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A novel LiF-based detector for X-ray imaging in Hydrogen loaded Ni films under laser Irradiation

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A novel soft X-ray imaging film detector, based on optically stimulated luminescence of active color centers in lithium fluoride, LiF, has been used to obtain the image of radiation emitted from a nickel film hydride loaded by electrolysis, under light coupling with an He-Ne laser.

1. Introduction

An innovative film-like soft X-rays imaging detector [1], based on optically stimulated luminescence (OSL) of radiation-induced active color centers (CCs) in lithium fluoride (LiF) thin layers [2], has been used to obtain the image of radiation emitted from a nickel film, which was loaded with hydrogen by electrolysis under light coupling with an He-Ne laser.

The novel detector, recently proposed [3] and developed for soft X-ray micro-radiography and microscopy applications, as well as for intense extreme ultraviolet (EUV) sources characterization [4], consists of a radiation-sensitive thin film of LiF, thermally evaporated on a glass substrate. Irradiation of this material with several kinds of ionizing radiation, such as charged and neutral particles (electrons, ions, neutrons) as well as gamma and X-rays, induces the stable formation of electronic defects, known as color centers (CCs) [2]. Primary and aggregate point defects are stable at room temperature (RT) in LiF, and a few of them emit intense visible photoluminescence from the exposed areas, even at RT.

The unusual optical and spectroscopic properties of this material allow imaging with sub-micrometric spatial resolution, simply by reading the green and red photoluminescence of F_3^+ and F_2 centers (two electrons bound to three and two close anion vacancies, respectively) stored in the LiF-based imaging plate. Irradiation with blue light excites the visible photoluminescence of the F_3^+ and F_2 defects locally created in the areas previously exposed to the X-ray beam. The image can be directly read in an optical microscope operating in fluorescence mode [1,4].

2. Experimental

A 45 nm thick Ni film is sputtered onto a 1 mm thick polyethylene (PE) substrate. The Ni is loaded with hydrogen by electrolysis, with 1 M Li2SO4 electrolyte in light water. Electrolysis lasts 40 minutes, with current ranging from 10 to 30 mA [5]. The LiF film (t=1.9 μm) detector is then mounted in contact with the back-side of the PE substrate.

The sample is positioned on a rotating support and, by selecting the proper incidence angle, a CW He-Ne laser (632.8 nm, 5 mW) is coupled to the black metallic layer through a glass cylindrical lens placed in close contact with the Ni surface, for an irradiation time of 3h. In this configuration, the He-Ne light can be coupled in the Ni metallic layer, by tightly focusing the laser beam in the contact region between the glass lens base and the black Ni surface and detecting a reflectance minimum through a Si photodiode. A rough sketch of the entire structure is shown in Fig. 1.

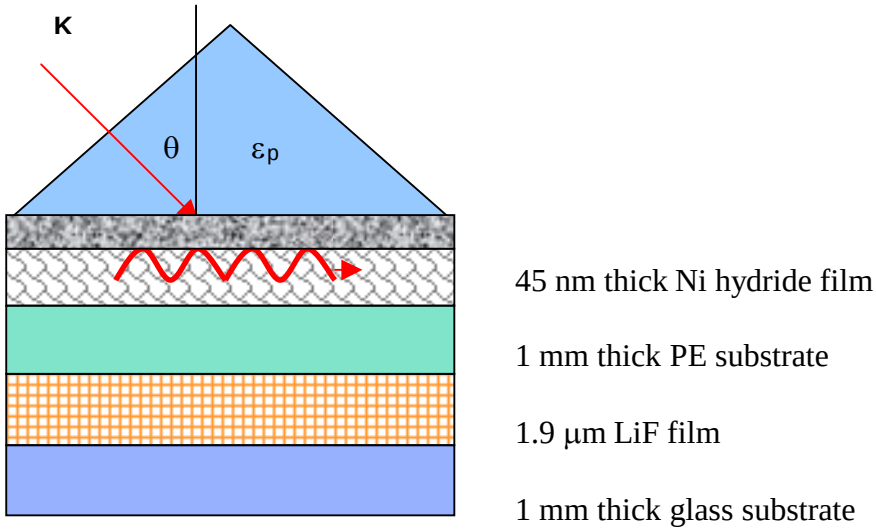


Figure 1. Sketch of the layered structure exposed to He-Ne irradiation. The upper triangle represents the glass lens, and the underlying layer the Ni film surface roughness, responsible of light coupling.

After removing the imaging LiF sensor, a carefully inspection of its surface is performed in a conventional optical microscope operating in transmission mode with

white light illumination, and in conventional fluorescence mode, under blue light from an Hg arc lamp.

A more complete and detailed optical investigation has been performed in a confocal laser scanning microscope (CLSM) Nikon Eclipse C1-80i equipped with a Coherent CW Argon laser operating at 458 nm, utilized to excite the photoluminescence of active CCs eventually produced in this radiation-sensitive thin film. The CLSM system provides the opportunity to collect, acquire and store these images, and to reach a spatial resolution of few hundreds of nanometers at the used wavelengths [6].

3. Results and discussion

Figure 2 shows the optical images of the exposed LiF film surface obtained in different microscope operation mode. Under UV light excitation, in reflection mode (Fig. 2b) a visible green-red photoemission from a limited region of the entire LiF film surface has been identified. The light signal in Fig. 2b often appears uncorrelated from the topographical features observed in transmission mode (Figs. 2 a, c, d; see white arrows). Dust and/or other surface imperfections outside the light emitting areas of Fig. 2b are not bright at all.

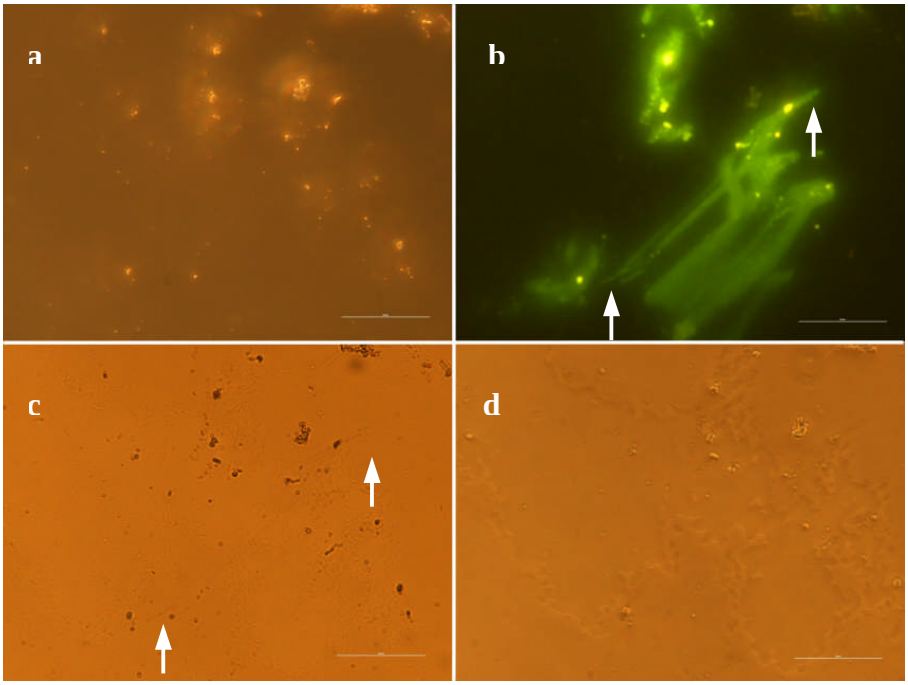


Figure 2. Optical images of the exposed LiF film surface obtained in different microscope operation mode. Transmission mode, dark field, a). Fluorescence mode, UV illumination, b). Transmission mode, white light, c). Transmission mode, phase contrast, d). Reference line = 50 μm.

In the light-emitting areas of Fig. 2b, interesting features have been observed in confocal laser scanning mode. The higher sensitivity and spatial resolution allows us to identify several light-emitting spots, closely grouped, with typical spatial dimension from tens to hundreds of micrometers, which are shown in Fig. 3.

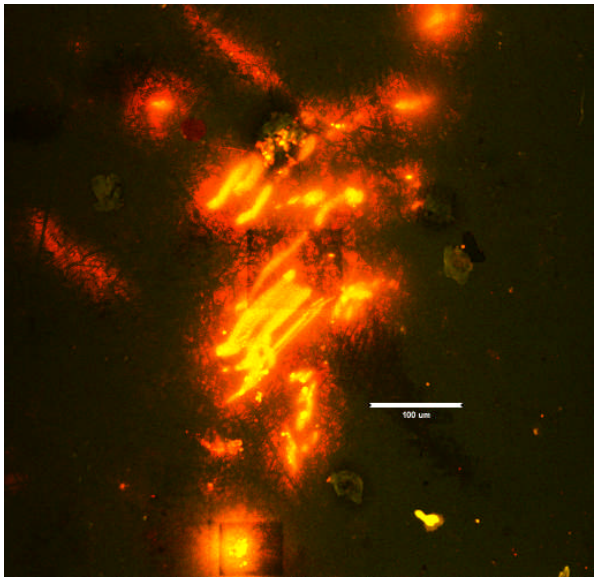


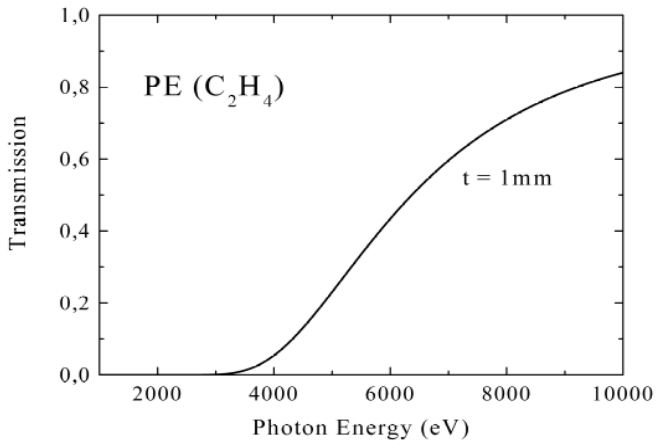
Figure 3. CLSM optical image in fluorescence mode of the exposed LiF film surface. Reference line = 100 μm.

The brightest areas are the same observed in Fig. 2b and could be attributed to light scattering phenomena from dust and/or other surface imperfections, while the observed fluorescent image we ascribe to the photoluminescence of F_3^+ and F_2 centers, created by ionizing radiation impinging the LiF-based imaging film during He-Ne irradiation of the Ni-hydride.

Surface plasmons (polaritons) are quantum of plasma oscillations created by the collective oscillation of electrons on a solid surface. They may be generated by mechanisms able to produce charge separation between Fermi level electrons and a background of positive charges (i.e. lattice atoms). The coupled e.m. wave can produce coherent oscillations of the Fermi-level electrons in the metal lattice, as its frequency is quasi-resonant with electronic plasma one. According with [7], the excitation could produce local intense electric field, and soft X-ray emission at energies below the Ni K_α edge (8.333 keV) can take place. The transmission of a 1 mm thick PE substrate has been reported as a function of the X-rays energy in Fig. 4, and it is not negligible for X-ray energies above 3 keV [8]. Depending on the X-rays energy, their penetration in LiF ranges from few tens on nanometers to several hundred micrometers [1,4].

Our novel detector integrates all the emitted radiation and indicates that its production is confined in an area of spatial dimensions comparable with the coupling region between

the evanescent wave and the black Ni surface. The spot nature of the image in Fig. 3 would be compatible with localized radiation sources, as observed in [9].



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