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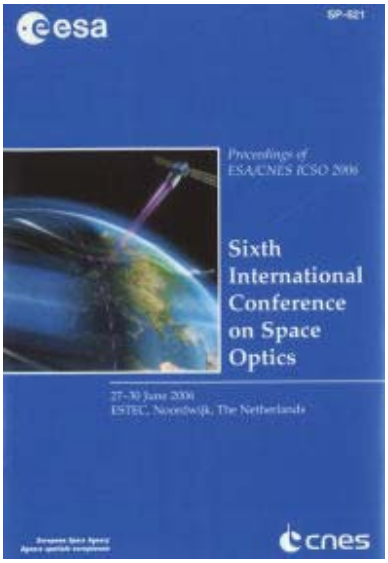

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INVESTIGATION OF UV LASER INDUCED DEPOSITIONS ON OPTICS UNDER SPACE CONDITIONS IN PRESENCE OF OUTGASSING MATERIALS

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ABSTRACT

We have investigated the formation of UV laser induced deposits on uncoated fused silica optics under simulated space conditions in presence of outgassing materials at 30°C and 100°C. We used a frequency tripled Nd:YAG laser with 355 nm wavelength, 3 ns pulse length and 100 Hz repetition rate. Optics were exposed to fluence values in the range of 0.5 – 1.0 J/cm². As contamination samples epoxy, silicone and polyurethane containing materials were used. The depositions were monitored online and in-situ by measuring the fluorescence intensity distribution with CCD cameras, where the UV laser beam itself served as excitation source for fluorescence emission. This method allows for a very sensitive detection of the onset of deposit formation. Contaminant layers with a thickness down to 20 nm can be consistently detected. The influence of water on the formation of deposits was investigated. Time-of-flight secondary ion mass spectroscopy (ToFSIMS) was used for chemical characterization of the deposits.

1. INTRODUCTION

The Atmospheric LAser Doppler INstrument (ALADIN) will be the sole payload on-board the upcoming ADM-Aeolus mission, which is to be launched into a low Earth orbit for laser-based global wind observations. The system operates in the near UV band at 355 nm wavelength. It fires laser pulses towards the atmosphere and measures the Doppler shift of the return signal, backscattered at different levels in the atmosphere. Due to the space environment the laser optics are exposed to harsh conditions: amongst others the outgassing of organic material under vacuum conditions combined with high laser fluences can lead to formation of deposits on the optics and thus can obstruct the beam partially, or even totally [1,2,3,]. For mitigation of such risks a fundamental understanding of the processes involved in laser-induced deposit formation under the presence of outgassing components is essential.

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2. EXPERIMENTAL

Fig. 1 shows schematically the set-up of the experiment. A Coherent Infinity 40-100 Nd:YAG laser system serves as IR-radiation source. The laser light is then frequency doubled and tripled by KD*P crystals in an Excel technology unit. The UV-light is focused by a plano-convex quartz lens. The focus is located approximately 15 cm in front of the entrance window and not in the test chamber. A small fraction of the beam intensity is coupled out of the main beam via a wedge for online energy measurement and beam profiling. For improvement of the beam quality a 1.2 mm diameter pinhole is inserted as a spatial filter. Fig. 4a shows a typical beam profile measured at a CCD camera position corresponding to the entrance window. The profile is nearly Gaussian with a 1/e² diameter of 320 µm.

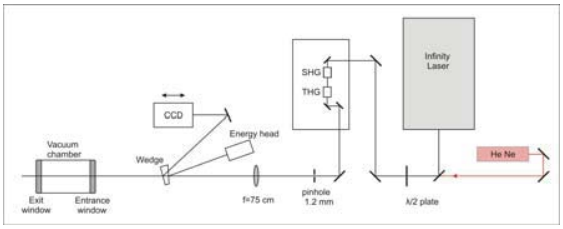

Fig.1: Contamination test set-up

The test chamber consists of a stainless steel tube (diameter 35 mm, length 270 mm). Entrance and exit windows (diameter 1" or 1.5", uncoated quartz) serve as optical test samples. The chamber is pumped by an oil free combination of turbo-molecular and membrane pumps. Typical base pressure is better than 10^{-6} mbar. By partial or complete closing of the vacuum valve between chamber and pumping system it is possible to perform the tests at different pressures. Heating ribbons are mounted at the outside of the chamber. Before each new run the chamber is baked out at 165°C for 24 hours to prevent cross-contamination between consecutive tests. A blank test is performed prior to each material test, using the same temperature, pressure and laser parameters and is deemed to be successful when no fluorescence is detected.

The contamination samples consisted of Al foils coated with different epoxy (samples A and B) and silicone (samples C and D) based materials. The samples were placed in the bottom of the vacuum chamber and heated directly by conduction. Two different tests were performed with each sample, one at T = 30°C and p = 10^{-2} mbar (vacuum valve partially closed) and a second at T = 100°C and a pressure between 10^{-3} mbar at the beginning and up to 15 mbar at the end of the test (valve completely closed). An additional test was done with a sample E with polyurethane based glue. Sample E was tested only at 40°C and a pressure of 10^{-6} mbar. For all tests, the peak on-axis laser fluence was 1 J/cm² at the entrance and 0.5 J/cm² at the exit window. The laser was fired for 5 million shots per test with 100 Hz repetition rate.

After the tests, the windows were inspected by optical microscopy. Surface profilometry of the deposits was then performed with a white light interference microscope.

For testing the influence of water on the formation of deposits a liquid reservoir with about 50 ml volume was connected via a needle valve to the chamber. The partial pressure of the water vapour in the chamber was measured with a gas type independent capacitance sensor. Prior to the experiment the water was ultrasonically degassed.

Since the tests are performed with UV laser light, in case of deposit formation the deposits are excited to fluorescence. This fluorescence is measured in-situ by a combination of microscope and CCD camera. The microscope is focused to the inner side of the window. For determination of the fluorescence intensity a laser beam analysing software was used. It calculates the integrated intensity of the fluorescence inside a chosen aperture around the beam position. The CCD has a very low sensitivity for 355 nm so that scattered light of the original laser beam is not impairing the measurement.

3. RESULTS AND DISCUSSION

In Table 1 the results of the microscopic inspection of the windows are summarized. Fig. 2 shows a typical light microscope picture of a deposit on the exit window. Materials A and B showed in all tests deposit formation, material C only in the 100°C test whereas in case of material D no depositions were found. The silicone based materials seem to show less affinity to produce deposit layers. But additional experiments are necessary to confirm this conclusion.

Contaminant	30°C 10^{-2} mbar	100°C 10^{-2} -15 mbar
Epoxy based material (A)	X	X
Epoxy based material (B)	X	X
Silicone based material (C)	O	X
Silicone based material (D)	O	O

Table 1: Results of contamination tests: x: deposits on entrance and/or exit window, o: no deposits on entrance and exit window

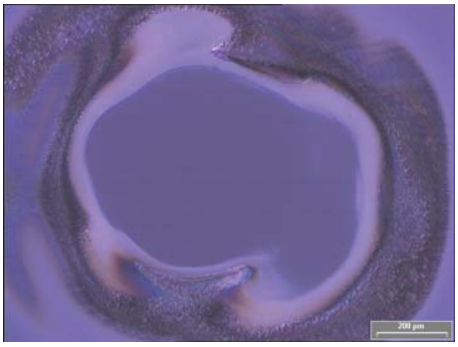

Fig. 2: Deposit on the exit window after a 100°C test with an epoxy based glue

By observation of the fluorescence the temporal evolution of deposit formation can be studied. Fig. 3 shows typical micrographs taken during a 100°C test with an epoxy based sample. It starts with a faint homogenous spot which evolves into a ring like structure.

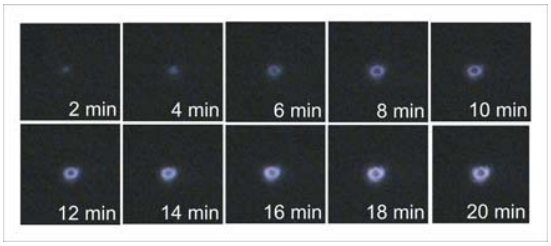

Fig.3: Dynamic of deposit formation from fluorescence measurements with an epoxy based resin as contaminant. The deposits have a diameter of approximately 400 µm.

Optical surface profilometry of the deposit is shown in fig. 4b together with the corresponding laser beam profile. In accordance with the fluorescence pictures the surface profile shows also a ring like structure. At the centre of the beam incidence point there is a crater surrounded by a steep wall. The height of the wall is approximately 50 nm. The wall is outside of the $1/e^2$-diameter of the impinging laser beam. Possibly the laser intensity in this region is so high that the deposits may built up there but they are then ablated or ejected to the outside. The fluorescence intensity in dependence of time shows a nearly linear increase (Fig.6) over the duration of the test.

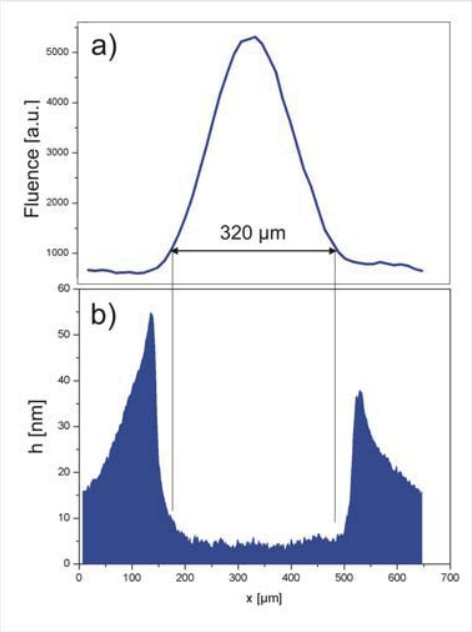

Fig. 4: Surface profile of a laser induced deposit (b) in correlation with laser beam profile (a)

For the test with the polyurethane containing glue (sample E) a ring like structured deposit was also found. The ToFSIMS analysis is consistent with a ring like feature. In the central area of the ring, measuring ~340 µm, the surface composition appears to be similar to that observed in the non-irradiated area surrounding the ring where the silica substrate and surface contaminants (including, amongst other species, nitrogen-containing material, carbonaceous material and PDMS (poly-dimethyl siloxane) are detected. The ring itself shows two distinct regions, a thin internal area where the composition is dominated by PDMS, unfunctionalised hydrocarbon and nitrogen-containing material (CN^- and CNO^-), and a wider external area, measuring between ~140 and 340 µm in width, where the composition is dominated by unfunctionalised hydrocarbon and PDMS (although at a relatively lower level to that observed in the inner part of the ring). The CN^- and CNO^- ions found in the internal part of the ring (Fig. 5) are possibly deriving from decomposed polyurethane. The origin of the PDMS is unclear up to now.

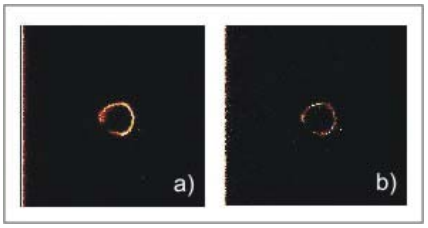

Fig. 5: CN^- (a) and CNO^- (b) intensity of a deposit formed in a test with a polyurethane based glue

Hovis et al. found [1] in investigations performed at 1064 nm, that the presence of air dramatically inhibits the formation of deposits in case of hydrocarbon contaminants. For a pure nitrogen environment they found a much higher probability for deposit formation. To investigate the influence of water to the formation of deposits, we performed a test with an epoxy based contaminant at a partial pressure of 5 mbar water in comparison with a test without water. As can be seen from the surface profilometry data (Fig.6) of the deposits and the fluorescence measurements (Fig.7) water reduces the deposit formation significantly. Additional investigations are planned to analyse this effect in detail.

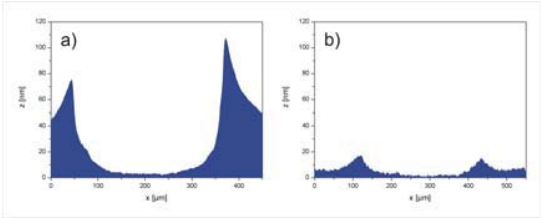

Fig. 5: Influence of water on deposit formation. Deposit surface profiles. a): without water, b): 5 mbar water

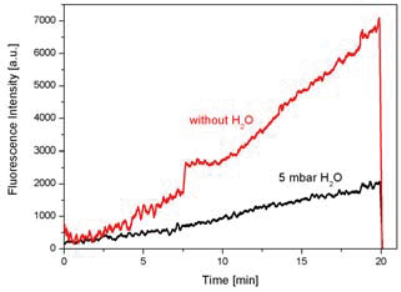

Fig.6: Influence of water on deposit formation observed by fluorescence measurement

4. Summary

Various non-metallic substances typically utilized in space applications were tested for their potential to build up harmful contaminant layers on laser optics. The tests reported in this paper were carried out in the UV spectral range at 355 nm wavelength on uncoated fused silica substrates. Online monitoring of the fluorescence emission showed that the deposits build up already within several minutes after starting the laser irradiation. Maximum deposition depth was found always outside the edges of the Gaussian beam distribution. By ToFSIMS analysis potential contaminant breakdown products have been detected in the deposits. In a first experiment we found a reduction in the deposit formation by water.

5. ACKNOWLEDGEMENTS

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