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Using Multi-Spectral Active Infrared Thermo-reflectivity to study temperature field evolution during high power laser illumination

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The development of High Energy Laser (few tens of kW) for the study of the vulnerability of solid materials requires the development of numerous imaging methods for the measurement of: (i) optical properties of surfaces, (ii) materials thermal properties (extreme conditions, phase change, non-linear properties...) and (iii) laser-matter interaction.
Such phenomena mostly lead to high thermal gradients which require a good knowledge of the systems temperature. Thus, it becomes essential to develop optical methods to measure temperature fields in order to characterize on the one hand the response of the material to laser engagement and on the other hand these properties which evolve non-linearly. The non-contact methods of imaging by IR thermography allow today a very good measurement of the luminance. However, the temperature field recovery from it is not straightforward as it is necessary to know the emissivity which is thermo-dependent and thus which evolve in time. In this work, we describe the development of a non-contact infrared and multispectral imaging technique based on the pyro-reflectometry technique and the specular reflection model. This approach allows to measure in-situ and in real time the emissivity fields and to self-calibrate the radiative intensity coming out of the sample by using an equivalent black body ratio, to finally deduce absolute temperature fields. Here, the transient measurement of these fields (emissivity and temperature) is presented during the laser drilling of a metal bulk. It will be shown that the oxidation problems of the surfaces affect especially the emissivity and that the developed method allows to take into account these evolutions.

1. Introduction

For more than decades, the strong demand for industrial applications using lasers of several KW has pushed the industry to increase the peak and continuous laser power [1].

The increase in power of continuous laser implies needs for characterization of materials illuminated by high power laser sources. Indeed, for reasons of laser safety and efficiency, it is interesting to determine the flux absorbed by the material. Moreover, the strong thermal gradients and the extreme conditions generated call into questions the thermal property laws established in quasi-static states.

It is in this context that the Vulnerability Test Facility was created. This experimental device allows the use of a fiber laser with a continuous power from 1 to 10~kW at 1,074 µm. The available optical head are a scanner, an optical zoom from 4 to 80~mm and two top head at 20 and 40~mm. This dedicated R&D facility is equipped with state-of-the-art instrumentation (visible and InfraRed camera, pyrometer, ...). All of this installed in a laser safety cabin protected from fire, toxic gaz vapour and so on.

With this material, it is of great interest to measure absolute temperature field to characterize material properties, to deepen the understanding of laser material interaction and so on. Infrared sensor seems to be the best compromise but involve some precautions. Indeed, as depicted in Fig. 1, the surface spectral and directional radiative properties depend on their optical properties and surface roughness and their variations due to temperature change. In addition to these properties, the radiative fluxes in a scene depend on the temperature field, the scene geometry and the participating atmosphere. Thus, when considering only opaque surfaces, the radiative flux measured by any IR sensor (see Fig 2) depends on emission, absorption, multiple reflection and multiple scattering.

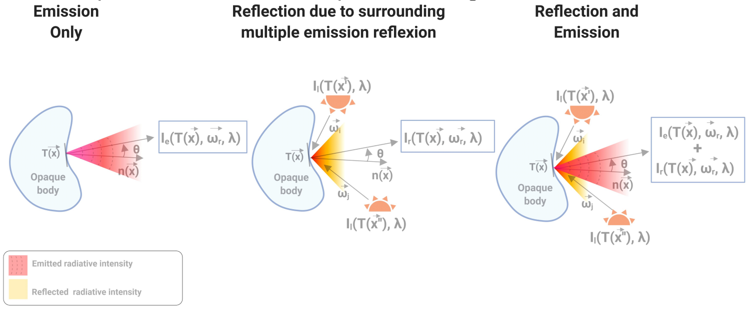

Figure 1 Schematic of the radiative problem of an opaque body at ambient temperature placed into an environment with notations used for ray reflection on an elementary surface at $\overrightarrow{x_i}$ (incident direction $\overrightarrow{\omega_i}$, reflected direction $\overrightarrow{\omega_r}$)

Today, few experimental techniques allow a simple, reliable, robust and precise measurement of the absolute temperature by contact less infrared sensors. Indeed, even if pyrometric measurements of radiance to determine temperature have been performed for decades, the characterization of emissivity has always been a major issue. To overcome this issue, a bi-chromatic [3] pyrometer has been implemented, which has been extended to a multi-spectral pyrometer [4]. These methods assume that the evolution of the emissivity between nearby wavelengths is constant or known. In addition to radiance measurements, the evaluation of the directional hemispherical reflectivity [6] was introduced to deduce both emissivity and temperature [5-7]. The adjustment of these methods for matricial sensors is still an ongoing research. To do so, in early 2000, the pyro-reflectometry [8,9] method was proposed by pioneer and adapted to an infrared camera with the thermo-reflectometry method [10,11] which requires the measurement of bidirectional reflectivity at two specific wavelengths in the near-infrared (NIR) region and assumes that the bidirectional reflectance distribution function (BRDF) is constant or known between nearby wavelengths.

The specific studied case of High Energy Laser (HEL) material interaction involve a particular attention to reflection phenomena and eliminates all sensors working around the laser wavelength. Recently, a novel approach [12] that takes into account both emissivity and reflection problems in order to measure absolute temperature and will be used in this study.

2. Experimental set up

The Fig.2 presents the experimental setup up.

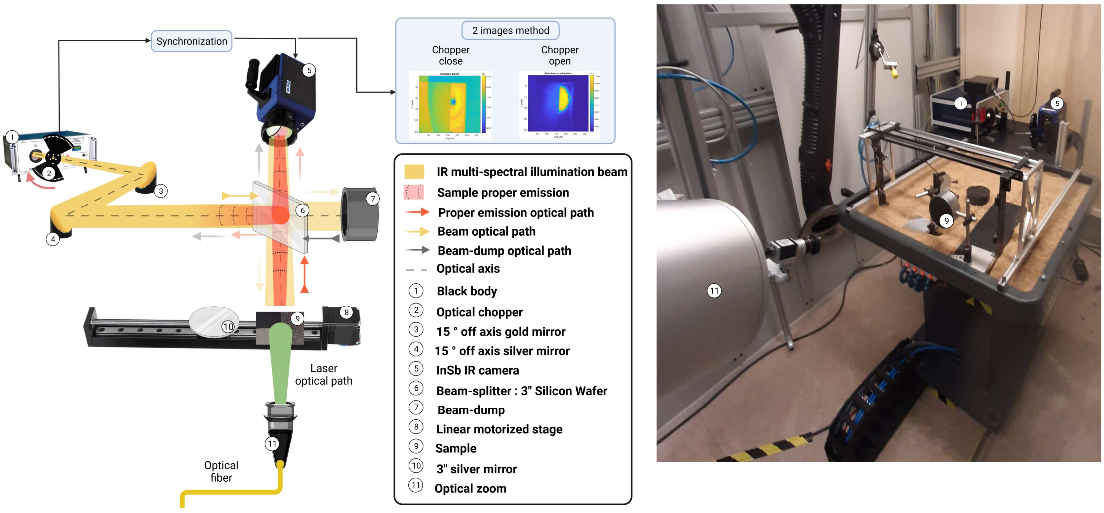

Figure 2 : Presentation of the experimental set up

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