

# ALL MULTIMODE SMART ENDOSCOPIC CLEANING SYSTEM MONITORED BY LIBS SPECTROSCOPY

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Many industrial applications require careful regular or periodic cleaning of inner regions of metallic elements such as citerns, tanks or tubes [1]. Techniques like sandblasting or chemical cleaning are often unsuitable as they cannot allow proper control of the progress of the cleaning process and because they cannot apply for hardly accessible regions. For addressing both issues, we report in this communication an endoscopic cleaning system based on the use of short energetic light pulses directed towards the area to be scoured by means of an endoscopic optical fiber, and completed by a remote real time Laser Induced Breakdown Spectroscopy (LIBS) analysis system.

As a light pulse source, we first developed a novel dual Q-switched laser based on a Nd:YAG crystal pumped by a Q-switched laser diode. The crystal was set in a 330 mm long cavity including an optoelectronic switch (Pockels cell +  $\lambda/4$  waveplate + polarizer) [2]. This versatile source provided either 10 ns pulses at 1064 nm or longer 180  $\mu$ s pulses only by removing a partially reflecting mirror inside the cavity. The pulse energy is 50 mJ at 1 kHz (peak power = 5 MW) and 450 mJ at 10 Hz (peak power = 45 MW). The output beam was focused on the input face of a large-core step-index silica multimode fiber (length up to 10 m, core/cladding diameter = 1500/1600  $\mu$ m, numerical aperture NA = 0.22). The coupling efficiency was measured to be  $\sim$  90%. The beam exiting this endoscopic fiber was focused on the sample to be cleaned, so that the energy density per pulse impinging the sample was  $\sim$  32 J/cm<sup>2</sup> (max reachable value  $\sim$  110 J/cm<sup>2</sup>) at 100 Hz. Due to this high energy density, the beam interaction with the sample generated plasma at the focal point. Part of the light emitted by this plasma was collected by the fiber and then guided back toward the input. Finally, the plasma light exiting the fiber was directed towards an optical spectrometer by means of a 45° dichroic filter set in the path of the beam (transmission coefficient = 99 % @ 1064 nm and reflection coefficient  $\sim$  99 % in the visible). This experimental setup is depicted in Fig. 1.

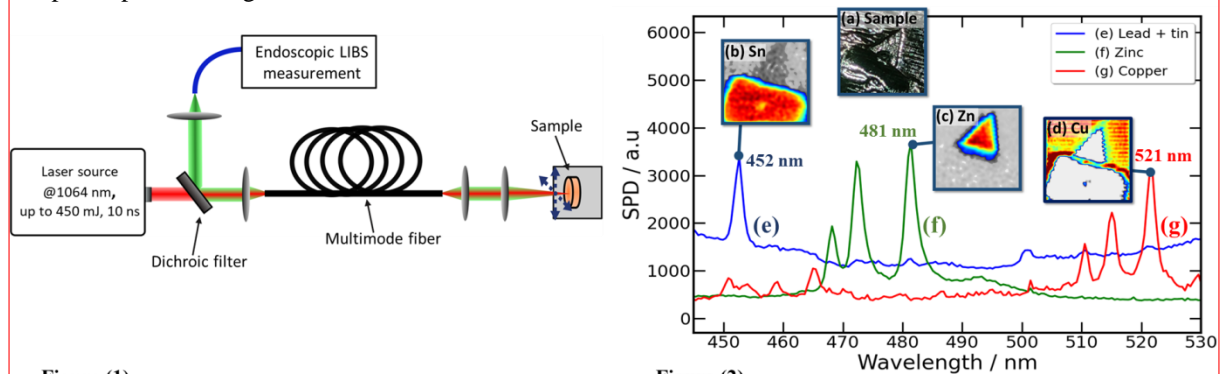


Figure (1)

Figure (2)

Figure 1: Experimental setup designed for remote cleaning of a sample by means of an endoscopic fiber, and for smart monitoring the cleaning process thanks to LIBS analysis ; 2: photo of a sample made of an assembly of different metallic pieces (a); 2D images showing the relative intensity of spectral lines at 450nm, 481 nm and 520 nm characteristics of Sn (b), Zn (c) and Cu(d) regions, respectively; typical spectra measured at any point of these Sn (e), Zn (f) and Cu (g) regions, respectively

The analysis of the spectrum displayed by the spectrometer makes it possible to determine if the beam interacts with a contaminant deposit or with a clean metallic substrate. Indeed, the latter situation results in the detection of lines specific of the metal, with low level background. The lines positions and amplitudes give information on the precise composition of the metal being cleaned, which is of great interest for determining the deep of the cleaning process when applied on multilayer materials. In order to perform images of the sample of interest, a scanning device was used. As an example, measurement results for a sample made of an assembly of metallic pieces of Sn, of Cu and of an alloy (40% Pb + 60% Sn) are displayed in Fig. 2. 2D images of the relative spectral power density (SPD) in characteristic spectral lines of the LIBS spectra (Figs. 2b, c, d deduced from spectra shown Figs. 2e, f, g respectively) allow to determine the composition and shape of the different pieces, which is not possible from a standard photo (See Fig. 2a). Further information on the laser source and on the performance of the overall device will be presented at the conference.

## References

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