-4026/

ablation threshold. When femtosecond laser beam focuses on the surface of object and interacts with the substance, electrons in object atom absorb laser photon energy; the energy of photon is converted into kinetic energy of small particles such as electrons. After the material particles are separated from the surface of the object, the temperature is up to 2000K and the plasma is formed [1]. Amoruso S believes that the duration of plasma generated by femtosecond laser continues to be about microseconds, and the wavelength of diffracted light is different from the laser wavelength, it can be easily detected. This makes it possible to study the process parameters such as the classification of ablation power by using the characteristics of diffraction light spot image [2]. Study on the changing process of ablated material by using spot image feature, and optimize ablation parameters are getting more and more applications. Ionin and Kudryashov et al. used scanning electron microscopy, atomic force microscopy and optical interference microscope to dynamically measure modified area generated from surface of ablated silicon, and the thermal dynamic results excited by laser are obtained [3]. Chang et al. [4,5] connect diffractive light with the depth of processed microgrooves, and use the concept of LAV (laser ablation volume) and spot brightness to realize the online judging for processing depth of microgrooves. Chao-Ching Ho proposed an online estimation method for laser drilling depth, image features was used in detection for laser induced plasma region, the relationship between pixel and hole depth is obtained by converting region size to pixel value [6]. By discussing the relationship between the size of plasma spot and ablated hole depth, Ho et al. [7,8] concluded that the machined hole depth is inversely proportional to the peak value of plasma diffraction light under the given laser ablation power, and the axial intensity of laser beam decreases with the increase of defocus distance.

With the change of ablation power and laser processing direction, the shape and geometric characteristics of spot image also change. How to accurately segment spot image and then ensure the reliability of extracted geometric feature parameters is very important to study processing parameters optimization and processing power recognition based on spot image feature. For the image segmentation of dim spot target, image segmentation effect of traditional Otsu [9] segmentation and PCA [10] method is compared in this paper, and the spot features are extracted. The comparative analysis shows that the correlation degree and conformance of characteristic changes between geometric characteristic parameters of spot segmented by PCA are high.

Based on the spot geometric characteristics as main parameter, the six-dimensional matrix of spot sequence image is constructed by combining the brightness changes of spot image, then the manifold learning method is used to reduce the matrix dimension. Through observation for distribution of characteristic scatter points in three-dimensional space and two-dimensional plane, we found that clustering effect of characteristic scatter points obtained by LPP algorithm and LLTSA algorithm is more effective.

## 2. Femtosecond laser ablation experiment

The processing experimental platform of femtosecond laser consists of two main parts: the upper part is femtosecond laser producing area, and the laser focal length and ablation power are controlled here, adjustment of laser focusing is realized by the upper and lower displacement in the *Z* axis. The lower part is motion control platform with three-degree-freedom, as shown in Fig. 1(a). *X* is the displacement of platform in left and right direction, *Y* is the displacement of platform in front and back direction, *U* is the rotation displacement of platform. The ablated silicon wafer sample is shown in Fig. 1(b).

The plasma luminescence phenomenon will be generated when silicon wafers is ablated by femtosecond laser. The plasma spot image produced from ablated monocrystalline silicon is captured by CCD, by extracting and analyzing image feature, the change rule of process parameters of femtosecond laser ablation process can be found, which has positive meaning to improve efficiency of femtosecond laser ablation. The power variation range of femtosecond laser used in experiment is: 0-100mW; frame frequency of camera is 30 frames per second.

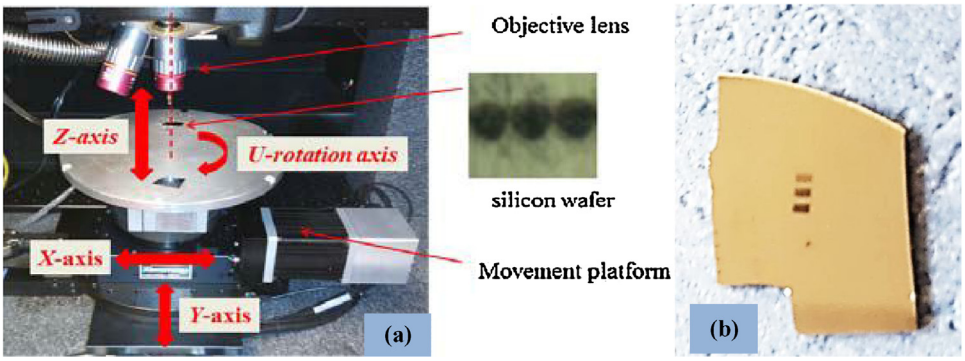


**Fig. 1.** femtosecond laser processing platform and ablated silicon wafer.