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3D dose distribution measurement using 2D imaging from NaCl optical crystals

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Abstract: In radiotherapy practice, 1D and 2D dosimeters are used for dose verification prior to patient treatment. Along with high accuracy and precision of dose measurements that these dosimeters provide, acquisition of dose deposition data in three dimensions requires extrapolation of measured data. Development of a 3D dosimeter would provide continuous information of dose distribution in matter. In this work, NaCl 3D crystal has shown that radiation deposition can be imaged using blue laser stimulation in two dimensions. It was further shown that the intensity of collected signal has near – linear dose dependence, however complete signal readout is required, to compensate for gradual signal collection at different depths along the profile of the stimulating laser beam, due to attenuation of the beam within the crystal. A method to extend dose measurement to three dimensions using imaging is proposed.

1. Introduction

For the last few decades, there has been a major interest in three-dimensional dosimeters for ionizing radiation. Non-reusable 3D dose detection techniques utilize almost tissue equivalent polyacrylamide gels (PAG), Fricke gels or radiochromic plastics as dosimeter materials [1]. 3D dose distribution maps can be read-out by high resolution magnetic resonance imaging (MRI) and computed tomography (CT). Present work investigated the feasibility of imaging the radiogenic Optically Stimulated Luminescence (OSL) signal from NaCl crystal, with the purpose of creating a new method for three-dimensional radiation dose distribution quantification utilizing a reusable material. The 3D image of dose deposition would be achieved by scanning the irradiated sample with a stimulating laser beam of appropriate wavelength, in XZ plane, while recording the emitted signal along the laser beam in XY plane, facing the camera. NaCl was chosen due to advantageous OSL dose response, excitation and emission [2].

2. Materials and Methods

2.1 Preliminary characterization of dosimetry – related luminescent properties of NaCl

23x41x5 mm NaCl optical windows were used for 3D imaging feasibility and for dose deposition imaging. For the feasibility observation, the crystals (optical windows) were irradiated with 10 Gy from a superficial x-ray unit (SXR), with a 100kVp, 3 mm Al HVL beam. The dose distributions were: uniform distribution and radiated stripes, perpendicular to the direction of the laser beam. Signal excitation used a 100 mW, 487.5 nm laser developed at the University of Adelaide [3]. The imaging setup included Thorlabs ACL5040U condenser lens, and a 1 mm UG11 filter to reject scattered blue light from the stimulating laser. Imaging was performed with Thorlabs 1501M-USB-TE - 1.4 Megapixel Monochrome Scientific CCD Camera, frame rate of 1 FPS, and integrated for 3 minutes. A simplified schematic representation of optical setup is shown on Figure 1.

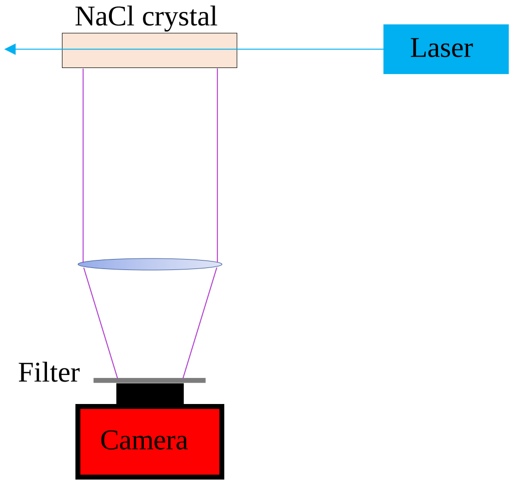

Figure 1. Optical setup for 2D dose deposition and dose dependence assessment imaging.

2.2 Two-dimensional radiation deposition imaging and dose dependence of x-ray irradiated NaCl crystal

25mW laser (Crystalaser, USA) was used for the 2D radiation deposition imaging and the dose dependence assessment. Once imaging feasibility was demonstrated, the crystals were irradiated with various doses (1 Gy, 2 Gy, 4 Gy, 8 Gy, 10 Gy, 15 Gy) and sequences of images from irradiated and laser - stimulated sample were collected for approximately 15 minutes. To analyse the character of the collected signal, the frames were integrated after laser activation for two sampling durations (1 and 300 seconds respectively). Horizontal profiles along the stimulating laser beam after such integration provide a detailed information on the nature of the signal emission progression from irradiated NaCl crystal at different stages of stimulation.

Dose dependence of the signal was assessed for five pixels along the laser path individually. To avoid as much as possible reflection from edges, proximal and distal pixels of interest were chosen at distance of 7 pixels from crystal edges.

3. Results

3.1 Preliminary characterization of dosimetry – related luminescent properties of NaCl

Following optical stimulation, light from the NaCl crystal was detected along the laser path in the uniformly irradiated sample, shown in Figure 2a. In stripe-irradiated sample, Figure 2b, the signal was recorded only from the region on the sample where the stripe was located.

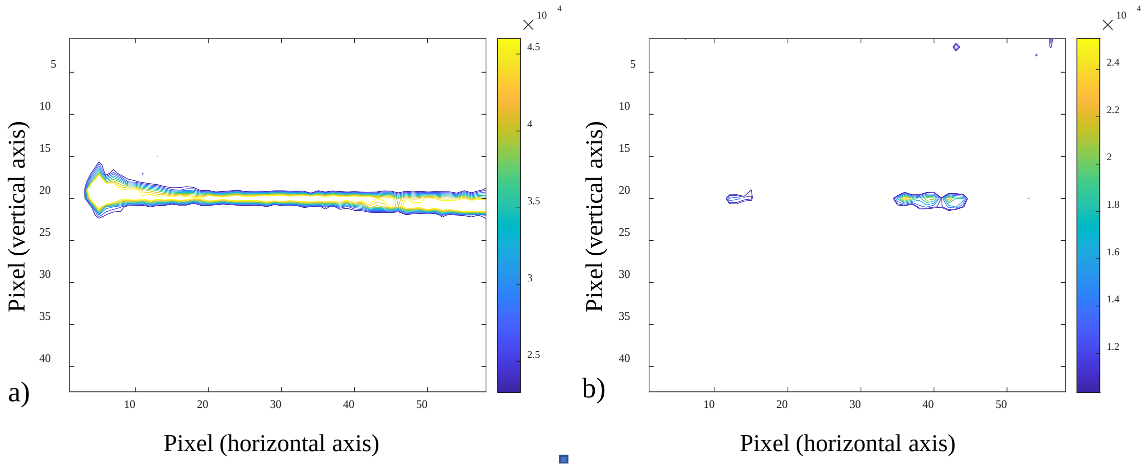

Figure 2. 2D image of signal, emitted from a) uniformly irradiated sample and b) stripe – irradiated during optical stimulation.

3.2 Two-dimensional radiation deposition imaging and dose dependence of x-ray irradiated NaCl crystal

Profiles of laser-stimulated signal from irradiated NaCl crystals, integrated for 1 and 300 seconds, are shown for 1 Gy in Figure 3a,b and for 15 Gy in Figure 3c,d. Immediately apparent are the variations in the profile shape, with higher signal coming from the sample face, proximal to laser entrance (left side on images), as a result of beam attenuation in the crystal. The difference in signal intensity is more evident at the first second of measurement (Figure3a,c). The difference between proximal and distal signal intensity increases with dose administered and is less prominent after longer integration times. However, during longer integration, more noise is introduced to the image, in addition to the signal.

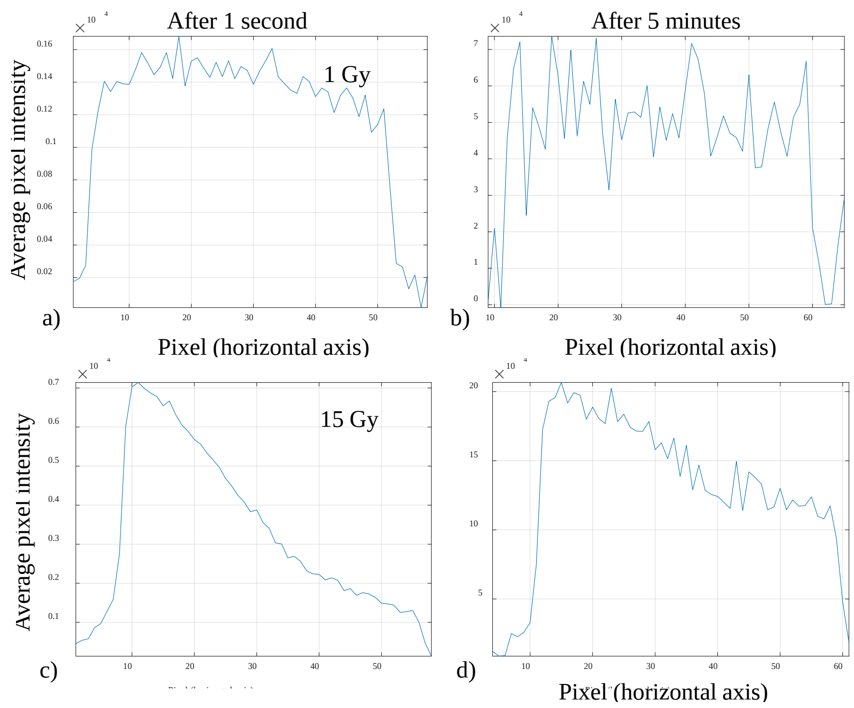

Figure 3. Laser beam profiles, measured after administering NaCl crystal with various radiation doses and integrating the blue laser – stimulated emitted signal for a) 1Gy, 1 second integration; b) 1 Gy, 300 seconds integration; c) 15 Gy, 1 second integration and d) 300 seconds integration.

Dose-dependent trapped charges, introduced to the crystal by irradiation, interact with incoming stimulating photons and attenuate the beam as it traverses the material. As charges are released with time at the proximal crystal face, stimulating photons can penetrate deeper in the crystal, releasing distal charges. At the beginning of stimulation, the difference between pixel intensity at proximal versus distal faces is the highest, as can be seen most clearly from Figure 3c. As the beam empties the traps, the slope of the profile becomes moderate at higher doses (Figure 3d) and flat at lower doses (Figure 3b).

Dose dependence of the five pixels along the profiles are shown in Figure 4after integrating the signal for 1 and 300 seconds. Figure 4a shows an arbitrary profile with identification of pixels, used for dose dependence indication. After 1 second (Figure 4b) in agreement with attenuation pattern, signal intensity is weaker for pixels, located far from proximal face, as a result of lower detrapping proportion by attenuated laser beam. The non-linear dose response is apparent starting from dose of 8 Gy for pixels 4 and 5. The longer the integration, the closer the values of the signal at higher doses (Figure 4c). Based on the reduction of discrepancy between the zones on the profile as a function of integration time we believe that longer integration times would give more accurate dose readout and allow building a dose response curve for unknow dose estimation. Due to the measurement duration, chosen for this work, we weren’t able at this point to test integration times longer than 300 seconds.

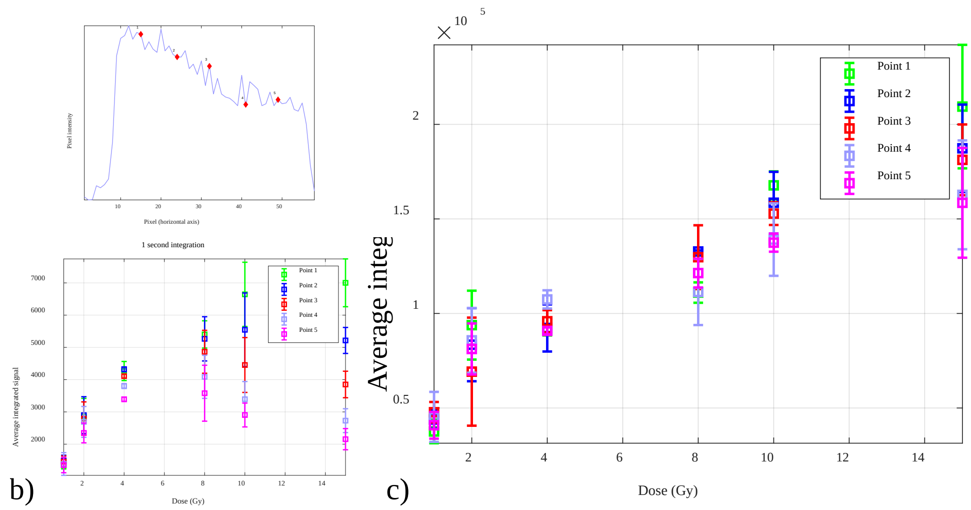

Figure 4. Dose dependence of five pixels along laser stimulated profile after integration for increasing time duration.

4. Conclusions

Dose mapping using NaCl crystals with blue laser stimulation is shown to be feasible for 2D dose localisation within the detector crystal volume and can potentially be extended to 3D dose measurements if scanned along the dosimeter side. The proposed imaging method allowed localization of deposited dose distribution pattern. Attenuation of stimulating laser beam as a function of distance from entrance face would require complete signal collection (no partial read-out). To make this method feasible in practice, stronger lasers will have to be used to collect the data within reasonable time frames, as well as to improve the signal-noise ratio. The dose dependence of individual pixels along the stimulation path of the laser has a promising pattern of near linear dose dependence at the doses of 1 Gy – 15 Gy.

5. References

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