

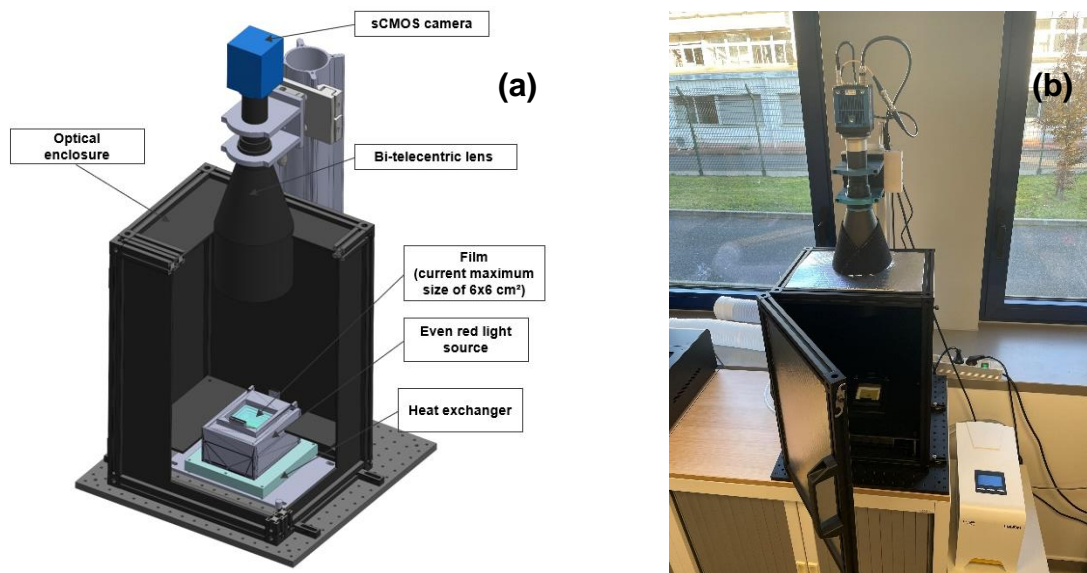
**Innovation/impact :** Having a reliable dosimetric measurement is a challenge for every user of radiochromic films. This is even more true in the actual context of new emerging radiotherapy techniques such as FLASH and VHEE, where traditional dosimetry tools (ionization chambers) have shown their limit until now, and where film dosimetry can and will play a crucial role in ensuring accurate dose measurements.

This dedicated instrument, which was patented<sup>1</sup>, uses well-chosen optical elements whose characteristics are tightly known and controlled and whose use can avoid known reading artifacts with flatbed scanners (cross-talk effect, lateral scan artifact, and increase in path-length), allowing rigorously qualified metrological performances. In addition, a key point is that the system is large enough to image a whole size of a 6x6 cm<sup>2</sup> film without scanning, and the sCMOS imager has enough resolution carefully matched to the lens to provide an ideal pixel size on the film to capture fine details in the exposed pattern (782 dpi : 32.5 μm pixel size in the image).

Finally, the measurement uncertainties can be truly quantified, which is currently lacking or incomplete due to the black box effect of flatbed scanners.

### **Key results :**

A schematic view and a photography of the system are presented in the Figure 1 below.



**Figure 1.** (a) Schematic view and (b) photography of the instrument.

Detailed features of each elements : light source, bi-telecentric lens and sCMOS camera are listed below.

- Even red light source:

- LEDs whose wavelength coincides with the maximum absorption peak of sensitivity of radiochromic films (632 nm)
- High output light source (large number of LEDs), maximizing the signal-to-noise ratio and reducing exposure time
- Adding current controllers for each LED string with voltage supply high enough to make the currents constant and therefore the light output constant for all LEDs in the string
- Maintaining a constant temperature thanks to a heat exchanger connected to a circulating thermostat allowing having a chromatic and thermal stability inside the

<sup>1</sup> <https://patents.google.com/patent/WO2022200554A1/en>

optical enclosure. The temperature is adjusted to synchronize the LED emission peak with the absorption peak of the radiochromic films

- Pulsed mode operation to limit unnecessary heat generation and illuminate the radiochromic film only during image acquisition (to minimize exposure of the film to light and to allow use of global shutter mode of sCMOS sensor)
- Added a cover with an anti-Newton glass plate to flatten the film and avoid the variation of pixel intensity with the curvature of the film (Callier effect)

- Bi-telecentric lens :

- Selection of light rays almost parallel to the optical axis (maximum angle of incidence of the light at the sensor:  $1.1^\circ$ ) in the object space (film) and image space (sensor)
- Treatment to avoid chromatic aberrations
- Blackened lens edges and black lacquered lens cover to avoid parasitic reflections

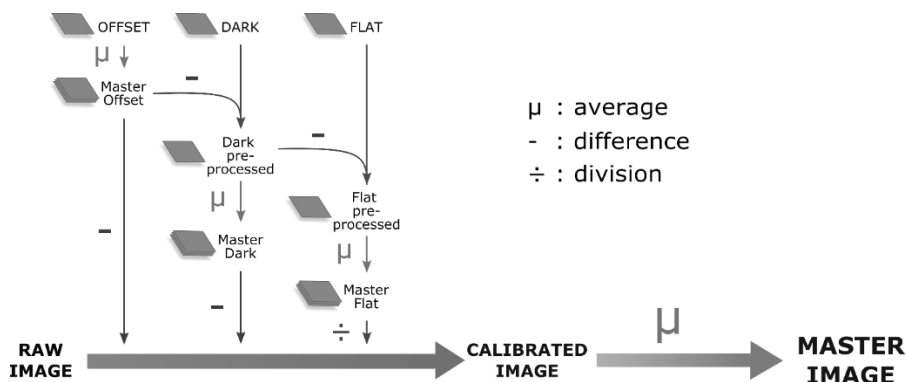
- Camera :

- sCMOS sensor (scientificCMOS) cooled and regulated by Peltier effect
- With microlenses in front of each pixel, increasing the collection quantum efficiency and drastically decreasing the effect of crosstalk with neighboring pixels
- Monochrome to avoid signal loss and artifacts in the Bayer matrix
- High resolution: 6.5um pixels per side (2048\*2048 pixels);
- Low thermal and readout noises
- High dynamic range of the sensor leading to a very good dynamic range of absorption measurement in the image

The assembly is encapsulated in an optical enclosure, with particular attention to the materials used to suppress all external light and parasitic reflection. The addition of reflective polystyrene on the exterior walls provides thermal insulation from its environment.

Moreover, the development of this new system has paved the way for a redesign and improvement of the reading protocol used until now thanks to the independent control of each element. The major innovations of this protocol are based on two points: 1- the realization of several images at high speed, thus reducing the statistical uncertainty on the measured quantity; and 2- the acquisition of three types of complementary corrective pictures, called dark, flat and offset, in order to carry out a pre-processing of the images in order to finally obtain a correct quantitative information. The flat field process essential calibrates each of the 4.2 million pixels of the CMOS chip as individual photometric measuring sensors. It also compensates for the curvature of the illumination system, all lights having an aperture-limited area of illumination.

The pre-processing sequence is explained in the Figure 2 below.



**Figure 2.** Schematic view of the pre-processing.