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Contents

1. Introduction

The main objective of FemtoSurf project is to develop, test and demonstrate industrial-grade solid-state 2-3 kW-level fs laser with parameters suitable for metal surface patterning applicable in industrial settings. FemtoSurf industrial-grade 2-3kW-level fs laser will be integrated in propose-built optical chain enabling multi-beam processing (100+ simultaneous beams) with individually tailored spatial distributions in each laser spot, integrated into a fully automated processing setup for efficient patterning arbitrary shaped metal components with sizes exceeding several meters while retaining micrometre level precision and on-the-fly quality assessment (zero faulty parts delivered).

Project description

Creating 3D patterns on surfaces changes their properties and the way they interact with other materials. Ultrafast lasers are proving particularly promising in this realm. Surface features on scales from nanometer to millimeter sizes can be controlled to fine-tune functionality and performance in numerous applications from aerospace to biomedicine with particular interest in wettability, attraction and repelling. The FemtoSurf project has a bold idea for these tiny patterns. The project partners are developing the technology to enable the simultaneous several beams of ultrafast laser beam for surface patterning. When integrated into an automated industrial setup, the system will enable patterning at the micrometer scale in components exceeding several meters in length. This technology will open the door to exciting possibilities to optimize aerodynamics in large structures such as planes, ships and implants.

Introduction

A relatively new field such as laser surface processing does not yet have a consensus as to “best practices” for quality control. Another important point is that each application must have different criteria for what constitutes adequate quality.

For an industrial process, the following criteria must also be met:

1. Fast enough
2. Easy to implement
3. Accurate enough compared to specifications
4. Value for money

With all these considerations in mind the following procedures were followed

1. Restrict ourselves to methods appropriate to a subset of expected end user requirements.

2. Scanning Electron Microscope, wettability resting, friction testing, confocal microscopy, are understood to be part of the testing phase to determine the correct laser parameters but are not a viable part of the quality control. They are also ruled out due to expense and usability, in that they cannot be on-line measurements.

3. Non-destructive Analysis (NDA) must be used on the machine, so any after the fact surface treatment, such as metallization is ruled out.

This led to the following set of systems.

1. Machine vision camera system, also part of the machine steering subsystem. (Ramteid GmbH).

This system consists of 6 high speed CMOS cameras equipped with long working distance telephoto lens. Each of the cameras and lens arrangement gives a resolution of down to 2 microns and positioning accuracy in 3D (using in-house stereographic imaging) of around 10 microns. This enables the system to see laser processed surfaces in 2D and where the surface plane is in real time.

2. White Light Interferometery system. (Heliotis AG).

The Heliotis HeliInspect H6 and H8 instruments are based on the principle of scanning white light interferometry: while performing a vertical scanning motion, changing interferometric patterns/signals are continuously captured by a customized CMOS sensor and are evaluated by built-in electronics, in order to extract the sample surface data. This allows for the acquisition of 3D surface profiles with very high vertical resolution. Through their modular design and easily exchangeable optics, the H6 and H8 allow for a good balance between lateral field of view and lateral resolution, to cover a wide range of sample requirements, while the very high vertical resolution is maintained for all configurations. The unique, Heliotis-designed CMOS sensor with pixel-by-pixel level, dedicated signal processing electronics (working like an optical lock-in amplifier, based on the principle of signal demodulation) and the deployment of FPGA signal postprocessing and surface reconstruction provides very high measurement speeds compared to other instruments with similar resolution. Therefore, the Heliotis instruments allow for the inspection of larger areas, while the compact and lightweight instrument design allows for mobile deployment (unlike most lab-based metrology devices).

3. Visible light, low power laser speckle and diffraction system. (FORTH-IESL).

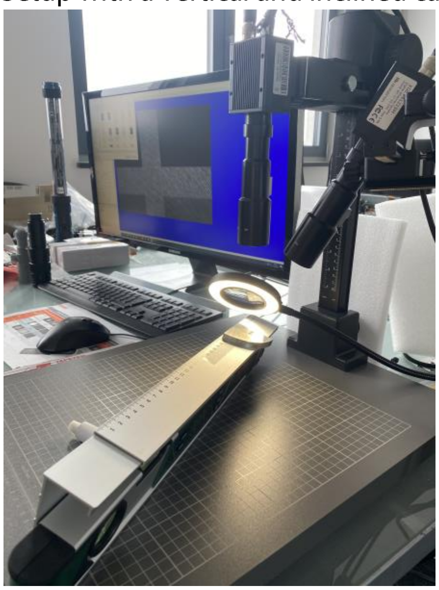
This system consists of a CMOS camera and lens imaging the reflection/diffraction pattern projected onto a screen from a vertically polarized Helium-Neon red laser. The laser is steering with two mirrors onto a sample holder with a rotation stage. With samples of a regular pattern, we see diffraction patterns in addition to the laser speckle from the reflection.

2. Results

Vision subsystem (Ramteid GmbH)

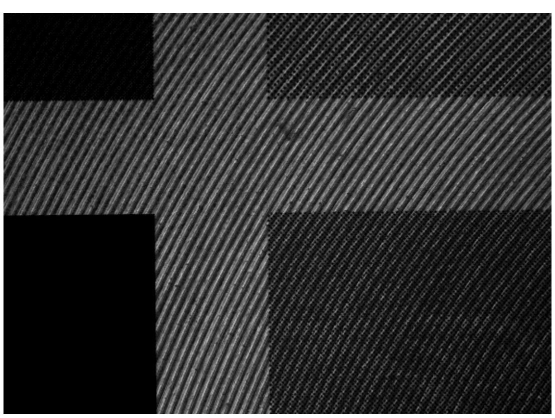
The final system will consist of 4 to 6 separate cameras, however, the present setup uses 2 parallel cameras and the images are tilted to simulate the images obtained from the extra cameras. The cameras therefore look at multiple angles and image the same 10mmx10mm area giving an effective resolution of 3μmx3μm per pixel. With the further addition of diffuse ring lighting the image quality is dramatically improved over a single camera with ambient light. This is shown in the first two figure below.

Setup with a vertical and inclined camera & tilted object:

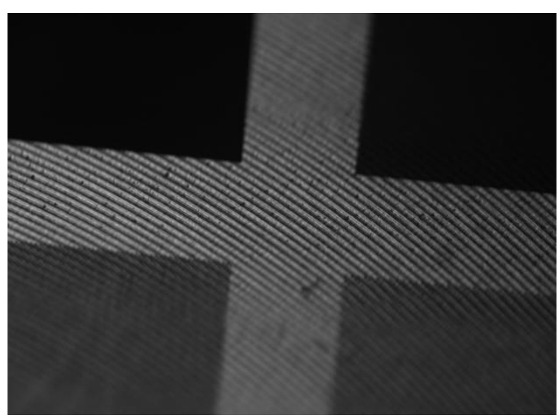


Below we can see typical images showing a vertical arrangement on the left a inclined camera and a tilted object. In these images the light cross type structure is the unprocessed metal part, and the darker areas are the laser processed samples.

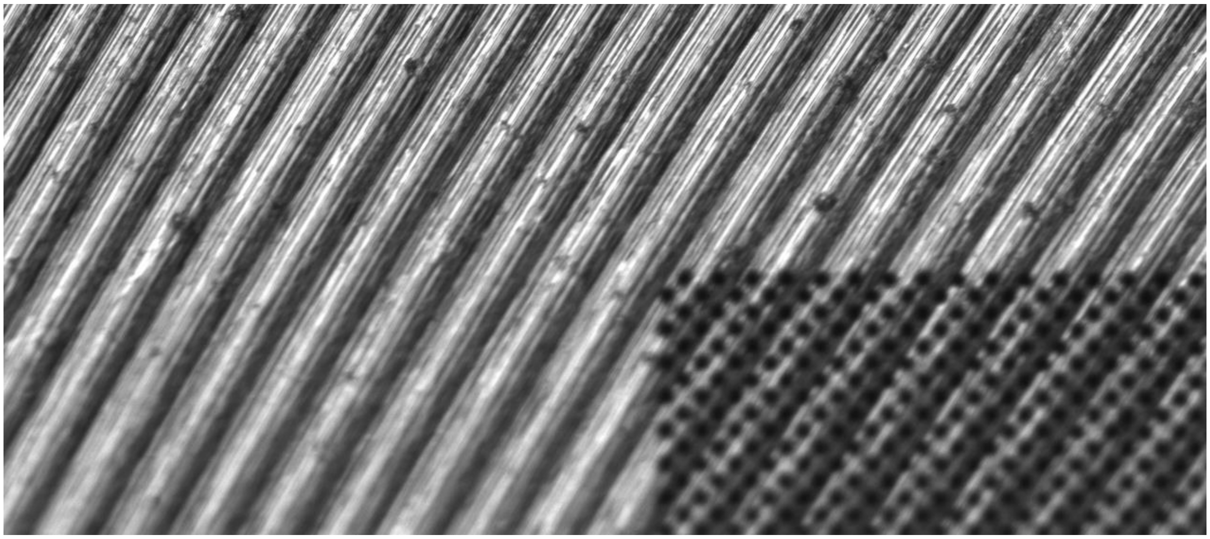
Shot with vertical camera & plain object



Shot with inclined camera and tilted object



A zoomed image is shown below where the quality of the images is readily apparent. The light area shows the lathe marking on the pre-processed metal surface and the black dots are due to the laser processing pattern.

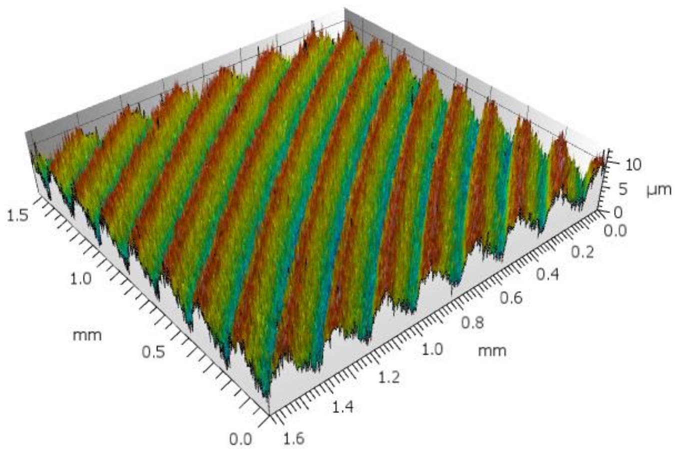


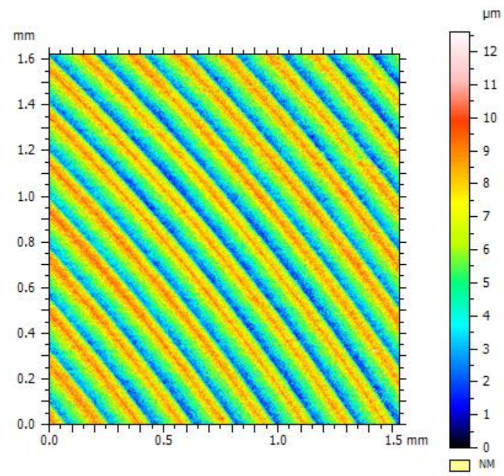
White Light Interferometery system. (Heliotis AG)

The system is shown below left. On the right we see the system running showing the LED lighting and interchangeable microscope objective.

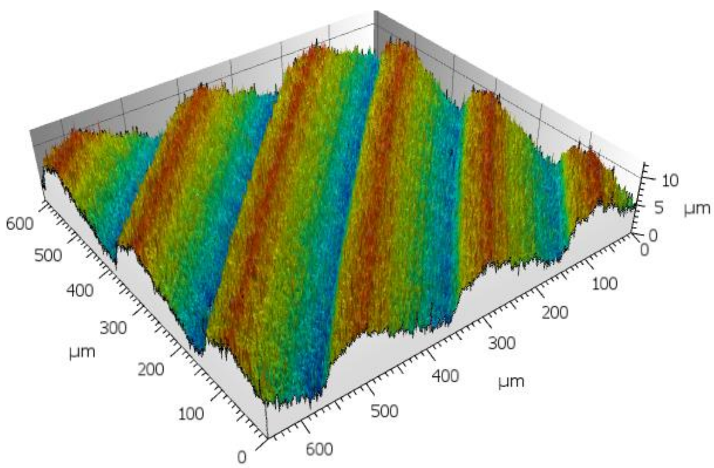
Here the two ways of showing the data are given, 3D view and false colour giving the height as shown in the legend. Both an 8x and a 20x magnification set of data are shown for an unprocessed lathe pattern on a metal surface.

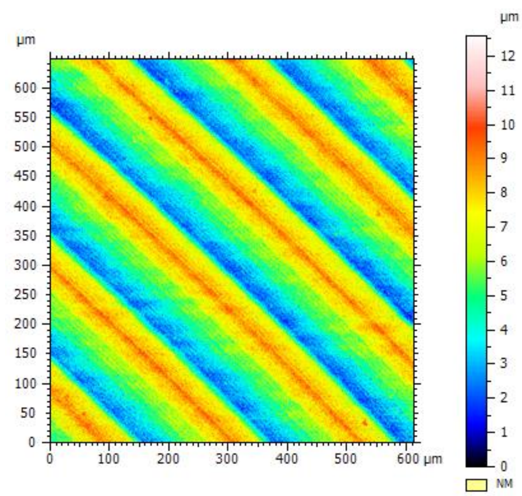
Standard Lathe pattern 8x magnification





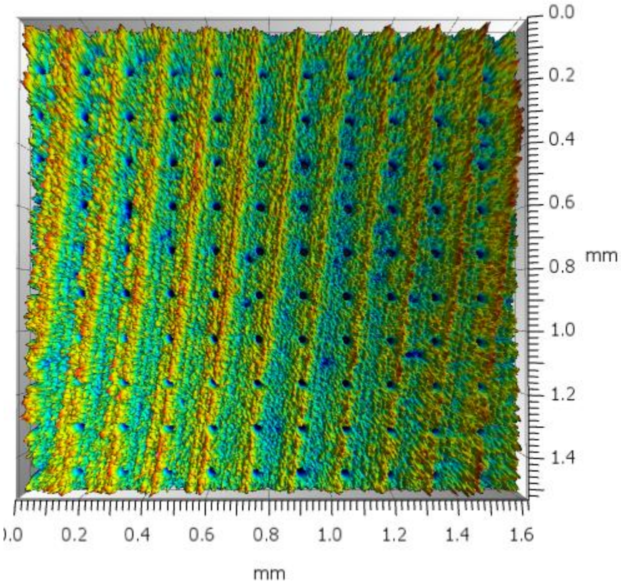
Standard Lathe pattern 20x magnification

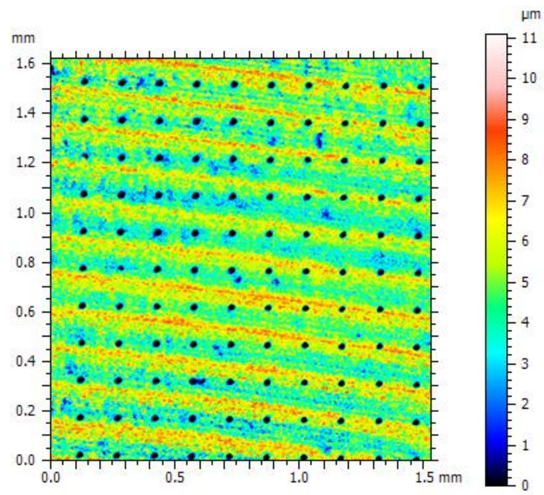




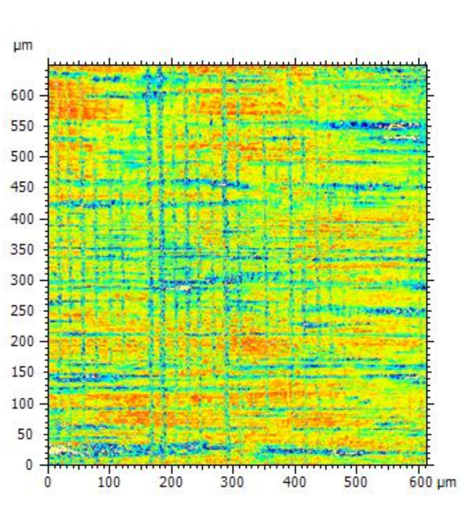
One of the strengths of this way of assessing the samples is given below, easily showing a pattern of dots similar to the Ramteid system above.

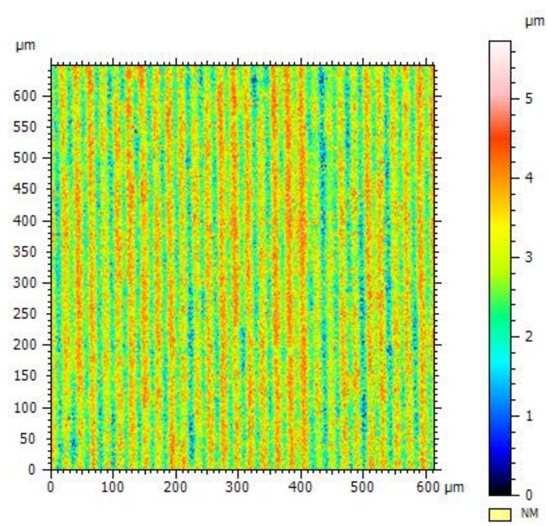
Standard Lathe pattern + laser dot pattern 8x





Where this system performs better than the others is seen here with different powers of laser processing giving different depth of the laser patterns due to increased laser power but the same pattern dimensions. The left showing less power and the right increased power giving a greater depth.



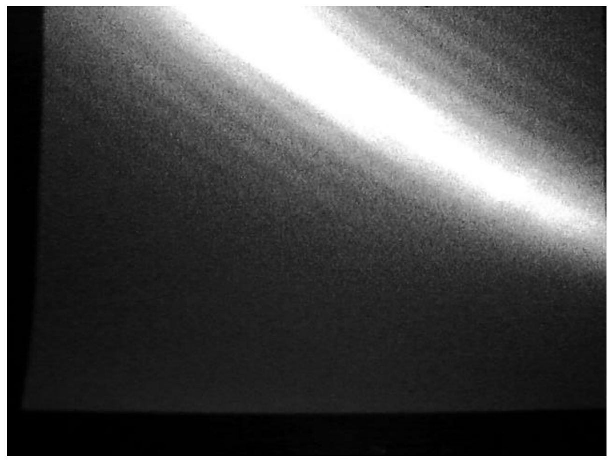


Laser speckle and diffraction (FORTH-IESL)

With the laser system when the sample is a random polished sample the pattern imaged is a smooth distribution as can be seen on the left image below. However, when a lathe pattern is introduced the system has difficulty distinguishing the pattern from the lathe markings. If the pattern from the laser is very strong we can see some diffraction as evident on the image below right. With a weaker laser pattern the lathe marking can completely quench the signal from the laser processed pattern.

Cu sample no laser irradiation (random polish)

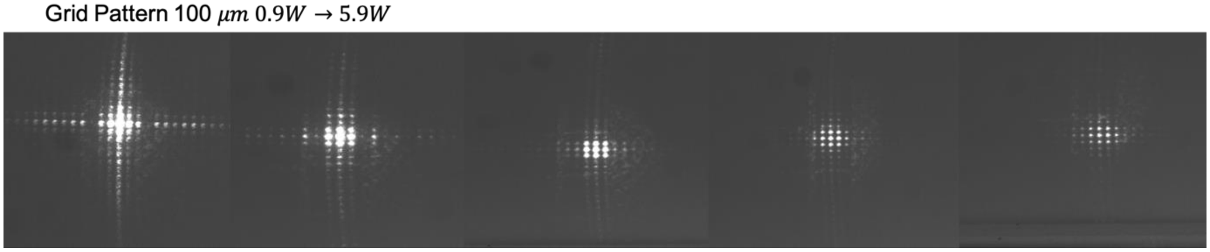
CoCrMo with Laser pattern and Lathe



When the sample is polished as the sample below on stainless steel the results are more promising. For the grid pattern shown below we can clearly see the same grid pattern for all laser powers, and as expected the signal intensity reducing as there is more scattering due to the deeper pattern.

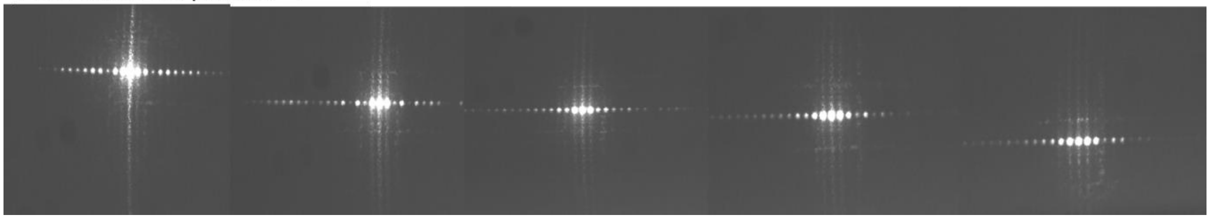
For polished steel we have the following:

Grid Pattern 100 μm $0.9W \rightarrow 5.9W$



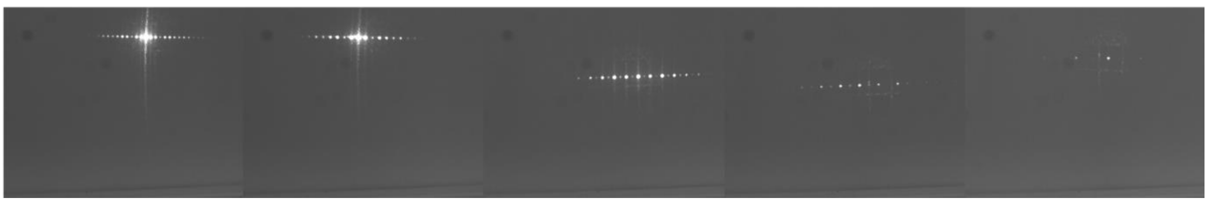
The same can also be seen for the line pattern below with the same pattern dimensions.

Line Pattern 100 μm $0.9W$ →



The sample below is for the opposite case of constant laser power but decreasing the pattern dimensions in this case starting from 100µm, 70µm, 40µm, 25µm, and 15µm.

Line Pattern (constant power 0.9W) Decreasing line spacing left -> right



By visual inspection you can see samples becoming darker with increasing laser power as more and more of the incident light as scattered. Also, as the feature size approaches the visible wavelength there is no apparent scatter increase until we get to within an order of magnitude of the wavelength.

3. Discussion

With the two camera systems we can see both patterns and the surface finish applied to the surface. With the Ramteid system you can see the two contrasted areas with lathe surface pattern and a laser pattern. With the same type of laser patterning the laser diffraction system (CoCrMo with Laser pattern and Lathe) the diffraction pattern is severely quenched and there is very little diffraction apparent. The figure in the example is with the greatest signal, and most of the cases examined no diffraction was present. The dots pattern from the Heliotis system shows clearly the lathe pattern curving down to the left and the dots clearly present.

It is also apparent from the laser diffraction patterns that the dispersion increases with laser power, over and above that from the diffraction angles. This gives a large drop in signal strength which can give problems with the detection. Moreover, it is a good indication of high quality laser treatment at submicron levels.

4. Recommendations

The two camera systems, the vision and the white light interferometry are complementary to each other as far as the quality assessment of the samples is concerned. The vision system gives an overview and a good assessment for large feature sizes, with apparent surface absorption also apparent in the images. The white light interferometry giving the extra dimension, literally, as the depth of the features and also a very fine resolution.

The laser system can also be used as a check external to the two camera systems, also as a risk mitigation method for difficult to characterize samples, for example extremely low reflectivity samples, and it could be fairly easily used as a double check and the know how is already available to the project. However, for the samples, and end users currently in the project its benefit does not seem enough to justify adding it the main system as the current cameras seem more than adequate.