Study on dynamic irradiation effects in ceramic insulators

T. Shikama, B. Tsuchiya, S. Nagata, and E.R. Hodgson[1]

Institute for Materials Research, Tohoku University, Sendai, Japan
[1]*On leave from Euratom/CIEMAT Fusion Association, Madrid, Spain*

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1. Background and purpose of proposed research period

Following many years of collaboration and fruitful exchanges between IMR (Shikama, and later Nagata and Tsuchiya) and Euratom/CIEMAT (Hodgson, and later Moroño), see annex I, coinciding with ICFRM14 chaired by Professor Shikama a visit by Dr. Hodgson was arranged in order to enhanced present and future collaborations. It is envisaged that such collaborations will be concerned with materials for future fusion devices (ITER, DEMO, PP – Power Plant) and be performed within both the ITER and BA (Broader Approach) frameworks.

The potential for material characterization using radioluminescence (light emitted during material irradiation), has so far received little attention. This is due in part to the limited number of installations where such measurements can be made, and also to the difficulty in interpreting the results. Taking advantage of the facilities available at IMR and CIEMAT to perform such measurements, and in particular the expertise at both laboratories, it was considered to be of mutual advantage to begin collaboration in this promising field.

2. Proposed plan

With the initial aim of carrying out a “Study on dynamic irradiation effects in ceramic insulators", discussions were held on the potential for materials characterization using radioluminescence. This neglected aspect of radiation effects could provide ample information not only on defect production, but also on material quality, degradation, effective irradiation temperature, etc. and is of particular interest to monitor in-reactor experiments. Both IMR and CIEMAT have developed in-beam accelerator systems which have demonstrated its potential use as a simple characterization tool, comparing "material quality" for example, or to remotely monitor material modification / degradation *in-situ* (Figs. 1&2 examples of luminescence from Li containing ceramics; potential materials for solid breeders). Radioluminescence could also be developed for use as a simple diagnostic tool (radiation level, dose, temperature). For such applications it is ideally suited, being generally insensitive to electrically noisy and harsh environments.

Radioluminescence from materials contains extensive information, but we still do not understand enough to make full use of it. However one can clearly appreciate differences between materials, as well as effects such as temperature and dose (and dose rate). Already it is used to observe defect production, transmission changes, and thermal annealing. It could be used as a monitor for RIED, as has been done in sapphire by observing the relative F and F^+ emissions, whether this can be extended to aluminas needs investigating. Radioluminescence has been successfully used to model oxygen interstitial trapping, and the sensitivity of the Cr line emission to temperature should permit one to monitor material temperatures.

Recent work at IMR and CIEMAT has been concerned with basic research on the characterization of SiC. This potential structural and functional material is being jointly investigated within the newly established BA activities. CIEMAT has observed that various types of SiC emit strong radioluminescence in the visible region above about 400 nm, hence even for these materials it could be used as a tool to characterize not only "quality", but also degradation. It was therefore considered to be of joint interest to firstly examine the possibility of applying radioluminescence techniques to this material.

3. Results and discussions

Initial work carried out early in 2009 at CIEMAT indicated marked radioluminescence emission with band structure above 400 nm from different SiC material grades during 1.8 MeV electron irradiation (Fig. 3). In particular the CVD grade provided by IMR (Tsuchiya) as part of the BA collaboration on SiC characterization, exhibited relatively strong luminescence. Despite the poor sensitivity of the CIEMAT system towards the IR region, the results are consistent with further intense emission in the NIR region (> 800 nm) for the CVD grade SiC (Fig. 3). This material has now been examined using the luminescence system mounted in the IMR ion accelerator beam line. The first irradiations using 1 Mev protons for a sample mounted in the ion beam analysis chamber were unsuccessful, in part due to the installed collimator (1 mm diameter) limiting the beam intensity and irradiated area. The luminescence system was then remounted in a different experimental chamber where the beam diameter was unrestricted. Finally following adjustment of the system wavelength resolution, spectra were successfully recorded (Fig. 4).

The results clearly show the expected intense IR emission (960 nm) for the CVD SiC. The results for emission below 800 nm are consistent with those obtained during electron irradiation, and can be used for normalization to allow intercomparison. The band structure observed during electron irradiation is not evident for the proton induced emission. This may be due to temperature differences between the two experiments, and must be considered, but the IMR data still requires correction for system efficiency, which will modify the spectrum below about 900 nm. However it is evident that the two systems can jointly provide extensive complementary information on radiation induced emission, and should be fully exploited not only for SiC, but also for the ceramics required for fusion applications.

4. Summary and perspective

The IMR experiment to measure ion beam luminescence for proton irradiated CVD SiC has been successful, with initial results correlating very well with those obtained during electron irradiation at CIEMAT. The expected IR emission has been clearly observed. Work should now continue to examine possible dose and temperature effects, and attempt to relate the observed radioluminescence with material degradation.

It is worth pointing out that radioluminescence could be developed not only for characterization of materials being irradiated in accelerators or fission test reactors, but also for use as a simple diagnostic tool (radiation level, dose, temperature) in future fusion devices, or even possible future irradiations in IFMIF. For all such applications it is ideally suited, being generally insensitive to electrically noisy and harsh environments. This will require the use of optical fibres, where the problem of transmission, in particular self-absorption, can to a certain extent be mitigated by use of the red and NIR regions, precisely the regions being studied. For these applications radiation resistant IR scintillating materials, and radiation resistant IR waveguides need investigating.

Figures:

Fig. 1: CIEMAT results for radioluminescence characterization of Li containing ceramics using electron irradiation (T. Hernandez, A. Moroño, E.R. Hodgson).

Fig. 2: IMR results for radioluminescence characterization of Li containing ceramics using proton irradiation (S. Nagata, T. Shikama, B. Tsuchiya).

Fig. 3: CIEMAT results for radioluminescence characterization of Hot Pressed (HP), Reaction Bonded (RB) and CVD SiC using electron irradiation. Visible region only (M. Malo, E.R. Hodgson, A. Moroño).

Fig. 4: IMR initial results for radioluminescence characterization of CVD SiC using proton irradiation. Visible and IR regions (S. Nagata, B. Tsuchiya, E.R. Hodgson).

Fig. 1: CIEMAT results for radioluminescence characterization of Li containing ceramics using electron irradiation.

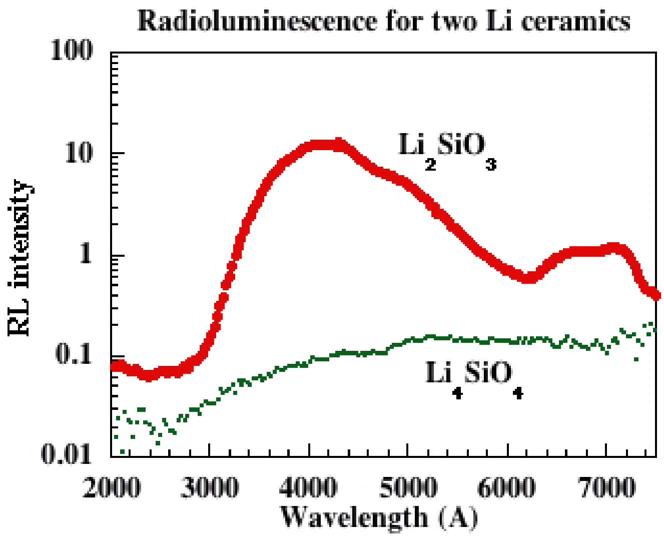


Fig. 2: IMR results for radioluminescence characterization of Li containing ceramics using proton irradiation.

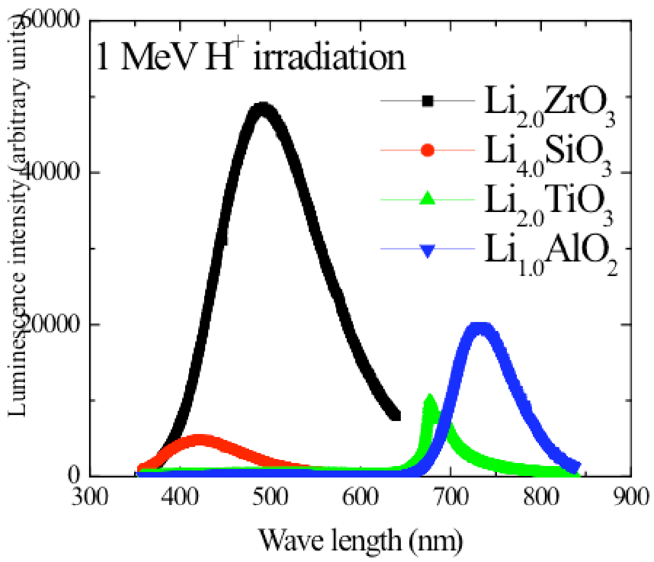


Fig. 3: CIEMAT results for radioluminescence characterization of Hot Pressed (HP), Reaction Bonded (RB) and CVD SiC using electron irradiation. Visible region only.

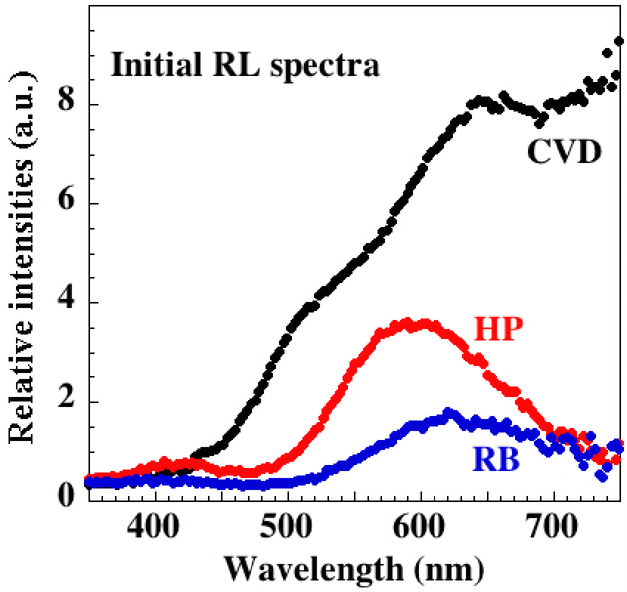
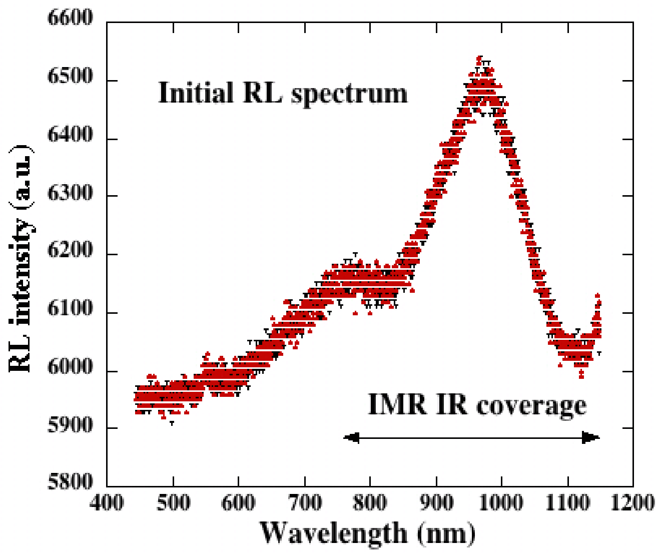


Fig. 4: IMR initial results for radioluminescence characterization of CVD SiC using proton irradiation. Visible and IR regions.



Annex I

Irradiation effects on potential diagnostic materials and components
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