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Closed-loop next generation laser polishing

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A novel fabrication parameter controlling method for laser polishing processes called C-Lasso (Control of LASer Surface Optimization) is presented, monitoring within the footprint the smoothing process as well as the removal of ssd in situ. Therefore, it is possible to determine and control the optimum dwell time a footprint needs to stay at a certain point before moving further enabling a more stable and cost optimized polishing.

Introduction

Among the various sub-aperture polishing techniques of glass existing, laser polishing [1] distinguishes itself by its scalable non-contact polishing spot as well as by the absence of any solid contact between tool and workpiece. Polishing is achieved by local absorption of laser power within the polishing spot (the footprint) causing the surface and its subsurface region to melt and flow reducing surface roughness and removing subsurface damage (ssd). To that aim, setting up process parameters is a tradeoff between continuous wave at lower laser power values melting the surface and near surface regions gently but risking the generation of shape deviations and mid-spatial frequencies due to material flow; and on the other hand the application of a pulsed laser illumination at high power values avoiding changes in shape and mid-spatials but risking high values of surface and subsurface tension caused by the high temperature gradients generated which might even cause local cracking. In both cases, the risk of vaporization of material is existing which might cause redepositioning of material by the laser beam being scanned along the surface.

In the following, a new fabrication parameter controlling (FPC) method for laser polishing processes called C-Lasso (Control of LASer Surface Optimization, Patent Pending) is being presented, enabling the determination and control of optimum local dwell times and process parameters.

C-Lasso: dwell time monitoring

It has been demonstrated that monitoring the intensity of a laser beam that is being reflected at an optical surface from within the sample while its outside is being abrasively ground and polished, surface roughness level reductions can be monitored in process on machine [2]. Consequently, applying intensity-detecting Internal Reflective Microscopy, iIRM [3], polishing time and cost can be optimized. Fig.1 shows the usually applied setting up onto a standard overarm polisher where the signal is being detected touching the surface under test optically from within the sample while being polished from the outside. Fig.2 demonstrateds the resolution of the IRM measuring technique: two samples have been polished and measured by whitelight interferometry previously. Subsequently, both have been measured ny IRM demonstrating its capability to destinguish levels of surface roughness in the sub nanometer range. Fig.3 shows the IRM resolution for the detection of sleeves and scratched caused during polishing.

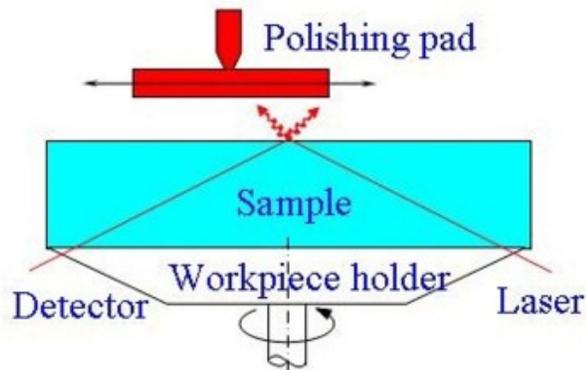
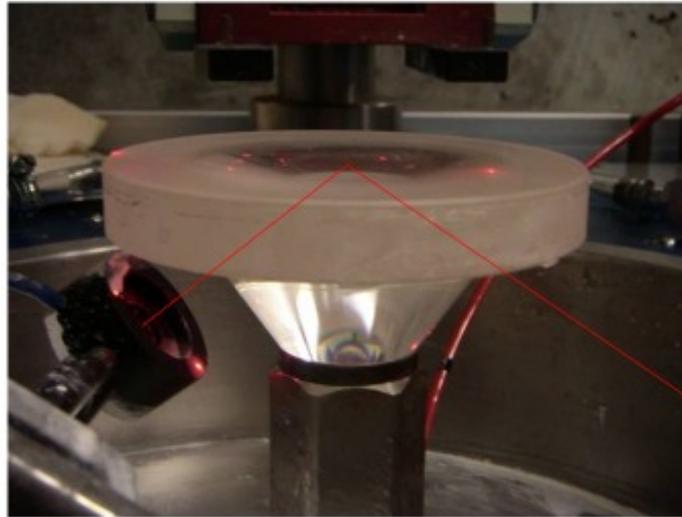


Fig.1 iIRM: while the sample is being polished, the intensity of a laser beam is being detected that is reflected from within the material at the surface under test.

Besides that, the influence of changing process parameters (such as e.g. the pH values of polishing slurries) to the generated surface roughness level being generated can be observed in situ, enabling the determination of the optimum set of polishing process parameters [4].

iIRM method has been developed further (see Fig.4 and [5]) to enable monitoring of laser polishing processes of fused silica. A HeNe laser beam is being reflected from within the sample at the surface under test and the intensity of its reflected beam is being monitored. The internal local sub-aperture surface area under test is chosen to be located at the very spot where the laser polishing footprint is being positioned from the outside of the sample, melting its surface locally.

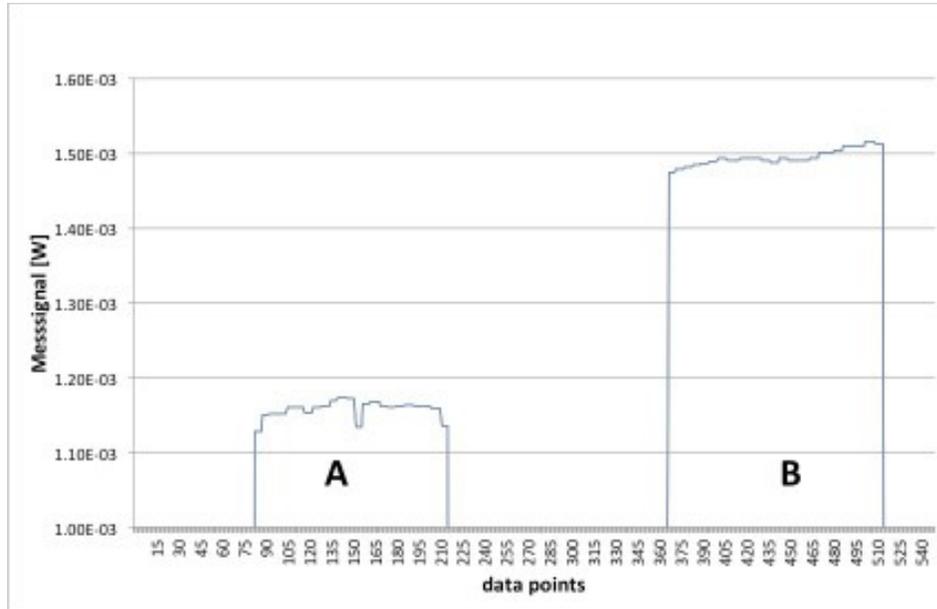


Fig.2 iIRM measurements of sample A ($Sq = 1.1 \text{ nm rms}$) and sample B ($Sq = 0.6 \text{ nm rms}$)

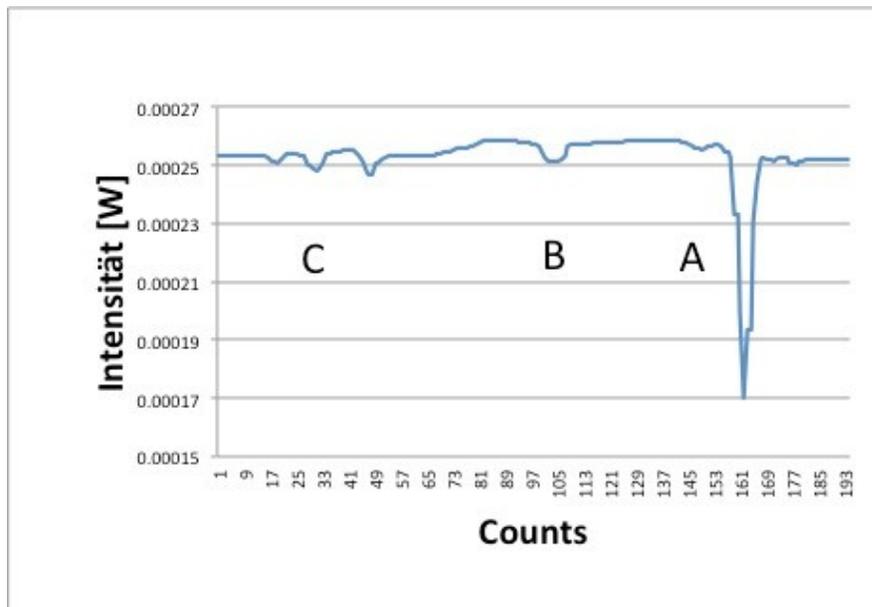
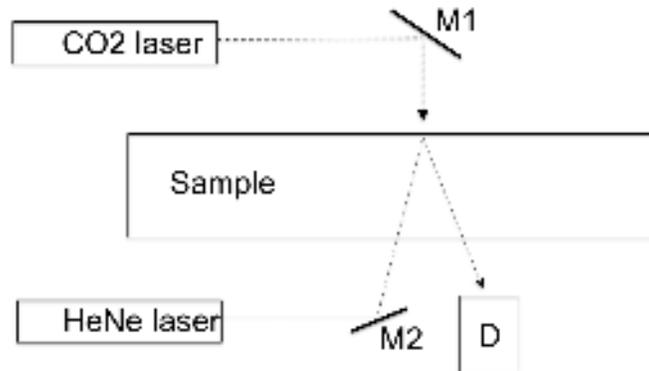


Fig.3 iIRM measurement of the generated grooves A (900 nm deep brittle scratch), B (150 nm deep ductile sleeve) and C (several polishing sleeves: the smaller ones of which are about 100 nm deep).

Thanks to the fact, that fused silica is not transparent at the operating laser wavelength of the applied CO₂ laser, the intensity of the reflected beam can be monitored enabling a in situ control of the laser polishing process. C-Lasso (Control of LASer Surface Optimization, Patent Pending) monitors within the laser footprint the surface smoothing process as well as the removal of ssd caused by the chosen set of laser polishing parameters being applied (such as e.g. dwell time and applied level of laser power).

(a)



(b)

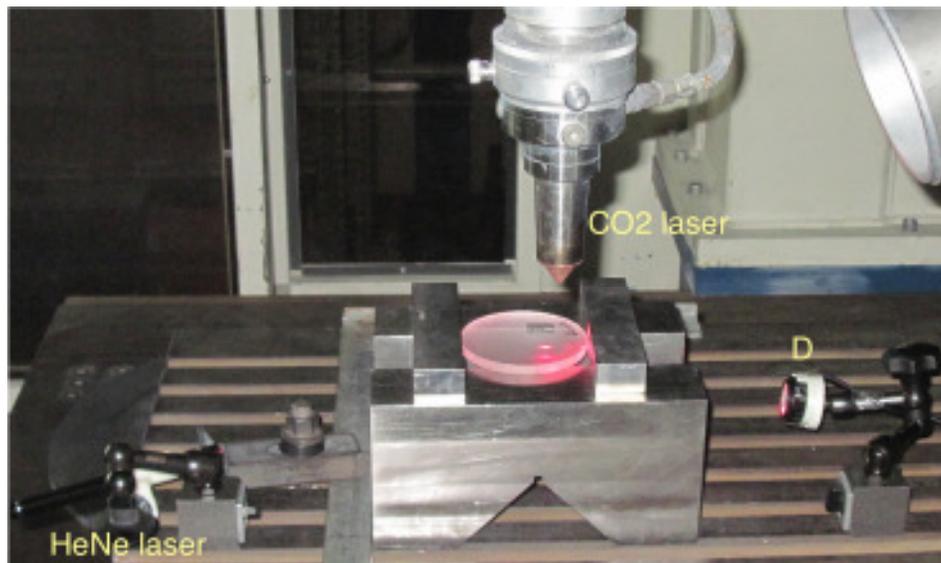


Fig.4 (a) Sketch of the C-Lasso set up for in situ monitoring of CO₂ laser polishing process. While the sample is locally being laser polished (see scanning mirror M1), the level of surface roughness within the laser footprint is being monitored by detecting the intensity of a HeNe laser beam that is being reflected at the CO₂ footprint area from within the sample. **(b)** Set-up used for the presented proof-of-principle generating C-Lasso's "First light".

Fig.5 shows a typical C-Lasso signal detected by monitoring surface roughness reduction during the laser polishing process. A previously fine ground fused silica surface (see Fig.6) is locally being laser polished while the footprint area is being monitored by C-Lasso.

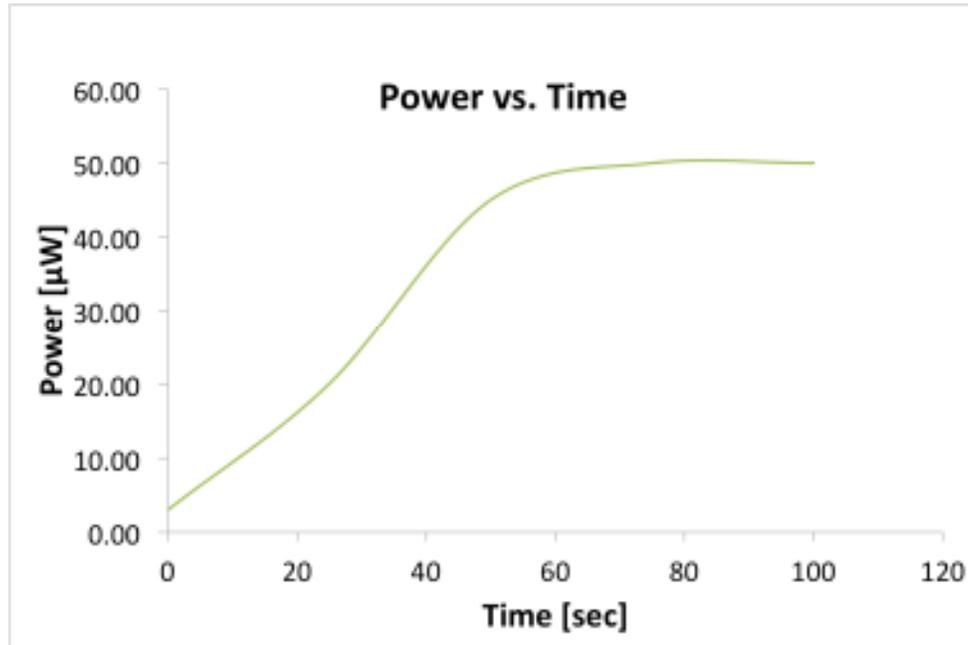


Fig.5 C-Lasso signal detected in situ while the footprint is locally laser polishing a fused silica surface: starting from a ground surface with about 300 nm rms a shiny surface is being generated featuring less than 5 nm rms.

As the level of surface roughness decreases due to the melting process, the intensity of the reflected C-Lasso beam increases until the final surface quality has been reached and the C-Lasso signal reaches a plateau. From that point on, any further laser polishing does not increase surface quality anymore.

Conclusions

It has been demonstrated that by applying C-Lasso method (Patent Pending), it is possible to determine and control the minimum dwell time a laser polishing footprint needs to stay at a certain point before moving further. Consequently, C-Lasso enables the optimization of laser polishing by avoiding unnecessarily long local dwell times minimizing the risk of generating shape deviations, ssd and mid-spentials as well as the vaporization of glass. Besides that, after having reached the eventual C-Lasso plateau, the influence of process parameters, such e.g. the applied CO2 laser power, to the generated level of surface roughness can be monitored in situ enabling the determination of an optimized set of laser polishing parameters. Currently, C-Lasso is being implemented into a laser polishing set-up to be employed for further investigations of laser polishing parameters in situ.

a)



b)

c)

Results	
Sa	1.964 nm
Sq	2.587 nm
Sz	36.329 nm
Size X	383.733 μm
Size Y	383.733 μm
FOV	0.42 x 0.42 mm

Results	
Sa	131.811 nm
Sq	166.209 nm
Sz	1094.199 nm
Size X	383.733 μm
Size Y	383.733 μm
FOV	0.42 x 0.42 mm

Fig.6 Starting and final roughness of a typical laser polished fused sample (the in situ in process monitoring of which is shown in Fig.2) measured by white light interferometry to be 160 nm rms before processing and about 2 nm rms of the finished part.

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