Substrate-enhanced photoluminescence of colour centres in lithium fluoride film-based detectors for gamma-ray dosimetry

A. Zerbini[1], M. Piccinini[1], A. Cemmi[2], I. Di Sarcina[2], J. Scifo[2], B. D'Orsi[2], A. Embriaco[2], M.A. Vincenti[1]

[1] ENEA C.R. Frascati, Nuclear Department, Via E. Fermi 45, Frascati (Rome), Italy
[2] ENEA C.R. Casaccia, Nuclear Department, Via Anguillarese 301, S. Maria di Galeria (Rome), Italy

* adriano.zerbini@enea.it

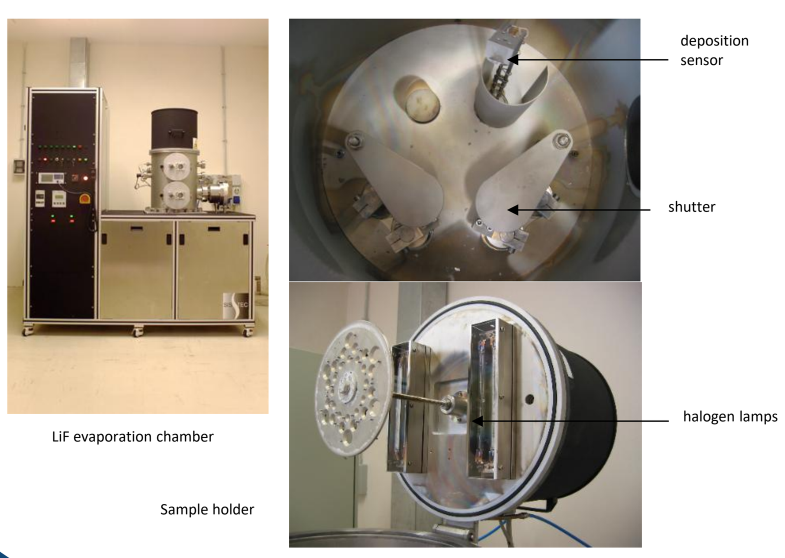
Nano Innovation 2026 Conference & Exhibition, Rome, 14-18 September

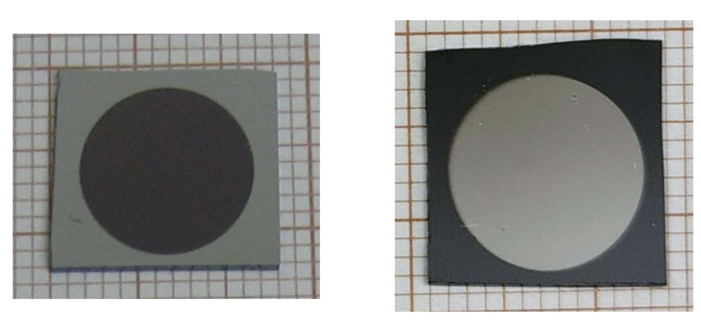
Abstract

Passive solid-state detectors based on lithium fluoride (LiF) thin films, with nominal thicknesses of 0.5, 1 and 2 µm, were grown by thermal evaporation on Si(100) and aluminum-coated silicon substrates at ENEA Frascati. Their operating principle relies on optical readout of radiophotoluminescence (RPL) emitted by radiation-induced F_2 and F_3^+ colour centres (CCs). These detectors offer high spatial resolution over a large field of view, a wide dynamic range and ease of use, with stable RPL enabling repeated evaluations without signal loss. LiF detectors on Si(100) and Al/Si(100) were irradiated over a wide dose range and multiple dose rates using the ^{60}Co source of the Calliope irradiation facility at ENEA Casaccia. RPL intensity showed a linear dependence on dose, consistent across the dose-rate regimes tested, and was approximately four times higher for films on Al/Si(100) than on Si(100). These results demonstrate the potential of LiF thin-film detectors for gamma-ray dosimetry over a wide dose range.

LiF-based thin film radiation detectors

Optically transparent LiF films with nominal thickness of 0,5, 1, 2 µm, grown by thermal evaporation on 0.5 mm thick Si(100) substrates, constantly kept at a temperature of 300 °C during deposition performed in a vacuum chamber at a pressure below 1 mPa at ENEA Frascati, Italy with a controlled deposition rate of 1 nm/s.
The same set of LiF films were also grown on a 30 nm thick Al film substrate, previously thermally evaporated on the Si(100).





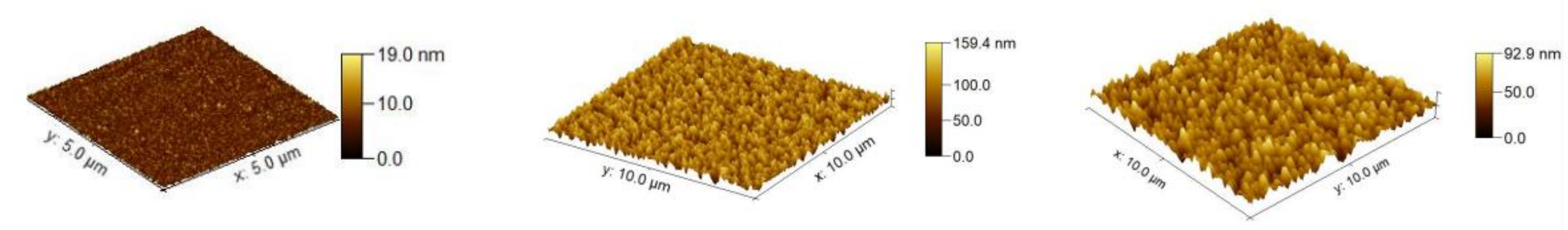
LiF film on Si substrate (*left*) and on SI/Al substrate (*right*)

Morphological Characterisation

Atomic Force Microscopy (AFM) measurements were performed using an A100 PLUS AFM (A.P.E. Research s.r.l.) operating in non-contact mode. Morphological analysis was carried out using the open-source software Gwyddion (**Table 1**).

Sample	Rq (nm)	Average grain size (nm)
Al film on Si(100)	1.68±0.07	43
LiF film on Al/Si(100)	12.41±0.37	189
LiF film on Si(100)	11.64±0.54	239

Table 1.



Al film (≈0.3 µm) on Si(100) — LiF film (1 µm) on Al/Si(100) — LiF film (1 µm) on Si(100)

LiF samples γ-irradiation

All the LiF samples were homogeneously irradiated with the ^{60}Co source of the Calliope irradiation facility at ENEA Casaccia, Italy, at five doses in the range from 20 to 1000 Gy (water equivalent), using two dose rates (10.84 and 182.65 Gy/h) across the dose range. For each irradiation dose, one sample of each thickness (0.5, 1, and 2 µm) was irradiated on both Si(100) and Al-coated Si(100) substrates, resulting in six samples per dose (**Table 2**).

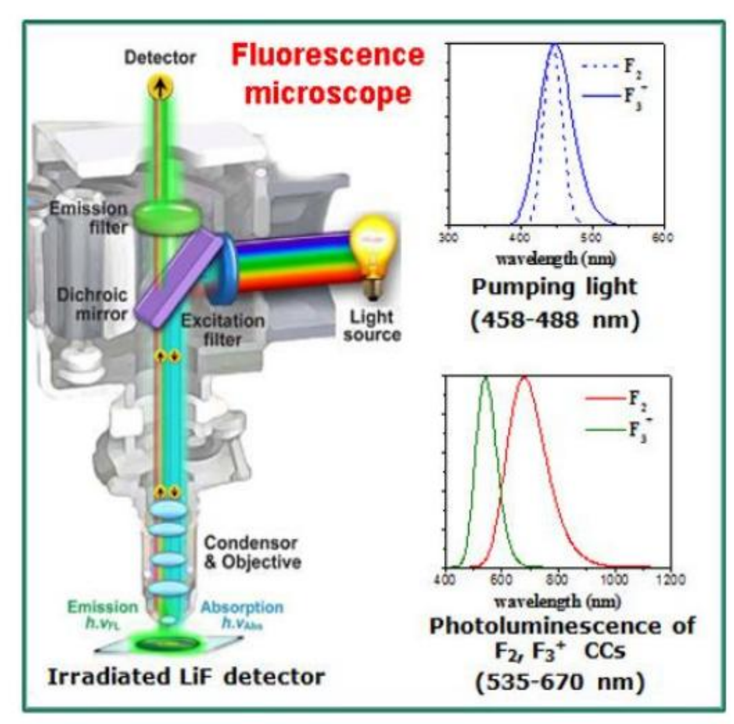
Calliope Irradiation facility

Dose (Gy)	Dose-rate (Gy/h)
20.04	10.84
59.59	10.84
100.46	182.65
502.29	182.65
1004.58	182.65

Table 2. Irradiation plan

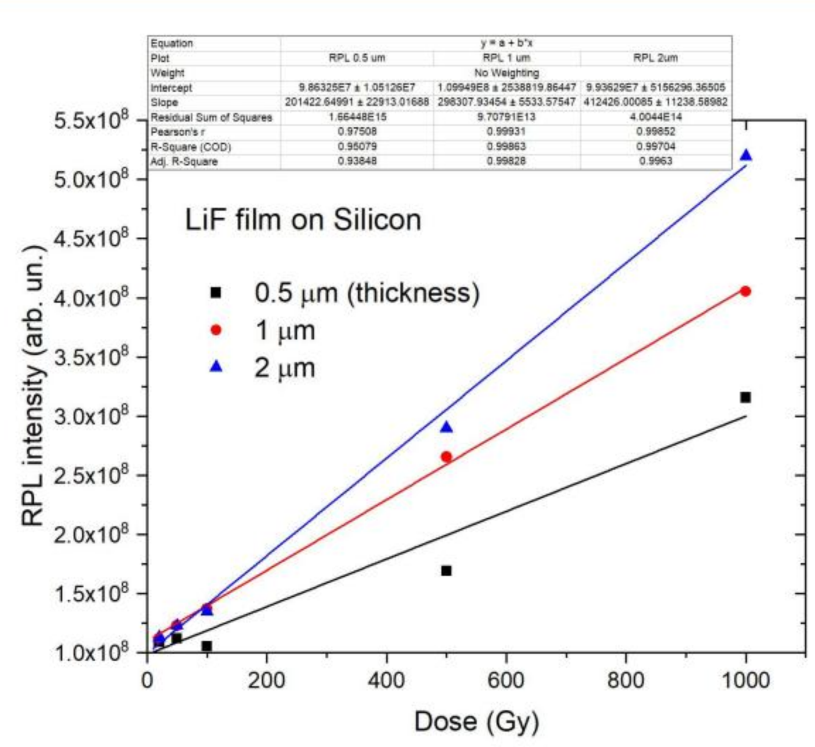
Optical readout of LiF detectors

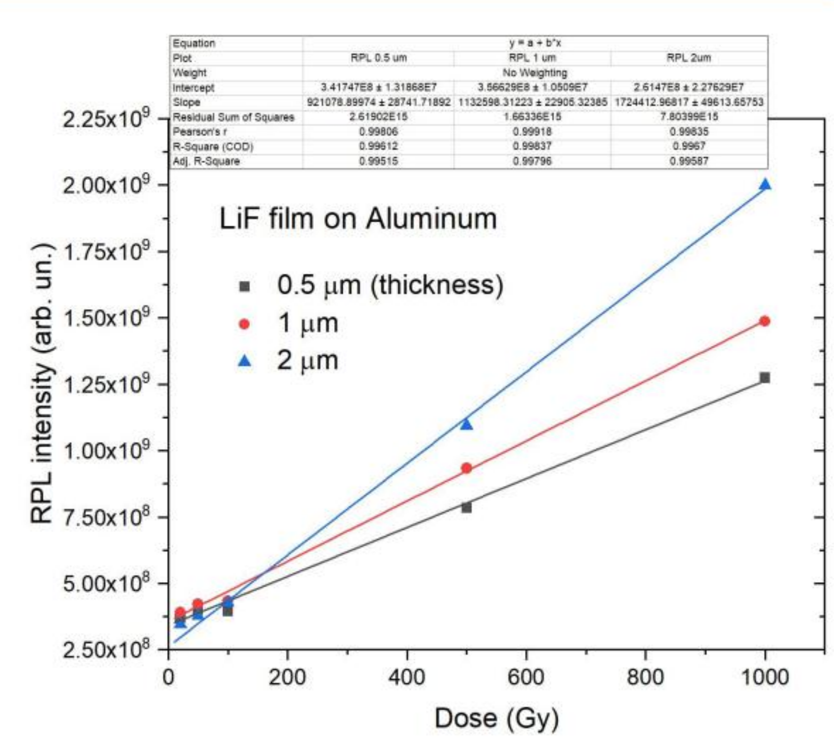
The principle of operation of these radiation detectors is the optical reading of the visible RPL emitted by radiation-induced F_2 and F_3^+ CCs. The RPL of the LiF films was measured by a Nikon Eclipse 80i fluorescence microscope equipped with a 4x objective, a blue LED source and Andor NEO sCMOS camera. The RPL measurements were performed by reading the integrated grey level intensity of the images acquired by the camera. The CCs are stable at room temperature, allowing repeated RPL readings without signal fading, and can be erased by thermal annealing to reuse the detector.



RPL response of LiF thin-film detectors

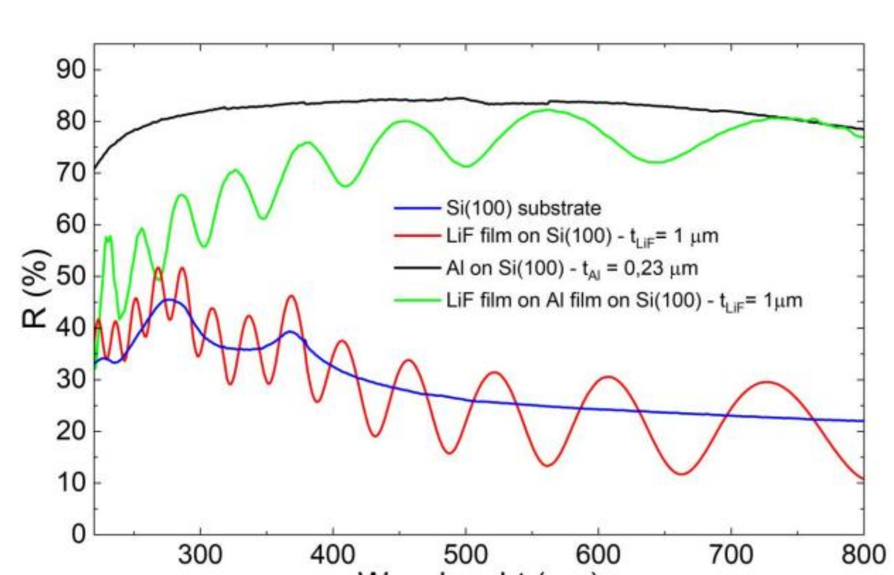
The RPL intensity of the integrated grey level of the images acquired by the microscope camera was plotted as a function of the dose. A central square area of 600×600 µm² was considered, and in this case the RPL signal selected by the microscope emission filter (Chroma AT515lp) included both the entire F_2 and F_3^+ CCs bands.
For all the films the RPL shows a linear behaviour vs. dose, with the RPL signal from films on Al consistently higher than on Si, resulting in better-quality data fits. The RPL signal intensity increases with film thickness, as expected. Due to the low RPL signal intensity, the LiF films can be exploited starting from a minimum dose of 50 Gy, using Al/Si as substrate.





Substrate RPL enhancement

Comparing LiF films grown on Si(100) and Al/Si(100) substrates under the same deposition and irradiation conditions, the higher RPL intensity observed on Al/Si(100) — consistent across all doses and thicknesses — is mainly attributed to the higher reflectivity of the Al/Si(100) substrate in the visible range, where the F_2 and F_3^+ emission bands are located. This corresponds to an RPL enhancement of about 400% (slope ratio ≈ 4 for all three film thicknesses, (**Table 3**). A contribution from the polycrystalline nature of the LiF films, which may affect colour-centre formation efficiency, cannot be excluded.



Nominal LiF film thickness (µm)	Slope ratio
0.5	4.57±0.52
1	3.80±0.15
2	4.18±0.23

Table 3.

Acknowledgments

These activities were carried out and partially funded within the framework of the "Space It Up!" project, ASI N. 2024-5-E.0