Laser Milling Ceramics Dioxide Zirconium and Disilicate of Lithium

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Abstract. The paper considers the possibility of using laser milling technology for precision processing of ceramic samples from pre-sintered and sintered ceramics zirconia and lithium disilicate. To find the best radiation source were compared different lasers. To find highest removal rate with acceptable accuracy was studied influence laser and scanning system parameters on ceramics. Accuracy problem of laser milling was considered. Examples of surfaces of prostheses were made.

1. Introduction
Laser processing was established as one of the precision methods to obtain three-dimensional structures. The widest distribution laser processing gets in micromachining. Nowadays transition from micromachining to full-scale milling of objects starts. For “big” objects laser milling may compete with tradition mechanical milling only with comparable material removal rate and range of milling materials.

Lately a few studies [1,2] where authors considered laser milling as new technology for creating dentures were published. These works show possibility of laser milling, but low removal rate shows the lack of prospects for laser processing.

The purpose of this work was to increase material removal rate up to comparable with mechanical milling with saving of accurate of the surface.

2. Materials and methods
2.1 Materials
The experiments were performed on commercially available blocks of pre-sintered and sintered blocks of Y-TZP (yttria-stabilized tetragonal zirconia polycrystal) ceramics and unsintered blocks of lithium disilicate.

2.2 Radiation source
To choose optimal laser we used range of radiation sources with different parameters. The basic parameters of radiation sources are listed in Table 1.

2.3 Methods
Measurement of different parameters was made with area processing. After that depth and roughness of the surface was measured. By this data was calculated material removal rate and other parameters. Surface analysis and depth was made with mechanical profilometer Dektak-150.
3. Results and discussions

3.1 Radiation source

Y-TZP ceramic is a typical dielectric with band gap 5.2-6 eV [3], also lithium disilicate is a dielectric. This type of material has good interaction with CO2 laser [4], but minimal focused spot diameter is larger than it needs for the precession laser milling. So solid-states and fiber pulsed lasers from UV to IR was chosen as main radiation source.

3.1.1 Wavelength

An estimate of the effectiveness of the radiation source can be obtained from measurement of absorption. The measurements are done at low energy, so it does not take into account high energy processes, but helps assess the prospects of radiation sources. Figure 2 (a) shows absorption of ZrO2 doped Y2O3 and figure 2 (b) shows absorption of lithium disilicate. As can be seen from graphs the highest absorption of the both materials are in UV part area the graphs. With lithium disilicate it proves in experiment. Ablation of lithium disilicate with nanosecond laser was obtained only on wavelength 355 nm and less. Material removal rate amounted up to 0.1 cm³/h with roughness Ra 3.4 μm.

Table 1. The parameters of the lasers

| Parameter          | Solid-state, 3d harmonic | Solid-state, 2d harmonic | Fiber | Fiber |
|--------------------|--------------------------|--------------------------|-------|-------|
| Wavelength, nm     | 355                      | 532                      | 1064  | 1030  |
| Average power, Wt  | up to 2                  | up to 10                 | up to 20 | up to 30 |
| Pulse frequency, kHz | 10-100               | 20-200                   | 20-100 | 200-2000 |
| Pulse width        | 2-6 ns                   | 20-50 ns                 | 100 ns | 5-20 ps |

Figure 1. Absorption of ZrO₂(a) [5] and Transmittance of Lithium disilicate (b)
3.1.2 Pulse width
Laser processing occurs by the mechanism of ablation. Ablation starts when fluence reached threshold fluence. Depends between pulse width and threshold fluence considered in [6]. In connection with it was used picosecond laser. This laser has lower threshold fluence and lower thermal affect on surface.

3.2 Laser and scanning parameters
There are a lot of different laser and scanning system parameters which have great influence on milling process: scan speed, hatch distance, scheme of scanning, frequency, average power, fluence, focus depth, spot diameter. The main parameters are scan speed and fluence.

3.2.1 Scan speed
Scan speed has affects on a thermal distribution and laser spot overlap (LSO). Thermal distribution is particularly important for ablation with nanosecond pulses. LSO determines roughness of surface. Dependence between scan speed and MRR for pre-sintered Y-TZP and lithium disilicate is on figure 2.

Graphs show that with increasing of scanning speed, MRR decrease. However, after some speed, reducing of scan speed is not increased MRR. It caused increasing of absorption of radiation by plasma. It caused by incubation effect during multi-shot laser ablation. Other materials have the same dependence.

Also scan speed related to LSO. Our experiments show that LSO is the main factor of roughness. Dependence with high MRR is similar for different materials (fig. 3). Roughness decrease up to “0%” LSO and after do not change much. For low MRR the lowest Roughness was obtained on “50%” LSO.

3.2.2 Laser parameters
As the main characteristic for laser radiation was chosen fluence. With changing only average power pronounced linear dependence can be seen (fig. 5).
Figure 4. Dependence between MRR and Average power for pre-sintered Y-TZP on nanosecond laser (a), pre-sintered Y-TZP (b) lithium disilicate (c) on picosecond laser.

That’s result let to chose average power as the main parameter for managing of the milling. With increasing of the average power this dependence would not be saved because of appeared plasma absorption [7]. High power lasers wouldn’t give high increment of removal rate.

3.3 Material removal rate
For each laser, the highest MRR was obtained with a given roughness. The results are in table 2.

| Laser                      | Material         | Pre-sintered Y-TZP | Sintered Y-TZP | Lithium disilicate |
|----------------------------|------------------|--------------------|----------------|--------------------|
| Fiber picosecond           | MRR, cm³/h       | up to 1.2          | up to 0.41     | up to 0.44         |
|                            | Ra, μm           | 2.1                | 1.76           | 2.5                |
| Fiber nanosecond           | MRR, cm³/h       | up to 0.44         | up to 0.11     | no ablation        |
|                            | Ra, μm           | 4                  | 3.7            |                    |
| Solid-state, 2d harmonic   | MRR, cm³/h       | up to 0.17         | up to 0.053    | no ablation        |
|                            | Ra, μm           | 1.7                | 1.2            |                    |
| Solid-state, 3d harmonic   | MRR, cm³/h       | "                  | "              | up to 0.1          |
|                            | Ra, μm           | "                  | "              | 3.4                |
| *- no data                 |                  |                    |                |                    |

3.4 Prosthesis’ surfaces
As result we get different prosthesis surfaces from pre-sintered Y-TZP with fiber nanosecond laser (fig. 5). That’s laser was chosen be because it has Z axis. Scanning system has repeatability up to 10 mkm, so flat sizes of prosthesis was precise. But Z sizes are different from given. But their differences were predicted and based on different processing area.
4. Conclusions

In this research the following results was obtained:
- The different radiation sources were compared.
- Dependence from main parameters was considered.
- Prosthesis surfaces were made. The time to made one was from 20 to 30 min.

The laser milling technology can be used in dental restorations manufacturing because of its benefits. There are some difficulties with precession and removal rate. In next researches these difficulties are being solved.

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