

# Micro-grooving of silicon wafer by Nd:YAG laser beam machining

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**Abstract.** Laser beam machining process is one of the thermal advanced machining processes use for machining all the types of metals, non metals, ceramics, semiconductor, polymeric materials and alloys. For the past few decades laser Beams are being used in various manufacturing processes. Viewing this fact, the researchers have explored number of ways to improve micromachining using Nd: YAG lasers of different materials in recent years. Hence, the present research attempts to explore the effects of the different process parameters such as diode current, frequency, on surface roughness, MRR during micro-grooving of silicon wafer.

## 1. Introduction

In the recent times with the emergence of rapid development in technology, requirement of rigorous design materials, unusual and intricate shape of work piece have taken place which has restrict the use of conventional machining methods.

Nd:YAG laser is one of the solid state lasers and are optically pumped using flash pumps or diodes lasers. However, Diode-pumped solid-state lasers offer many advantages over lamp-pumped solid state lasers. High efficiency, reliability, compactness and long operation lifetime are few advantages. Due to capability of changing the wavelength and frequency, Nd: YAG laser can be applied to machine high reflectivity and dielectric materials [6]. Moreover, Nd: YAG lasers are operated in both continuous and pulsed mode. Pulsed Nd: YAG lasers are operated in so called Q switching mode. Materials with high thermal conductivity can also be machined using short pulse duration i.e. micro-nanosecond without any thermal damage. A pulsed Nd: YAG laser produces high intensity infrared radiation at a wavelength of 1.06  $\mu\text{m}$  with output powers ranging from 500 to 12000W. Due to its short wavelength, it has capability of processing of highly reflective materials with less laser power. Nd: YAG pulse lasers have low beam power. However when operated in pulsed mode high peak power is achieved which is capable of cutting even thicker materials [1-6].

It has been depicted that the efficiency of side pumped Nd YAG lasers depends upon the absorption coefficient of of pump light by Nd: YAG rod which is determined by the wavelength of pump light. Moreover, it has been found that the directly close- pumping configuration aided in increasing efficiency of the diode pumped laser system [4]. When titanium(Grade2) and alloy Ti-6Al-



4V sheets were cut using Nd:YAG laser, gas supply was found to be significant parameter affecting the quality of cut [5]. During pulsed Nd: YAG laser turning of ceramic material, high pulse frequency was found to be effective for achieving minimum depth deviation in the laser micro grooved surface of aluminium oxide [6]. Moreover, spot diameter, thermal conductivity and reflectivity of material were observed to be important factors during machining[7]. Lowest level of roughness was observed at higher frequency ( $>7500$  Hz) and low sweep speed [8]. Pulse frequency and air pressure were also found to be dominant parameters for taper and hole circularity[9]. HAZ and taper formation were found to be critical factors which can be minimized but cannot be removed completely[10]. During surface engraving by Yb: Fiber laser of 1064 nm wavelength, scan speed was observed as main effective parameter for surface roughness[11]. Sankha Deb and Ratnakar Das [12] in their book “Laser Micromachining” illustrate that laser micromachining is ideal for the production of fine structures in materials such as silicon.

## 2. Experimental set up

Figure 2.1 below shows the experimental set up to perform micro-grooving operation in silicon wafer to study the effects and to find optimal values of process parameters that can achieve maximum MRR, minimum roughness. Nd: YAG which was used as a lasing medium was pumped using diode. The experimentation was performed using CNC controlled Diode pumped Nd: YAG laser system manufactured by Sahajanand laser Technology Ltd. India. The power of 230 V AC was supplied to the diode from AC mains which in turn enhance the ND: YAG laser that leads to stimulated emission of the photons causing lasing process. Vacuum operated workpiece holder has been used for holding thin sheets of silicon wafer and deionised water was used as cooling medium.

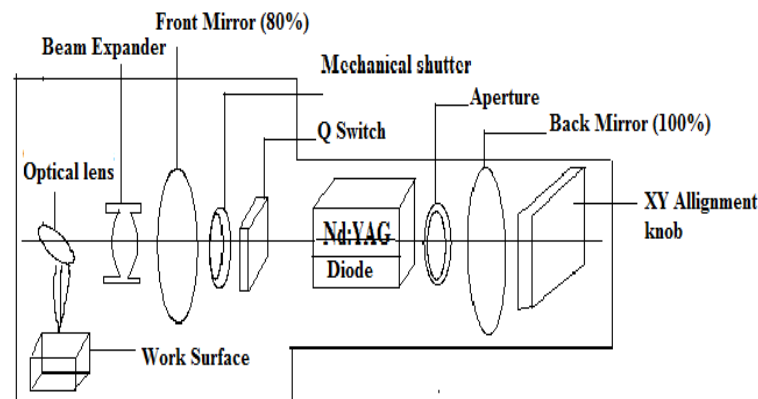


Figure 2.1 Experimental Set up of Nd-YAG laser Beam machine

The beam of system operates in fundamental mode ( $TEM_{00}$ ). The wavelength of the beam generated was 1064nm and was operated in Q-switched mode where beam was focused to the spot size of  $20\ \mu\text{m}$  using a lens of 69mm focal length. Parameters such as cutting speed, pass were controlled by the CNC controller and the Current and voltage was operated manually through the laser machine. Axial feed to the sample in transverse direction was provided by the CNC X-Y table movement automatically operated through personal computer attached to the laser machine. Figure 2.2 shows the photographic view of the Nd-YAG laser machine used in the machining.



Figure2.2 Photographic view of diode Nd: YAG laser machining system

### 3. Experimentation

The process parameters considered are diode current (A) and frequency (Hz) whereas material removal rate MRR (mg/min) and surface roughness Ra ( $\mu\text{m}$ ) are the response parameters under consideration.

Silicon is one of the most common semiconductor materials. The thin film of semiconductor with a very low thickness is silicon wafer. Silicon wafer was coated with aluminum oxide using PVD (physical vaporization deposition) to prevent corrosion. So, sample was cleaned before the machining. Setting the goal for the experiments, to perform micro-grooving on a silicon wafer and to investigate the effect of different process parameters considered on the machining performances, the present experimental investigation has been planned based on random experiments using one factor at a time approach (OFAT) where each operating parameter is varied once keeping the other parameters constant. Table 1 below shows the various properties of the work material silicon

Table1.Properties of silicon

Properties	Description
workpiece	silicon
structure	cubic
critical pressure	1450 atm
critical temperature	4920 <sup>0</sup> C
Molecular weight	28.086
Boiling point	2628 K
Melting point	1430 <sup>0</sup> C
Density at 300 K	2.3290 g/cm <sup>3</sup>
Thermal conductivity (300 K)	148 W/mK
Thermal expansion (10-50 <sup>0</sup> C)	4.05x10 <sup>-6</sup> /K
Specific heat	0.7 J/g <sup>0</sup> C
Youngs Modulus	131 Gpa

### 3.1. Experiments conducted

Table 2 and table 3 shows the experiments conducted during micro-grooving of silicon wafer varying diode pump current and frequency while keeping other factors constant.

Table 2 Experimental table with variation of diode pumped current

S.No	Id(A)	V	f(Hz)	N	C.S (mm/min)
1	14.5	20.3	4000	1	5
2	16	20.3	4000	1	5
3	16.7	20.3	4000	1	5
4	17	20.3	4000	1	5

Table 3 Experimental table with variation of frequency (Hz)

S.No	f(Hz)	V	Id(A)	N	C.S (mm/min)
1	4000	20.5	18	1	5
2	4200	20.5	18	1	5
3	4400	20.5	18	1	5
4	4600	20.5	18	1	5

## 4. Results and Discussions

Table 4 Material removal rate and roughness obtained with varying diode current

S.No	Id(A)	V	f(Hz)	N	C.S(mm/min)	MRR(mg/min)	Ra( $\mu$ m)
1	14.5	20.3	4000	1	5	0.2322	0.029
2	16	20.3	4000	1	5	0.2284	0.059
3	16.7	20.3	4000	1	5	0.231	0.071
4	17	20.3	4000	1	5	0.2543	0.091

### 4.1 Effect of varying diode current and frequency on Material removal rate and surface roughness:

Using the data of table 5, graph of MRR and Ra with respect to the diode current (Id) have been plotted in figure 3.1 (a) and 3.1 (b) respectively. Figure 3.1 (a) shows the effect of the diode current on the Material removal rate keeping other parameters constant i.e. frequency at 4000 Hz, single pass, cutting speed at 5mm/min and 20.3 V diode voltage. Initially MRR is more at 14.5A diode current and it is observed to have decreased as the current increases. Higher MRR at 14.5A diode current is due to

melting and ablation of material. The decrease in MRR from 14.5A to 16A may be attributed to the resolidification of molten material in the form of HAZ (heat affected zone) or recast layer showing low MRR. This increase in MRR may be attributed to the availability of higher pyrolytic energy.

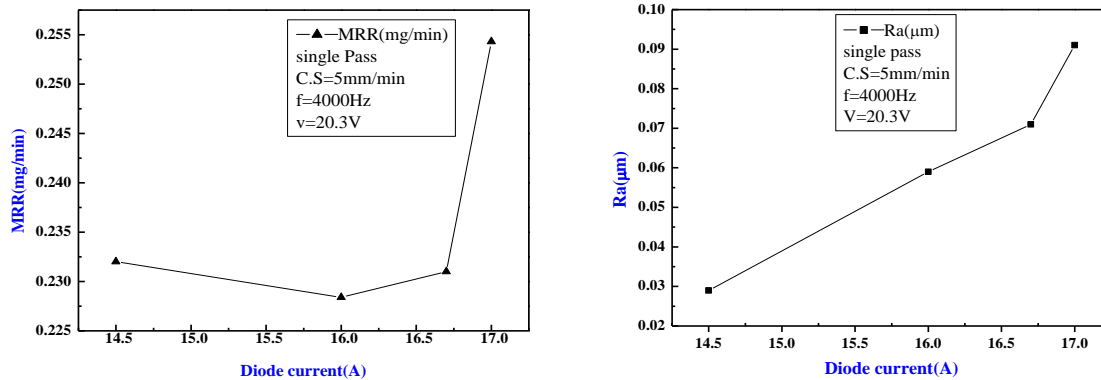


Figure 3.1 Variation of (a) Material removal rate (mg/min) and (b) surface roughness (Ra) with respect to the diode current

The effect of diode current on surface quality of the micro-grooved surface of silicon wafer is shown in figure 3.1 (b) keeping other parameters constant as enlisted in table 5. It is observed from the plot that surface roughness increases with increase in diode current. At low level of diode current, the power of laser beam is low which leads to low melting rate and the formation of HAZ would be minimum leading to low burr formation. However, as the diode current increases, the power of beam increases leading to surface vaporisation. The rapid vaporisation leads to the formation of HAZ due to expelled material forming burrs and cracks. Thus roughness increases with respect to the diode current.

Table 5 Material removal rate (mg/min) and roughness (μm) obtained with varying frequency (Hz)

S.No	f(Hz)	V	Id(A)	N	C.S (mm/min)	MRR(mg/min)	Ra(μm)
1	4000	20.5	18	1	5	0.1284	0.523
2	4200	20.5	18	1	5	0.465	0.071
3	4400	20.5	18	1	5	0.4657	0.39
4	4600	20.5	18	1	5	1.542	1.299

Using the data of table 5.8 graph of MRR and Ra with respect to the frequency (Hz) has been plotted in figure 5.3 (a) and 5.3 (b) respectively. Figure 3.2 (a) shows the influence of frequency on material removal rate of the micro-grooved surface while keeping other parameters constant diode current of 18A, cutting speed at 5mm/min and single pass. It is found that MRR increases with the increase in frequency. At low frequency number of pulses striking on the work sample is low leading to less material removal. However, as frequency increases number of pulses striking the work sample also increases leading to high material removal rate.

Figure 3.2 (b) shows the influence of frequency on the surface quality of the micro-grooved surface considering other parameters constant i.e. single pass, diode current of 18A, cutting speed at 5mm/min. Initially the roughness value is high at the frequency of 4000 Hz. As frequency increases further, the minimum roughness is obtained at the frequency of 4200 Hz which may be attributed to more number of pulse striking the surface with material removal. However, after 4200 Hz surface roughness increases monotonically with the increase in frequency. This may be due to more number of pulses striking the work sample that increases heat conduction leading to formation of HAZ (heat affected zone) and increase in roughness.

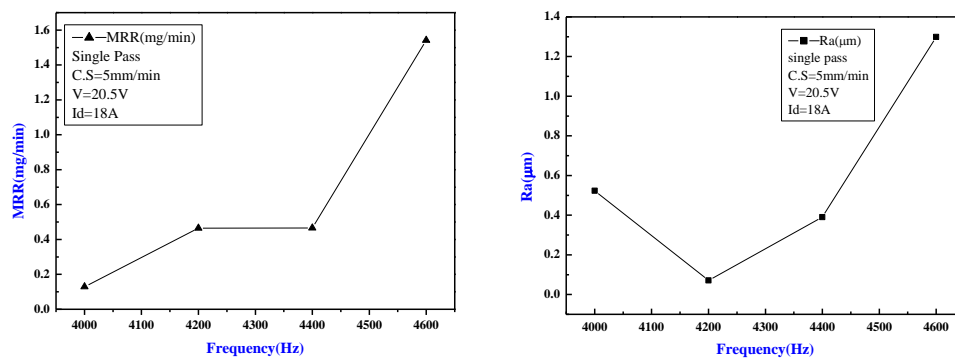


Figure 3.2 Variation of (a) Material removal rate (mg/min) and (b) surface roughness (Ra) with respect to Frequency (Hz)

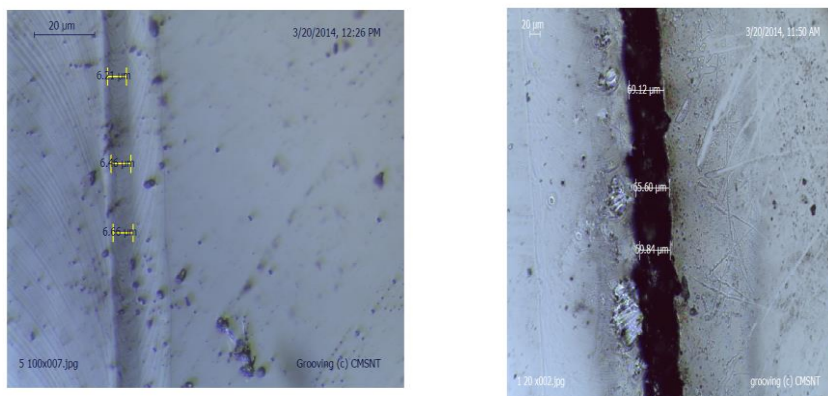


Fig.3.3 Microscopic view of grooved surface at (a) Id-18 A, 20.5 V, 4600Hz, single pass, C.S-5mm/min (b) Id-16A, 20.4V, 4000 Hz, single pass, C.S-5mm/min

The figures show few microscopic views of micro –groove silicon wafer taken with using optical microscope with varying process parameters.



## 5. Conclusion

Initially non-linear variation of MRR was observed with respect to the diode current. However, MRR increases exponentially after it reaches diode current of 16A. Non linear variation of MRR was observed with respect to the diode current. However, material removal rate was found to increase linearly with increase in frequency.

Surface roughness was observed to decrease with increase in diode current owing to appropriate material removal at higher diode current. However, surface roughness was found to increase with increase in frequency.

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