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LASER SURFACE CLEANING AS A NOVEL CLEANING APPROACH FOR GENESIS SOLAR WIND COLLECTORS

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Introduction: The Genesis mission returned pristine solar wind material implanted in ultrapure collectors to Earth in 2004 [1, 2]. Unfortunately, the return of the spacecraft resulted in a crash landing shattering the solar wind collectors into small fragments and exposing them to desert soil and other debris at the landing site. To permit for accurate analysis of embedded solar wind within a collector, surface cleaning is a necessity. A number of chemical and mechanical cleaning methods have been developed for this purpose [3,4]. However, some contaminants resist removal by these methods and call for novel less conventional cleaning approaches.

Lasers are characterized by emitting monochromatic and coherent radiation, which can be highly focused, making them one of the most versatile tools in science and technology. Among other interactions of lasers with solids, desorption and ablation occur on surfaces of materials irradiated by a laser beam. These phenomena have been utilized for non-invasive cleaning of delicate historic objects such as manuscripts, paintings, and sculptures [5]. Laser cleaning is also commonly applied in the semiconductor industry as an alternative to the traditional wet chemical treatments of wafers which produce large quantities of harmful chemicals [6]. To test the suitability of laser surface cleaning for Genesis samples, we selected a silicon wafer fragment, contaminated it intentionally and applied dry laser cleaning under grazing incidence angle to the fragment to remove the contamination.

To check whether cleaning was effective and no damage to the surface did occur, the sample was inspected before and after cleaning using an optical microscope and total reflection X-ray fluorescence (TXRF) analysis. Contaminant concentrations were calculated before and after cleaning using external calibration curves as described in [4] and the spectral backgrounds were compared to evaluate for surface damage.

Experimental: A silicon wafer was contaminated by rubbing a mixture of sand, dirt and white paint onto its surface. The mixture was chosen in order to approximately simulate the contamination encountered for the Genesis collectors, with sand and dirt representing soil and white paint representing space craft paint. The wafer was inspected optically using a microscope coupled with a CCD camera (Axioscope 1.0, Zeiss; Moticam 5.0, Motic.com) and spectrochemically using TXRF analysis (S2 PicoFox, Bruker AXS, Madison, WI). After that the wafer was subjected to a nanosecond pulsed Nd:YLF laser at 527nm and under 3.5° incidence. The laser power density was 5.31W/cm^2 with a pulse duration of 300-400ns at 1kHz repetition rate and 6.85mJ per pulse. The laser beam was carefully swept across the surface to cover a large area. Figure 1 shows the laser cleaning process schematically (left) and in action on the sample (right). After laser treatment the sample was reexamined optically and spectrochemically as described above.

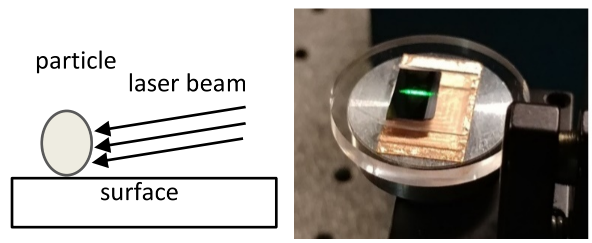

Figure 1: left) Laser surface cleaning at grazing incidence schematics; right) Laser surface cleaning of silicon wafer in action.

Results and Discussion: In Figure 2 the micrographs of the silicon sample before (left) and after (right) dry laser cleaning are compared. The difference is clearly visible showing that the laser cleaning indeed did remove a substantial amount of contamination. In Figure 3 the TXRF spectra taken before (black) and after laser cleaning (red) are displayed. Also here the difference between contaminated and cleaned sample is clearly noticeable. More importantly, the TXRF spectra show no visible difference in spectral background for

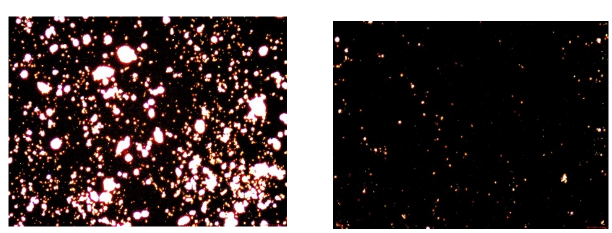

Figure 2: Microscope CCD camera images of the same area and magnification of the silicon wafer sample surface: left, after intentional contamination and right, after laser cleaning at grazing angle.

the sample before and after laser surface cleaning. Since TXRF is highly surface sensitive an increase in spectral background reflects an increase in surface roughness or surface damage. Both spectra show comparable background signals indicating that the sample surface was not compromised by the laser, an essential requirement for Genesis solar wind sample cleaning. In Table 1 the concentrations of selected contaminants were calculated before and after the dry laser cleaning. The concentrations were obtained using external calibration curves as described in [4] and are shown for area analyzed (~2x5mm or 10mm^2) by TXRF.

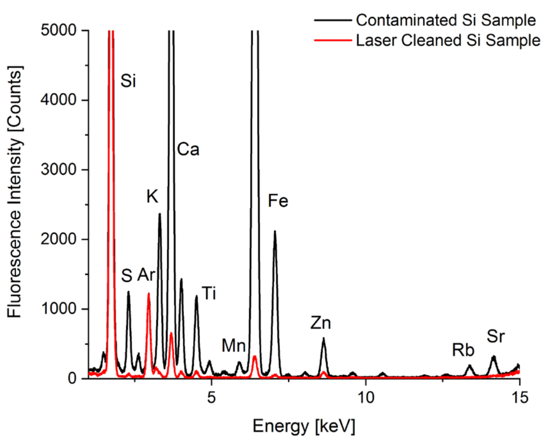

Figure 3: TXRF spectra of contaminated (black) and laser surface cleaned (red) silicon wafer.

A number of contaminants were reduced below the detection limit of the method and others were reduced by a factor of 10 or more. For example, the concentration of Mn was reduced from $2.2x10^{12}$ atoms to $7.1x10^{10}$ atoms and the concentration of Fe was reduced from $2.1x10^{14}$ atoms to $4x10^{12}$ atoms for the area analyzed. Especially Fe is a common contaminant for Genesis samples and being able to reduce it or ultimately remove it would be very beneficial for most analyses of solar wind. It is important to note that the laser cleaning was done under normal laboratory conditions in this experiment and not in a clean room or clean bench. Moreover the sample had to be transported from UIC to Loyola. This most likely explains the presence of common laboratory contaminants like Ca, Fe and Zn. Future experiments will address this issue.

Element	Si wafer contaminated [atoms]	Si wafer laser cleaned [atoms]
Ca	5.6e14	3.1e13
Ti	3.5e13	2.4e12
Cr	1.1e13	
Mn	2.2e12	7.1e10
Fe	2.1e14	4e12
Cu	4.2e11	
Zn	3.2e12	4e11
Rb	4.8e11	

Table 1: Calculated concentrations of surface contaminants before and after laser surface cleaning. All data are shown as atoms per area analyzed (~2x5mm or 10mm^2).

Conclusion : Dry laser cleaning under grazing incidence was applied to remove surface contaminant particulates from an intentionally contaminated silicon wafer. It was found that this cleaning method was effective in reducing contamination by at least an order of magnitude and in many cases below detection limit of the TXRF analysis. In addition, inspection of the spectral background in the spectra showed no visible differences before and after laser cleaning, indicating that the surface of the wafer was not compromised by the laser beam. Despite these are preliminary experiments, we believe that laser surface cleaning could be a valuable alternative for cleaning of Genesis samples, where chemical or mechanical methods are insufficient to remove contaminants. Additional experiments involving different collector materials and also flight spares are planned for the near future.

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