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SURFACE MODIFICATIONS USING EXCIMER LASERS; FUNDAMENTALS AND APPLICATIONS

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Abstract: It is the purpose of the present investigation to describe and to explain the occurring phenomena during the interaction of intensive, pulsed UV-light with technical metal and ceramic surfaces, on the one hand, and based on this knowledge, to show possible technological applications on the other hand.

1. Introduction

For several years now, laser processing has been an accepted technology commonly applied in industry. The different processes performed with the different types of lasers are shown in the power flux density - interaction time - diagrams, see figure 1. Cutting and welding is possible using cw-lasers with medium power flux densities, whereas new processes and new types of surface modifications can only be achieved using pulsed lasers, e.g. high power excimer lasers. So far, only a few industrial applications of excimer lasers are known, e.g. structuring of microelectronic components [1] and marking of glasses.

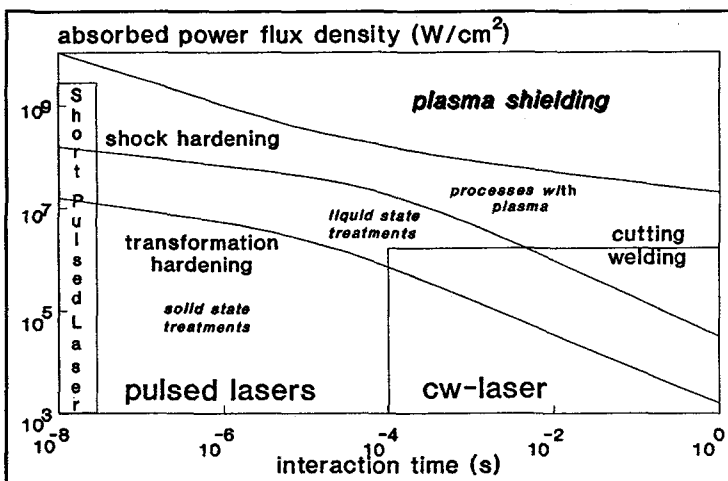


Fig. 1 Power flux density - interaction time - diagram for materials processing with lasers

2. Experimental investigations on the interaction of UV-radiation and technical metal and ceramic surfaces

The fundamental experiments were carried out with a Siemenstype excimer laser (laseractive medium (XeCl)^{*}, wavelength 308nm, pulse duration 40ns, pulse energy 2J, repetition rate 20Hz) using the mask projection technique. The evaluation of the results was almost exclusively performed using optical methods such as differential reflectometry [2], because the treatment is always restricted to very thin layers. Parallel to the detection and characterization of the surface changes, the technically interesting properties of the devices (mechanical, electrical, wear or corrosion properties) were tested under service conditions. After studying the influence of the laser parameters and the pre-treatment, the dependance of surface modifications on the physical properties of the different materials was investigated.

2.1 Influence of the laser parameters

Using a special type of excimer laser, the wavelength, pulse duration, and maximum repetition rate were determined. Changing the wavelength results in decreased or an increased absorption by the irradiated material. The influence of these parameters can easily be estimated. An increasing pulse duration leads to a higher penetration depth because of the longer interaction time. For surface treatments, the repetition rate is of minor significance. Up to 100Hz and energy densities of 40mJ/mm² for metals no thermal influence could be detected. Therefore the power flux density is the most important parameter and normally the only one which can be changed by the user.

The following figure 2 shows the influence of the power flux density on the change of materials properties. The drawing can be applied to different metals and ceramics as the given flux density is normalized over the flux density where the plasma ignition starts (plasma flux density). The different processes occurring with increasing fluxes are demonstrated.

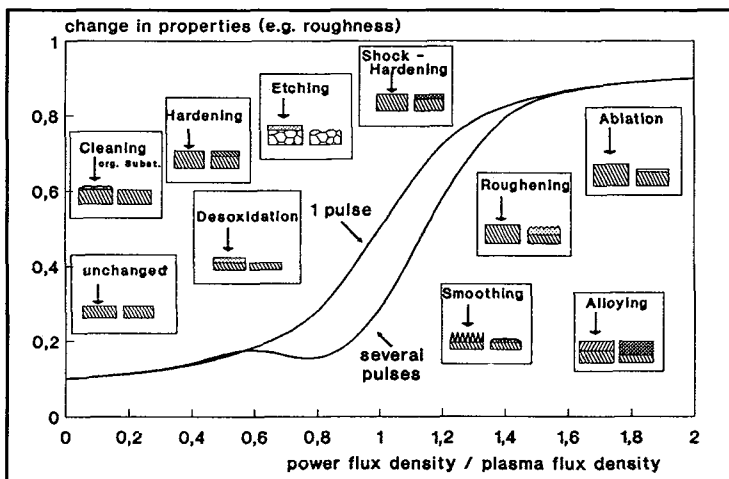


Fig. 2 Possible processes during interaction of intensive UV-light with metal surfaces

2.2 Influence of the pre-treatment

Due to the small penetration depth of the laser radiation, the pre-treatment of the substrates is of essential interest. Each production step leaves its finger-prints on the metallic or ceramic samples. A typical technical surface with different layers is shown in figure 3 on top of the next page.

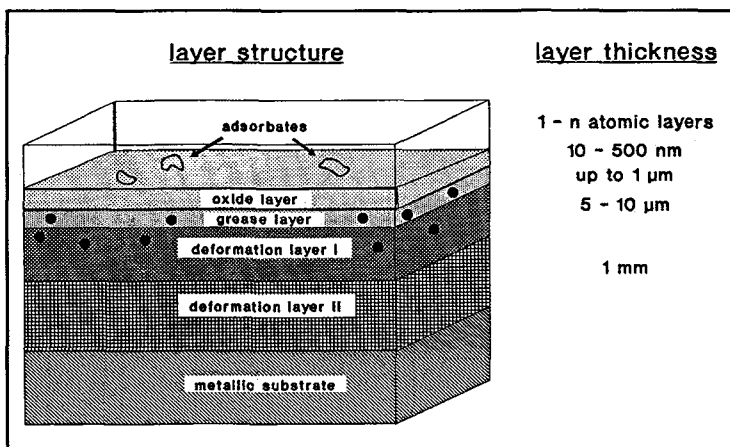


Fig.3 Schematic drawing of a technical metal surface

Depending on the different surface layers, interaction with the laser radiation is changed from a thermal (metallic substrate) to a photolytic (organic or oxide layers) mechanism. This allows to remove oxide or deformation layers from the substrate without thermal load.

In addition to the surface modifications generated by the production process, the deviations from ideal single crystal have to be considered. In general, all defects like dislocations, grain boundaries and porosities increase the absorption of the laser radiation. Therefore different parameters are needed to achieve similar surface conditions, e.g. for cold rolled and recrystallized materials.

2.3 Influence of the material properties

A systematic investigation was carried out to determine the influence of the materials properties. More than 20 different pure metals and alloys with different crystal structures were examined. Assuming a 1-dimensional heat conduction model, the melting depth can be calculated as a function of the normalized thermal conductivity, see figure 4.

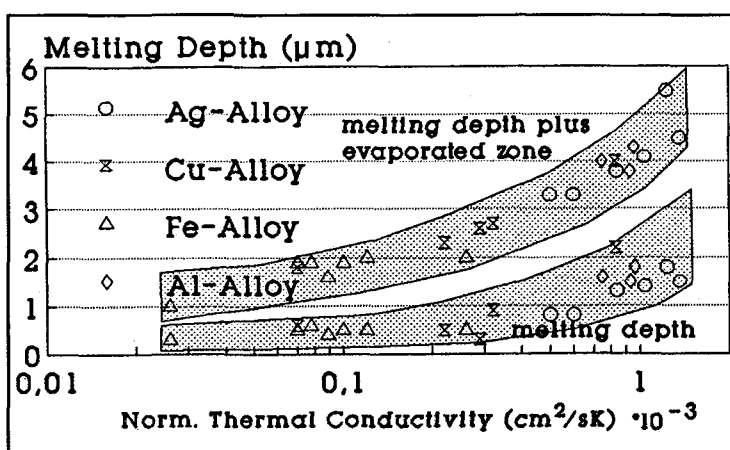


Fig. 4 Melting depth as a function of the physical properties of the alloys investigated

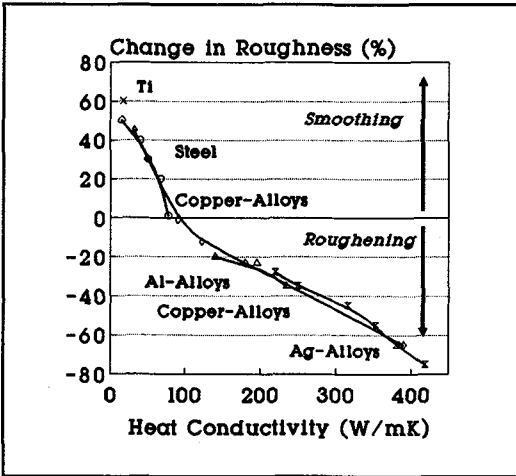


Fig. 5 Surface modification of different alloys as a function of the heat conductivity

The melting depth is mainly influenced by the thermal conductivity of the material. For surface modification, two different regions have to be considered. If the heat conductivity is high, the laser power is transferred into the volume by heat convection very quickly. This results in an increased roughness as the melt does not exist for a time long enough to allow thermal flow processes. For this reason, a smoothing of material surfaces with low heat conductivities can easily be obtained. Figure 5 exhibits the two different regions of smoothing and roughening for the materials investigated.

3. Possible applications for surface treatments of metals and ceramics

The basic know-how gained during the fundamental phase was used to leave the field of the fundamentals of surface modifications and to achieve technological surface treatments. For this purpose, components of different industrial branches (e.g. electronic and automotive industry) were chosen, where surface properties are essential for the function of the devices. Three examples will be discussed more detailed in the following sections.

3.1 Improving of the bonding behavior of lead frames

The investigated contact materials were lead frames with copper, nickel, gold, and silver bonding areas.

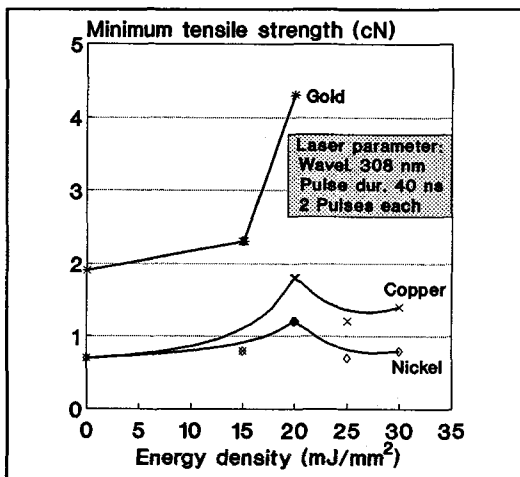


Fig. 6 Bonding behavior of Au-, Cu- and Ni-bonds after excimer laser treatment

The correlation between the decrease of reflectance (measured by means of spectral differential reflectometry), bonding behavior and surface layers generated by annealing the untreated samples to pollution atmosphere could be demonstrated. Figure 6 shows the minimum tensile strength of the different bonds as a function of the applied laser energy density. Up to a value just below the threshold for ignition of a metal plasma on the surface, an improving of the bonding behavior can be achieved. The method of the measurement of the tensile strength with 50 to 500 bond tests gives statistically significant and reproducible values.

3.2 Laying bare of graphite for parts of the automotive industry

The process of optical etching (see fig. 2) by irradiating ferritic-pearlitic nodular cast iron can be an alternative to the industrial processes using a chemical etching technique to avoid pollution problems /3/, /4/.

The laying-bare of the graphite during this process is of great interest, because the excimer laser treatment reopens the graphite inclusions as well and this will lead to an improved self-lubrication in the critical running-in phase of automotive parts. Figure 7 exhibits the influence of the surface roughness on the maximum of free graphite. Because of the small penetration depth of the laser light, there is a small processing window. The original surface roughness should not exceed a minimum roughness threshold for this process. The correlation between reflectance decrease and percentage of opened graphite spherulids on cast iron samples can be seen in figure 8. With increasing values of opened graphite, the signal amplitude of the reflected light will drop due to higher absorption of the measurement light. This effect can be used for a quality or on-line process control for materials processing with excimer lasers.

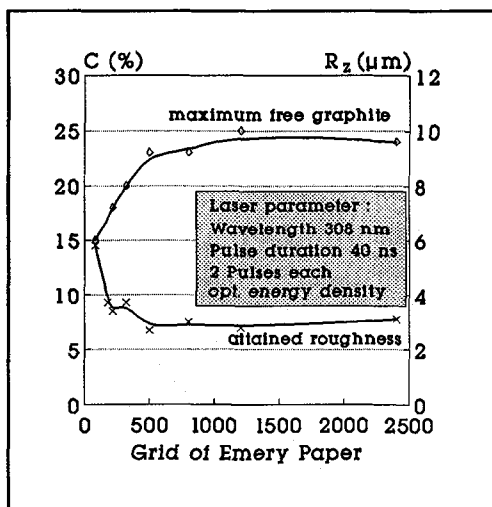


Fig. 7 Laying bare of graphite by excimer laser treatment of nodular cast iron

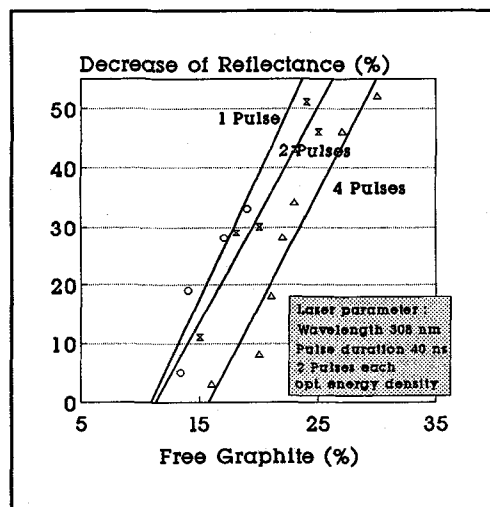


Fig. 8 Correlation between reflectance decrease and percentage of free graphite

3.3 Improving the wear resistance of alumina samples

Engineering ceramics are of high interest for electronic and medical applications. The ablation and smoothing of ceramics is a well known process, reported in literature, e.g. /5/. A typical application is the improving of the wear resistance against mechanical and dynamical stresses.

The authors examined the surface treatment of alumina samples using the effect of sealing the ceramic surface by simultaneously smoothing and reduction of the surface porosity. The influence of the pre-treatment and the purity on the bending strength and Weibull modulus is detected /6/. In figure 9 the improving of the weibull-modulus as a function of the energy density of the laser irradiation and the influence of the purity can be seen. The Weibull modulus could be increased twice compared to the untreated samples. Therefore, the laser treated samples will have a much lower percentage of failure in an industrial process.

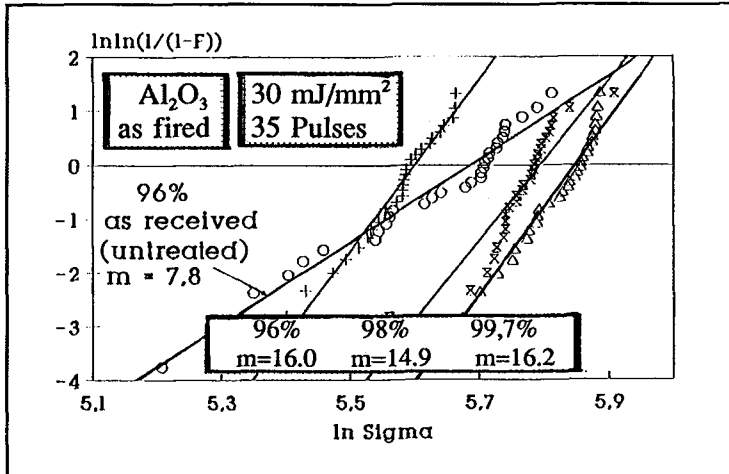


Fig. 9 Weibull modulus as a function of pre-treatment and purity for alumina samples

4. Conclusions

Excimer lasers with uniform beam profile and high pulse energy offer interesting possibilities for materials processing of metals and ceramics. Due to the wavelength and penetration depth, the excimer laser is an excellent working tool for surface treatments without damaging the workpieces. If the critical problems for industrial application (e.g. beam homogenizing, beam shaping and guiding, reliability of electrical circuit components and an on-line process control) can be solved in the future, a wide range of application for these new processes can certainly be anticipated.

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