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INDUCED BY THE ABSORPTION OF MEDIUM
INTENSITY LASER PULSES ON SOLIDS

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THE DECREASE OF OPTOACOUSTIC SIGNALS INDUCED BY THE ABSORPTION OF MEDIUM INTENSITY LASER PULSES ON SOLIDS

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Abstract - Simultaneous measurements of optoacoustic signals in the absorbing solid and in the surrounding gas have been performed in order to study surface modifications on various solids, caused by the absorption of the first few laser pulses of fluence 0.4 J/cm² and duration 20 ns.

Introduction - Using laser as the excitation source in pulsed optoacoustic spectroscopy, it may readily happen that the incoming light beam intensity exceeds the damage threshold of the irradiated material, thus leading to the considerable increase of the optoacoustic signal. It is well known however, that there exist several other surface modifications induced by laser pulse intensities well below the visible damage threshold, which are difficult perceivable by other methods. The aim of this article is to demonstrate the possibility of indicating these modifications by observing the changes of OA response induced by the absorption of the first few laser shots in various solid surfaces. In order to get more exhaustive data on the complex source mechanisms, it is convenient to measure simultaneously the transient OA waves in the absorbing solid and in the surrounding gas.

Apparatus - In the "free" air geometry experimental arrangement (Fig. 1.) a Q-switched Nd-YAG laser was used to produce single pulses with energy of 0.1 J, duration 20 ns and diameter of 5 ± 1 mm. This provided the fluence of approximately 0.4 J/cm², which is below the damage threshold for most metals. Transient OA waves in the solid were detected by the 200 kHz resonant acoustic emission PZT transducer bonded to the specimens - plates of different dimensions. The OA waves in the surrounding gas were detected by B&K 4133 microphone placed in front of the absorbing surface. Signals of both kinds were amplified and fed to a digital transient recorder triggered by a fast photodiode. The digitized data was then stored via process computer for later analysis.

Experiments - Various metals and glasses were chosen for the experiments. For each material several series of laser shots were performed on as-received, on grinded and on polished and carefully cleaned
surfaces. Except on as-received surfaces no visible deterioration of the irradiated specimens could be observed.

Several couples of transient optoacoustic responses detected by microphone and PZT transducer simultaneously are shown in Fig. 2. The waveform of the microphone signal is found to be practically constant in a broad amplitude interval from 2 mV (AR thin film) to 5 V (Al plate). Since the duration of the laser pulse and corresponding acoustic pulse in a gas is very short in comparison with the resonance period of the microphone, the waveform is mainly determined by the impulse response function of the microphone. By analogy to the simple ballistic pendulum the amplitude of the microphone signal is assumed to be proportional to the linear wave momentum carried by the optoacoustic wave in a gas.

The structure of the PZT signal is considerably more complex. It is influenced not only by resonant nature of the transducer, but also by the excitation of different wave modes (longitudinal, shear, surface) and by numerous reflections and mode conversions of the original optoacoustic wave inside the solid specimen. PZT responses on different specimens show great differences in waveform structure, while their amplitudes cover relatively narrow interval from 1 mV to 10 mV at the transducer output.

Regarding the above restrictions it is very difficult to compare the results of single shot experiments on various specimens. The situation is better, however, if successive optoacoustic responses are observed during multiple laser shots on the same surface area of the specimen. Since the sensitivity of the experimental system is remained constant in this case, any change of the optoacoustic response could be used as the evidence of laser induced surface modifications.

Common characteristics to all experiments in which laser pulses of the fluence 0.4 J/cm² were used, was the significant decrease of the simultaneously measured optoacoustic response in gas and solid after the first few laser shots. For the most part the amplitude of the second response was found to be less than 10 % of the corresponding initial value. Shown in Fig. 3 are the simultaneous optoacoustic responses as obtained by the first four laser shots on grinded steel surface. Comparable with the decrease of the amplitude of the microphone signal which is not changing its waveform, is only the decrease of the first peak in a complex burst signal of PZT transducer. Time intervals between successive reflections of this wave confirm that it corresponds to the longitudinal component of the optoacoustic wave. It is evident that the longitudinal component is much more sensitive to the laser induced surface modifications than the rest of the optoacoustic signal, which corresponds to the shear and surface waves.

Several mechanisms, such as surface cleaning, adsorbed thin liquid layer evaporation, annealing or some other (to us unknown) phenomena could lead to surface modifications related to the changes of optoacoustic response. Different behaviour of longitudinal and shear optoacoustic wave component could be useful in seeking adequate theoretical explanation of the above described phenomena.

Discussion - In summary, simultaneous measurements of the "free" air and solid sample optoacoustic response have been carried out on various substances. Considerable decrease of microphone signal and the changes of PZT response have been found to be closely related to the surface alterations induced by laser pulses of fluence.
below the single-shot surface damage threshold. The exact mechanism of the observed phenomena has not been determined.

Though uncomplete, the experiments indicate the utility of simultaneous detection of the "free" air and solid sample optoacoustic signals for the study of laser induced surface modifications. Additional experimental and theoretical techniques should be used to extract more detailed information about the complex optoacoustic source mechanism. We believe that this would open several interesting applications of the above described technique in surface cleanliness monitoring and laser-induced damage threshold determination.

References

Fig. 1 - Schematic of the experimental set-up for simultaneous observation of the "free" air and solid sample optoacoustic response.
Fig. 2 - Simultaneous "free" air and solid sample optoacoustic responses on various specimens (a-Al plate, b-common glass, c-optical thin film on absorbing glass substrate, d-TiO₂ thin film on non-absorbing glass substrate)
Fig. 3 - The decrease of optoacoustic response in gas (a) and solid (b) induced by successive laser shots on grinded steel surface.