# Micromarking of plastic substrates by applying *Q*-switched fiber IR laser radiation

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# Micromarking of plastic substrates by applying *Q*-switched fiber IR laser radiation

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**Abstract**
In this work results obtained on the marking of thermoplastics (polyethylene terepthalate, polyethylene napthalate and polyimide) using an ytterbium *Q*-switch pulsed laser are presented. In these experiments the fiber laser beam was directed onto the substrate by a laser scanner. A test form has been created to study the influence of variable laser parameters such as power level, repetition frequency and mark speed in microstructuring.

(Some figures may appear in colour only in the online journal)

## 1. Introduction

Using laser radiation, sharply defined characters can be generated quickly on all types of plastic materials. Laser marking at a rate of up to 2000 mm $s^{-1}$ is possible and it is a non-contact process with minimal service and running costs. The marking produced by laser radiation on a substrate is scratch proof, rub fast and solvent resistant, with no waste or fading [1].

Examples of laser systems used for marking are Nd:YAG, $CO_2$, excimer and fiber lasers. Among these, Nd:YAG lasers are more suitable than $CO_2$ lasers because of their wavelength, but the maintenance costs are higher [2]. Excimer lasers also add substantial costs to the process.

Ytterbium fiber lasers have low maintenance costs and are also suitable for the cutting and marking of many types of plastic materials. The beam quality of ytterbium fiber lasers is high when compared to Nd:YAG, $CO_2$ and excimer lasers. Maintenance is less when compared to other laser systems because there is no need to replace flash lamps, diodes or laser tubes. The high electrical efficiency of fiber lasers further reduces operating costs. A better beam quality with very low divergence allows the user to generate very small spot diameters [3].

Laser marking is a thermal process that employs a high intensity laser beam to create a mark [4]. Laser marking has a huge variety of applications.

(1) It is used in packaging for marking, e.g. of serial numbers, manufacturing dates or use-by dates on bottles, tins or cans.
(2) It is used for marking keyboards, e.g. in computers. The marking can withstand abrasion and other rough handling in long-term use.
(3) It is used for marking printed circuit boards, electronic components and cables.
(4) It is used for marking logos, barcodes and other information on products.

In addition, laser cutting is a process by which a substrate is cut using a high intensity laser beam. The precision level and edge quality achieved with laser cutting can be better than traditional cutting methods. Laser cutting enables the cutting of complex shapes using marking software. It also allows the cutting of small diameter holes.

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## 2. Experimental set up

- The thermoplastic is exposed to laser radiation from the top.
- An aluminum substrate is positioned underneath the substrate.
- A pulsed ytterbium *Q*-switched fiber laser [5] with an average power of 30 W at a wavelength of about 1064 nm. The laser machine is shown in figure 1.
- The maximum repetition frequency is 200 kHz.
- A laser scanner with movable mirrors is employed to direct the laser beam. There is also a shutter to interrupt the radiation. The movement of the mirrors is controlled by a galvanometer [6].
- All the control information needed for the micromachining task is channeled in a sequential mode. As the platform for this code, a Microsoft Visual Basic script is used. The working environment .MicroMMI is the Visual Basic script extension provided by the laser manufacturer 3D-Micromac AG. It offers direct access to control the hardware of the micromachining plant.
- The laser control program consists of instructions for controlling the laser parameters (power level, frequency) and the scanner unit (jump speed, mark speed, jump delay and mark delay).

**Figure 1.** Laser machining plant.

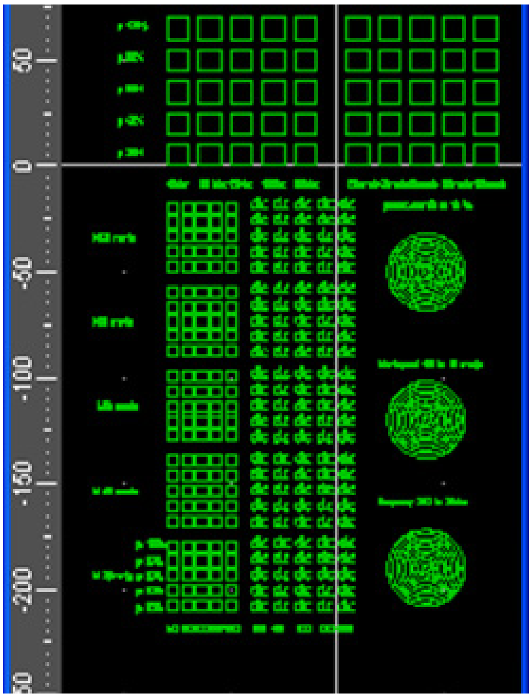


**Figure 2.** Layout of test form (hardcopy).

## 3. Results and discussion

Laser marking on materials was investigated by changing the three parameters power level, mark speed and frequency.

The power level can be changed from 0.1 to 1, with 0.1 meaning 10% and 1 meaning 100%.

The parameter mark speed is the rate of movement of the mirrors directing the laser beam over the target.

The third parameter is frequency, describing the number of pump pulses per second and expressed in Hz. The frequency can be chosen in the range 20–200 kHz.

The test form (see figure 2) is designed to study the influence of power level, frequency and mark speed in microstructuring. The size of the test form is DIN-A4. This test form can be used for accurate determination of the power level, mark speed and frequency for different substrates. The influence of each parameter in the interaction can be studied individually or combined. As part of the test form, a text fragment ‘dlc’ with varying parameters is also provided.

The first 25 squares are used to study the influence of the power level and frequency of the laser interaction. The size of each square is 10 mm × 10 mm. The power level is changed from 20% to 100% along the *y*-axis and frequency is changed in a similar way from 40 to 200 kHz along the *x*-axis.

The next 25 squares are used to study the influence of power level and mark speed on micromarking. The size of each square is 5 mm × 5 mm. The mark speed is changed from 20 to 100 mm $s^{-1}$ in steps of 20 mm $s^{-1}$.

The next 125 squares are used to study the influence of all three parameters in microstructuring. The size of each square is 5 mm×5 mm. The frequency is changed from 20 to 200 kHz along the *x*-axis and the power level is changed from 20% to 100% along the *y*-axis. For each set of 25 squares, the mark speed is changed from 20 to 100 mm $s^{-1}$.

Next the letters ‘dlc’ are repeated 125 times. The power level is varied along the *y*-axis. The frequency is altered along the *x* axis. The mark speed is varied from 20 to 100 mm $s^{-1}$ along the *y*-axis for each set of 25 ‘dlc’ characters. The main

**Table 1.** Frequency versus pulse duration and energy.

| Frequency (kHz) | Pulse duration (ns) | Energy ($\mu$J) |
|---|---|---|
| 20 | 25 | 250 |
| 40 | 12.5 | 125 |
| 59.7015 | 8.375 | 83.75 |
| 80 | 6.25 | 62.5 |
| 100 | 5 | 50 |
| 121.212 | 4.125 | 41.25 |
| 139.931 | 3.625 | 36.25 |
| 160 | 3.125 | 31.25 |
| 181.818 | 2.75 | 27.5 |
| 200 | 2.5 | 25 |

purpose of these letters is to confirm the results achieved with the squares in section 2. Another use is to observe the marking of text content.

The last section consists of three sets of concentric circles used to study the influence of the individual parameters on micromarking and cutting. The first set of concentric circles are used to check the power level and its value decreases from 100% for the outer circle to 10% for the inner circle. The next set of concentric circles are used to check the mark speed and the value decreases from 100 to 10 mm $s^{-1}$. The last set of concentric circles are used to check the repetition frequency and the value decreases from 200 to 20 kHz.

The observations of the test patterns show that as the power level increases the ease of cutting and micromarking of the substrate becomes greater. In contrast, as the mark speed and frequency increase, cutting is reduced and the micromarking level weakens.

This latter effect is due to the dependence of pulse energy on frequency. The pulse energy $E$ is the energy contained in a pulse, given by the product of the peak power $P_p$ and the pulse duration $t$ [7].

$$E = P_p t. \quad (1)$$

The pulse duration is greater at lower frequencies, thus the pulse energy is higher. Conversely, at higher frequencies the pulse duration is less and so is the pulse energy.

Table 1 shows the calculated values of pulse duration for each frequency. The energy in joules is calculated using equation (1).

From the graph in figure 3 we can observe how the pulse duration decreases with increasing frequency.

The average power $P_{ave}$ is the product of the pulse energy $E$ and frequency $f$.

$$P_{ave} = Ef. \quad (2)$$

$P_{ave}$ increases as the frequency $f$ increases.

The pulse energy of a ytterbium $Q$-switched fiber laser is 1 mJ and the pulse duration is 100 ns [8]. The peak power can be calculated as:

$$\text{peak power} = \frac{1\ \text{mJ}}{100\ \text{ns}} = 10\ \text{kW}$$
$$\text{average power at 20 kHz} = 20\ \text{W}.$$

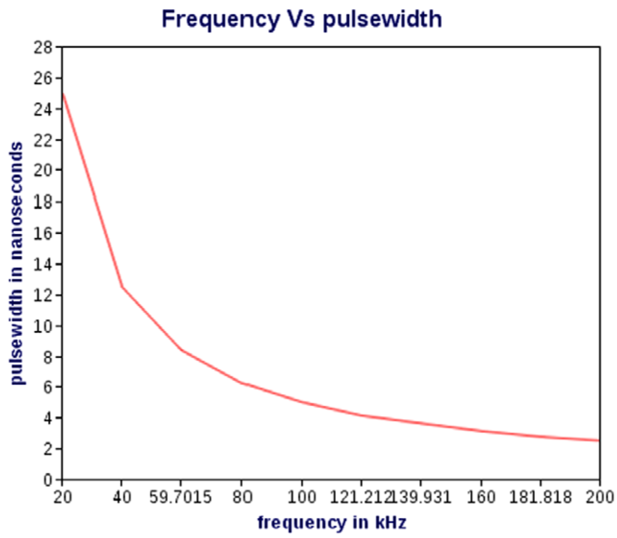


**Figure 3.** Frequency versus pulse duration.

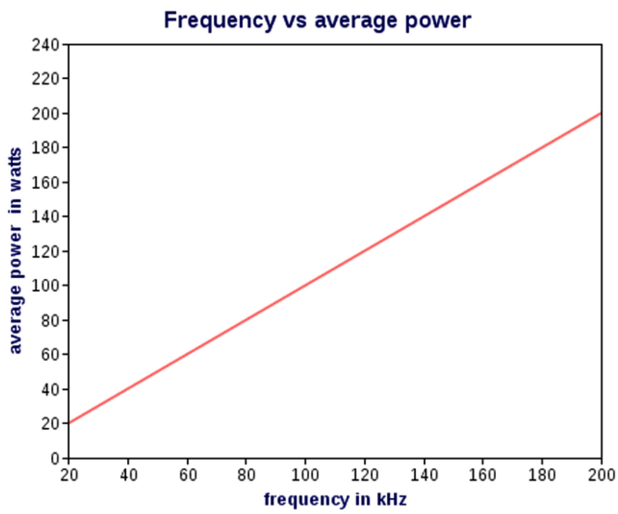


**Figure 4.** Average power versus frequency.

**Table 2.** Optimum parameters for marking.

| Material | Thickness ($\mu$m) | Power | Mark speed (mm $s^{-1}$) | Freq (kHz) |
|---|---|---|---|---|
| PET | 100 | 0.8 | 50 | 50 |
| PEN | 100 | 0.6 | 200 | 100 |
| PI | 100 | 0.8 | 50 | 100 |

The relation between frequency and average power is linear, as shown in figure 4. The average power should be less for low threshold materials such as thermoplastics.

Figure 5 shows an exponential decrease between energy and increasing frequency. The maximum energy can be found at a low frequency of 20 kHz while the minimum is at a higher frequency of 200 kHz.

The optimum values found are given in table 2 for micromarking and in table 3 for cutting applications.

Figure 6 shows the transmittance curves of polyethylene terepthalate (PET), polyethylene napthalate (PEN) and

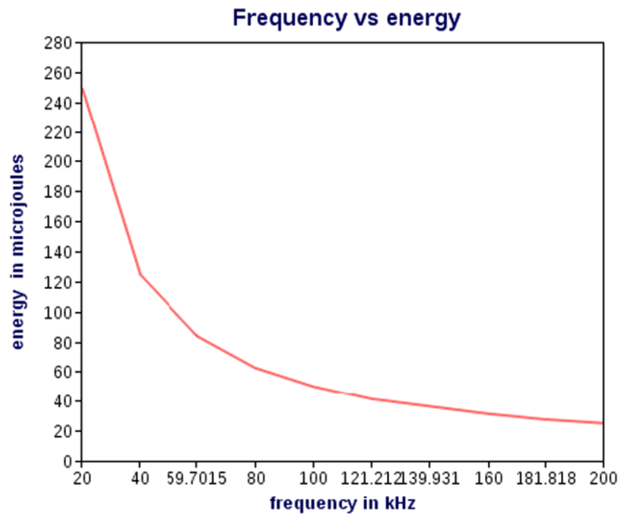


**Figure 5.** Frequency versus pulse energy.

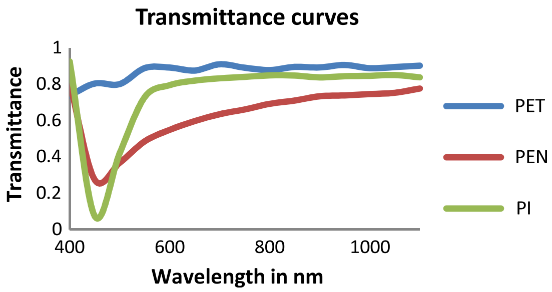


**Figure 6.** Transmittance spectra of PET, PEN and PI.

**Table 3.** Optimum values for cutting.

| Material | Thickness ($\mu$m) | Power | Mark speed (mm $s^{-1}$) | Freq (kHz) |
|---|---|---|---|---|
| PET | 100 | 1 | 20 | 20 |
| PEN | 100 | 0.8–1 | 20–50 | 20 |
| PI | 100 | 1 | 20 | 50 |

**Table 4.** Absorption of samples.

| Sample | Transmittance $T$ (%) | Absorption $A$ $A = 1 - T$ (%) |
|---|---|---|
| PET | 87 | 13 |
| PEN | 77 | 23 |
| PI | 85 | 15 |

polyimide (PI). The transmittance of PEN is less than PET and PI. This implies that absorption of PEN is higher than of PET and PI. The percentage of transmittance and absorption of PET, PEN and PI at a wavelength of 1064 nm is given in table 4. The absorption is calculated simply by assuming that reflection and scattering are negligible.

In the following, the experimental results are discussed obtained using the test layout of figure 2 on the PET film.

In figure 7 the power level is increased from the inner to the outer circles. The picture is taken with a white sheet kept in the background of the transparent PET substrate. At lower

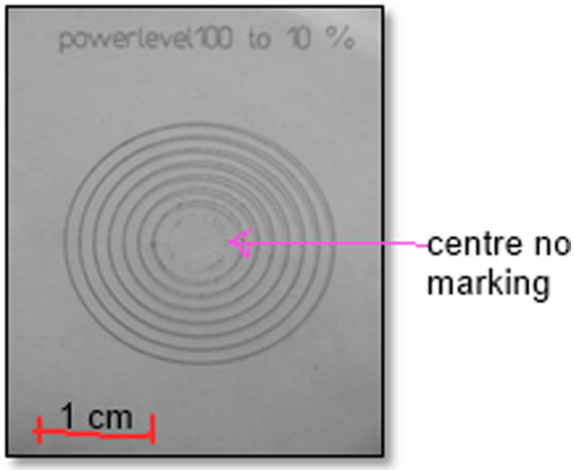


**Figure 7.** Circles with varying power level.


**Figure 8.** Circles with varying mark speed.

power levels there is no marking of the circles. The marking starts at a 20% power level and is rated 'good' up to 80%. At higher power levels the cutting effect is observed.

In figure 8 the mark speed is increased from 10 to 100 mm $s^{-1}$ from the inner circle to the outer circle and a cutting effect is observed at a low markspeed of 10 mm $s^{-1}$.

In figure 9 the frequency is increased from 20 kHz in the innermost circle to 200 kHz in the outermost circle. It is observed that at lower frequencies marking can be rated as 'good', while at higher frequencies marking must be rated as 'very poor'.

Figure 10 shows the effect of power level and frequency in marking.

At lower power levels there is no marking. At a 40% power level a slight marking is observed for low frequency. At higher power levels marking can be rated as 'good'. When the power level is maximized and the frequency is minimum, cutting of the substrate is observed.

Figure 11 shows the effect of mark speed and power level in micromarking and cutting. At the lower mark speed cutting is observed. At higher mark speeds there is a gradual decrease in the interaction.

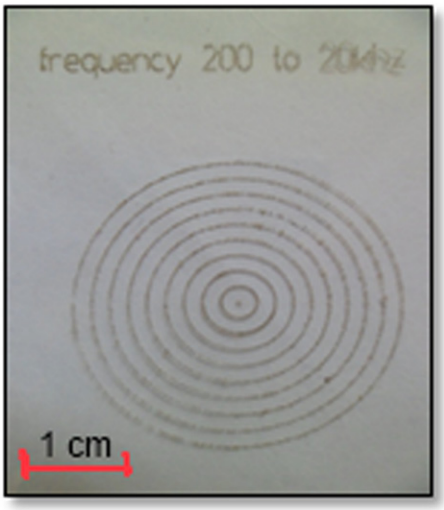


**Figure 9.** Circles with varying frequency.

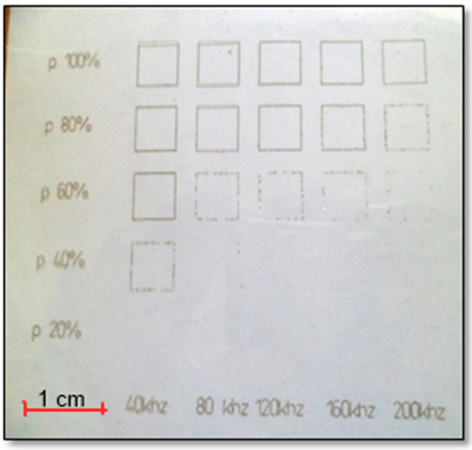


**Figure 10.** Varying frequency and power levels.

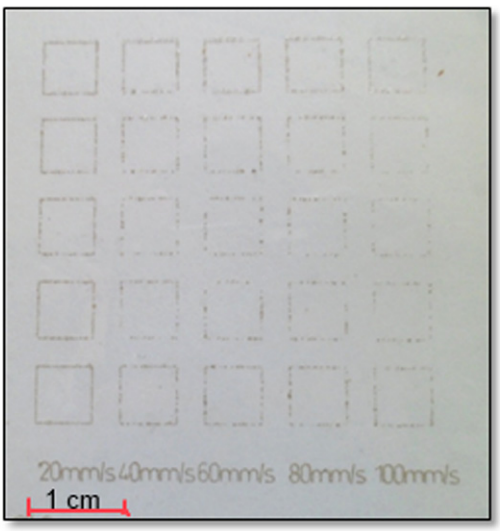


**Figure 11.** Power level versus mark speed.

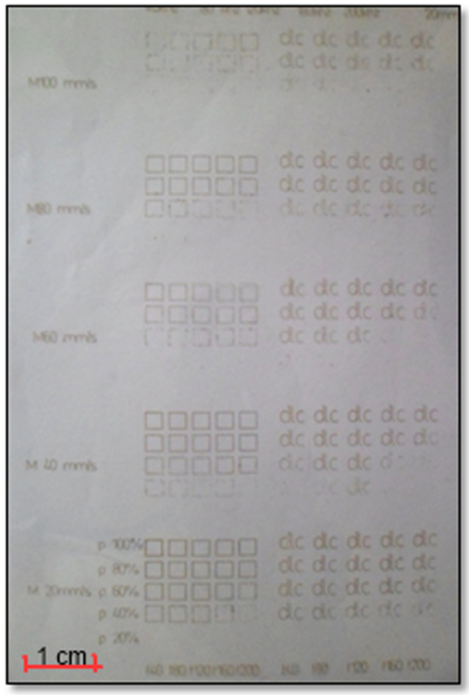


**Figure 12.** Effect of three parameters in marking and cutting.

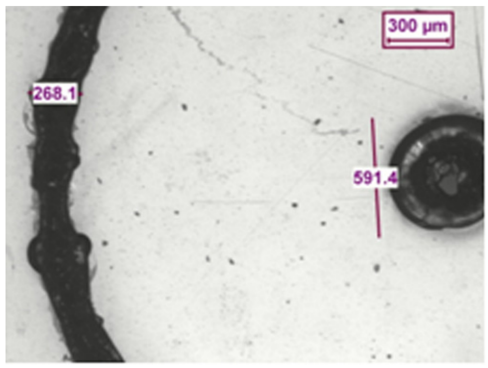


**Figure 13.** Microscopic image of the inner low frequency rings.

The results shown in figure 12 are the same as already seen in individual parameter variations and using two parameters in micromarking. That is, ablation increases with the power level and decreases with increasing mark speed and frequency.

In figure 13 the substrate is cut at the inner circle because of the high laser energy using a low frequency. Similarly in figure 14 the substrate is cut at the inner circle because of the high laser energy using a low mark speed. This implies a reduction of pulse repetition rate has the same effect as a reduction of mark speed.

In figure 15 the circles are not marked properly up to a threshold value of 20%. Foaming of plastic [9] is observed at lower power levels.

In figure 16 the cutting effect is observed in between the letters ‘dlc’ because of the high laser energy due to the low mark speed and low frequency. At low mark speeds

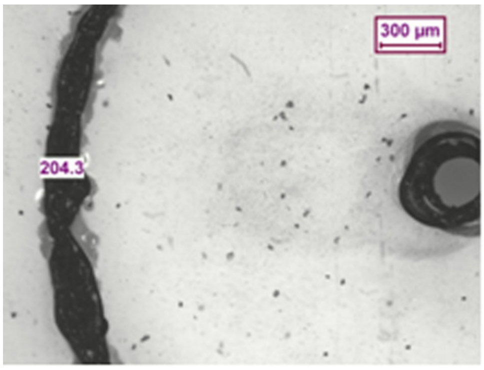


**Figure 14.** Microscopic image of the inner low mark speed rings.

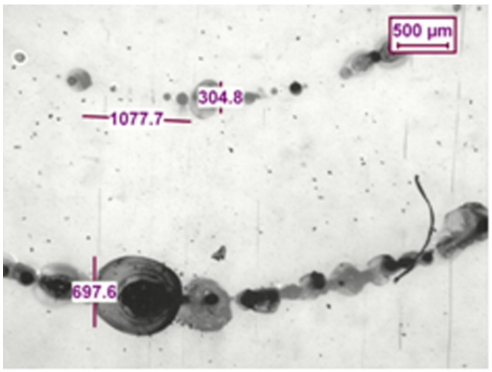


**Figure 15.** Microscopic image of rings marked with lower power level.

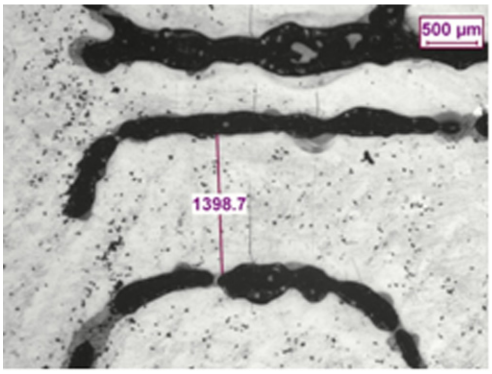


**Figure 16.** Microscopic image of letters dlc marked at a frequency 40 kHz, with mark speed 20 mm $s^{-1}$ and power 60%.

overlapping of laser pulses takes place, resulting in increased energy.

In figure 17 the letters are marked properly because of the optimal parameters. Thus, increasing the pulse repetition rate by a factor of five while keeping the marking speed and average power values the same improves the quality of marking.

In figure 18 the square is not marked properly due to the low input energy. With low input energy the fluence of laser light is also reduced.

In contrast to figure 18, in figure 19 the squares are marked properly because of the optimum input energy of the laser radiation.

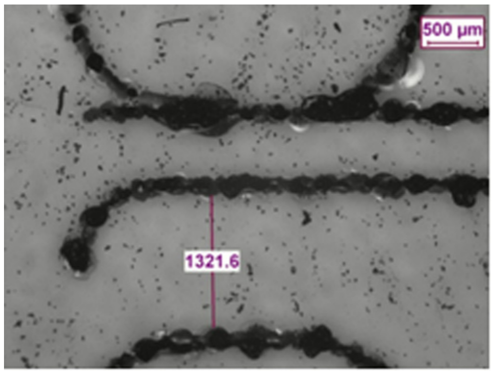


**Figure 17.** Microscopic image of letters dlc marked at a frequency 200 kHz, with mark speed 20 mm $s^{-1}$ and power 60%.

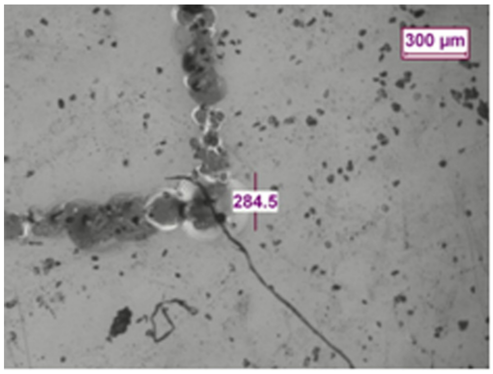


**Figure 18.** Microscopic image of the square marked at a mark speed of 200 mm $s^{-1}$, at a frequency of 200 kHz and power 60%.

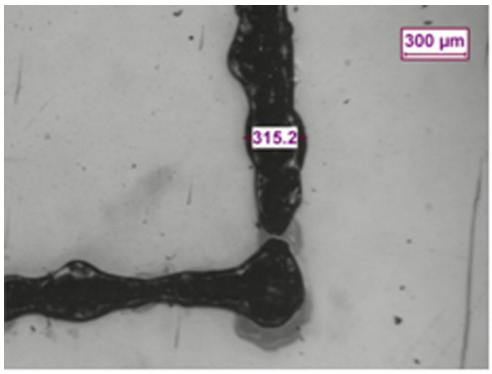


**Figure 19.** Microscopic image of the square marked at a mark speed of 80 mm $s^{-1}$, at a frequency of 40 kHz and power 100%.

## 4. Conclusion

The effect of the three parameters mark speed, frequency and power level on the micromarking and cutting of the polyethylene terepthalate (PET), polyethylene napthalate (PEN) and polyamide (PI) is studied. A test form has been created for in depth study of these three parameters. It has been observed that the power level and frequency play important roles in marking and cutting with a ytterbium *Q*-switched fiber laser. When the mark speed is low, cutting takes place, whereas at higher mark speeds above 200 mm $s^{-1}$ no marking is observed. When the frequency is low, a greater energy is carried by the laser pulse, resulting in good ablation. The power level should be maintained at an optimum level between 0.6 and 1.

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