Ultraviolet nanosecond pulse laser 3D micro-fabrication system

Chunyang Liu, Xing Fu, Yong Wu, Fengming Sun, Xiaotang Hu

State Key Laboratory of Precision Measuring Technology and Instruments
Tianjin University, Tianjin, 300072, P. R. China

Tel.: +86-22-27409446-7 Fax: +86-22-27406941 E-mail: chunyangliu@tju.edu.cn

Abstract

In this paper, a designed ultraviolet nanosecond pulse laser micro-fabrication system is introduced. The system consists of ultraviolet nanosecond pulse LASER, computer software, control system, 3D work platform, mechanical and optical structure. The 3D work platform is driven by step motors with single step about 625nm in each direction. Step motor in Z direction is used for focusing. Computer software supports the graphics, then the control circuit drives 3D work platform to move for the fabrication procedure. And raster ruler is used to measure the veracity of the system movement. Some structures on silicon, on plexiglass, and on ceramic tube are fabricated by the designed system.

Keywords: 3D micro-fabrication, nanosecond pulse laser, movement measurement

1. Introduction

With the development of semiconductor LASER and control technology of work platform, Short/ultra-short pulse laser micromachining technology has been researched as a focus of study recently. With advantage of non-contact processing, less pollution, more fabrication targets and less effect of heat, it is used widely in the design and fabrication of MEMS, aerospace, medical device and so on [1-2]. Compared with femtosecond pulse laser micro-fabrication, nanosecond pulse laser can realize precision processing with high efficiency [3-4]. A new ultraviolet nanosecond pulse laser micromachining system is designed to realize high precision micro-fabrication with minimal heat-affected zone and satisfy the requirement of the effect and the efficiency in micro-fabrication.

2. System

The micromachining system design is shown in Fig. 1. Control system based on DSP (Digital Signal Processor) and FPGA (Field Programmable Gate Array) is the core part of the system. It can realize high-speed digital signal processing and achieve real-time parameters control, because DSP works at a very high system clock and FPGA works in a parallel processing function. Its high performance determines that the ultraviolet nanosecond pulse laser micromachining system can get high quality and efficiency of processing.
Ultraviolet nanosecond pulse LASER, AVIA355-3000, is selected as the light source in the micromachining system. The wavelength is 355nm, the pulse repetition frequency can be set from single shot to 100kHz, and duration of the laser pulse is less than 40ns up to repetition frequency of 60kHz. The average power of the laser is 3W at repetition frequency of 20kHz. The most utilizable function of the LASER is that the parameter can be changed through RS232 communication, including the repetition frequency, the energy, etc.

Computer software is programmed by Visual C++ to process graphics. Its function includes resolving graphics file, setting micromachining parameter and so on. Graphics resolved by computer software is shown in Fig. 2.

The graphics data and relevant commands are transmitted through parallel port in a particular defined format. Control circuit processes the data and drives step motors to scan. 3D work platform realizes X/Y direction scanning according to graphics. And Z-directional step motor is used to drive the motion of optical structure to focus. The travel range is 150mm in X/Y direction and 100mm in Z direction. The maximum moving speed is 40mm/s. Single step can move 625nm in each direction.

The fabricated process can be observed through a CCD camera which is illumined by ring lighting at the bottom of the focusing lens. And raster ruler is used to measure the veracity of the system movement. The feedback of the measurement helps the control system drive the motors to move and reduce the error of movement.

3. Experiments

Using single crystal silicon wafer, plexiglass and ceramic tube as micromachining targets, some microstructures are fabricated by the designed system. Different materials may need different parameters, and different parameters will lead to different machining results. Parameters of the micromachining system, such as the moving speed of the work platform, the energy of laser, the repetition frequency of pulse, should be optimized experimentally before micro-fabrication.

3.1 Silicon wafer experiments

Because the highest average power is 3W at the repetition frequency of 20kHz, the system will achieve highest machining efficiency when repetition frequency of the laser is adjusted to 20kHz. Then the energy can be set from 0 to 150uJ by changing the proportion of energy on the front panel of the LASER. Some experiments are tried to optimize the parameters of the machining on silicon. It is obvious that low moving speed of the work platform is helpful to the linearity of fabrication. When work platform moves fast, the line becomes discontinuous dots. Energy of the laser is injected into the materials. Then the temperature increases. When temperature exceeds the melting point, the materials of target
are vaporized. So higher energy will bring more splashes of heat-affected zone and lead to deeper and wider processing.

![Fig. 3-a circle structure.](image)

![Fig. 3-b square structure.](image)

Fig. 3. Graphics fabricated by the system.

Figure 3 shows the results of fabrication on single crystal silicon wafer which are fabricated by optimized parameters. Repetition frequency is 20kHz, energy of pulse laser is 140uJ, and the moving speed of work platform is 2mm /s. In Fig. 3-a, the diameter of the circle structure is 1mm, and the line of circle is 25um wide and 10um deep. In Fig. 3-b, the square is 500um×500um, and the line is 40um wide. The edge of the line is smooth with less splashes of heat-affected zone in the picture. The result shows that single crystal silicon wafer can absorb 355nm ultraviolet pulse laser very well, and the system can realize micro-fabrication on silicon with good quality and high efficiency if the parameters are optimized.

### 3.2 Plexiglass experiment

355nm ultraviolet pulse laser is also used in the fabrication on plexiglass. The result shown in Fig. 4 testifies that the plexiglass selected as the target in the experiment cannot absorb 355nm ultraviolet pulse laser well. The structure cannot be fabricated efficiently on the surface of the target. Some holes with taper section are formed discontinuously instead of line, and the structure looks like the crack of glass.

![Fig. 4. Fabrication on plexiglass.](image)

The experiment proves that the energy of pulse laser cannot be transferred and conducted well within the plexiglass. So it is very important to choose suitable target in pulse laser micromachining. In order to realize fabrication with good quality, we should choose the material which can absorb the pulse laser well.

### 3.3 Ceramic tube experiment

Ceramic tube with 1mm thick is used as a conjunctive device in an optic communication instrument. Light fibers are placed through the tube, and two sensors are mounted at the symmetrical position on the tube. Two holes which diameter is 1.5mm are fabricated to drill through the ceramic tube by the ultraviolet nanosecond pulse laser micromachining system.
Figure 5 shows the result of the fabrication on the tube. The whole device is shown in Fig. 5-a. The ceramic tube is fabricated, and the ablation track is visible in the area of machining. Figure 5-b shows the detail of the hole. The edge of hole is very clear, and the curve is smooth. From the picture, we can see that the ceramic can be fabricated by 355nm ultraviolet pulse laser but the heat-affect zone is obvious and visible.

4. Conclusion

Some microstructures are fabricated on single crystal silicon wafer, plexiglass, and ceramic tube by the designed ultraviolet nanosecond pulse laser micro-fabrication system. The system can work well and achieve real-time high efficient 3D micro-fabrication. After optimizing the parameters, single crystal silicon wafer and ceramic tube can be fabricated with good quality. Plexiglass is not suitable for 355nm ultraviolet pulse laser machining because the absorbability is not so efficient. By analyzing the experiments of machining, we find that it is very important to choose the suitable target and optimize the parameters before fabrication. The system can be used in the practice application.

References