

PhD Dissertation Title: “Development and demonstration of 2D dosimetry using optically stimulated luminescence from new Al₂O₃ films for radiotherapy applications”

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ABSTRACT

Purpose: The goal of this work was to develop and demonstrate a 2D dosimetry system based on the optically stimulated luminescence (OSL) from new Al₂O₃ films for radiotherapy applications.

Motivation: With the development of highly conformal and high dose per fraction radiation therapy techniques, such as, stereotactic radiosurgery, devising a robust quality assurance protocol is critically important. Unavailability of a 2-D absolute dose detector, however, is one of the biggest challenges towards such development. Even the most recent report by the Task Group (TG) 120 of the American Association of Physicists in Medicine (AAPM) recommends the use of two detectors combined to obtain accurate 2D dose information: small ion chamber or diodes for measuring the central axis absolute dose, and films for 2D relative dose distribution. This is mainly due to poor resolution of 2D active detectors (ion chamber or diode arrays) and inherent limitations of radiographic (energy dependence) and radiochromic films (narrow dynamic range, non-linear dose response and one-time use). As a result, luminescence techniques, such as thermoluminescence (TL) and OSL, are being extensively studied due to the availability of semiconductor materials with high sensitivity to radiation, linear response over a wide dynamic range and near-tissue equivalence. The OSL technique is already used in computed radiography (CR), except that the image plates are optimized for imaging of diagnostic X-rays employing storage phosphors of high effective atomic numbers ($Z_{eff} \sim 50$), thus not suitable for dosimetry. Al₂O₃:C, originally developed as a TL detector, has several OSL properties for which it has been used for personal dosimetry for almost two decades and is increasingly used in medical dosimetry. It shows no energy dependence for megavoltage energy beams ($Z_{eff} = 11.3$), allows extremely low dose measurements, has linear dose response over a wide dynamic range (> 5 decades) accompanied by independence on dose-rate, relatively stable signal at room temperature and little dependence on irradiation angle. Despite the mentioned good dosimetric properties of Al₂O₃:C, its application in 2D dosimetry using laser-scanning technique similar to that used in CR has so far been prevented by the long luminescence lifetime of Al₂O₃:C main luminescence band (F-center peaks at ~415 nm and emits with a lifetime of 35 ms, compared to ~ μ s for storage phosphors). OSL films could also be imaged using a position sensitive detector, such as CCD camera, but this approach requires highly sensitive cameras, such as electron multiplying CCDs, which are expensive and provide little flexibility compared to laser-scanning approach. Therefore, Al₂O₃:C OSL film has demonstrated ability for point dosimetry and is attractive for 2D dosimetry, but its successful implementation is technically challenging.

Methods: A 2D laser-scanning system consisting of a 532 nm diode laser coupled with a dual-axis Galvo mirror system and a photomultiplier tube coupled with UV bandpass (260 – 395 nm) filter was developed for the readout and two newly developed OSL films (Al₂O₃:C and Al₂O₃:C,Mg) were tested

(Ahmed et al., 2014). The films consist of 47 μm active layer (powder + binder) with median grain (of powder) size of 15 μm deposited on a 75 μm thick polyester substrate and printed in rolls of 30 cm width by 125 μm total thickness. In an image scan, consecutive rows are scanned in alternate directions with each row separated by ~ 0.17 mm. Each row is scanned with a pixel separation of ~ 0.15 mm and an acquisition time of 327.68 μs . These parameters are adjustable. The total scan time, including readout overhead, is ~ 7 minutes. A complete dose reconstruction algorithm addressing corrections required for the characteristic material properties and the properties related to the system design was developed. The material property corrections are mostly related to the background phosphorescence and contamination of signal from previously stimulated pixels due to slow luminescence, which we refer to as 'pixel bleeding'. The pixel bleeding correction algorithm takes advantage of the simultaneous detection of emissions from the slow F-center and fast F^+ -center (another luminescence center in Al_2O_3 OSL films, peaks at ~ 330 nm, emits with a lifetime < 7 ns). The algorithm is based on the least squares fitting of two adjacent signal profiles obtained in alternate scan directions, essentially a deconvolution of the signal with a kernel that is based on the lifetime of the two luminescence centers. The major corrections required due to system design are position dependence of light collection efficiency, as a single PMT is used to collect light from the entire image scanning area, and geometric distortion inherent to galvanometer mirror system. A position dependent light collection efficiency function was identified and a matrix ray tracing algorithm was developed to correct for geometric distortion. The dosimetric properties of the system were tested using clinical X-ray (6 MV) beam. The feasibility of small field dosimetry was tested using heavy ion beams (221 MeV proton and 430 MeV ^{12}C beam). For comparison, clinical tests were performed with ionization chamber, diode arrays and commercial radiochromic films (Gafchromic EBT3) when applicable.

Results and Conclusions: The results demonstrate that the developed image reconstruction algorithm enabled $> 300\times$ faster laser-scanning readout of the Al_2O_3 films, eliminating the restriction imposed by its slow luminescence decay (Yukihara and Ahmed, 2015). The algorithm facilitates submillimeter spatial resolution, reduces the scanner position dependence (of light collection efficiency) and removes the inherent Galvo geometric distortion, among other corrections (Ahmed et al., 2016a). The system has a minimum detectable dose of < 1 mGy, linearity correction factor of $< 10\%$ up to ~ 4.0 Gy and $< 2\%$ dose uncertainty over the clinically relevant dose range of 0.1 – 30 Gy (Ahmed et al., 2016b). The system has a dynamic range of 4 - 5 orders, only limited by PMT linearity. The absolute response from $\text{Al}_2\text{O}_2:\text{C}$ films is higher than $\text{Al}_2\text{O}_2:\text{C},\text{Mg}$ films, but with lower image signal-to-noise ratio due to lower concentration of fast F^+ -center emission. As a result, $\text{Al}_2\text{O}_2:\text{C},\text{Mg}$ films are better suited than $\text{Al}_2\text{O}_3:\text{C}$ films for small field dosimetry, which requires precise dosimetry with sub-millimeter spatial resolution (Ahmed et al., 2017). The dose uncertainty associated with OSL film dosimetry is lower than that associated with EBT3 film dosimetry due to lower background, simpler calibration and wider dynamic range. In conclusion, this work demonstrates potential of the laser-scanning 2D OSL dosimetry system based on Al_2O_3 films for both relative and absolute dosimetry in radiotherapy applications.

Disclaimer and acknowledgements

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References to author publications that relate specifically to the dissertation:

1. **Ahmed, M.**, Eller, S., Schnell, E., Ahmad, S., Akselrod, M., Hanson, O., Yukihara, E., 2014. *Development of a 2D dosimetry system based on the optically stimulated luminescence of Al_2O_3* . Radiation Measurements 71, 187-192.

2. **Ahmed, M.**, Schnell, E., Ahmad, S., Yukihiro, E., 2016a. *Image reconstruction algorithm for optically stimulated luminescence 2D dosimetry using laser-scanned Al₂O₃:C and Al₂O₃:C, Mg films*. Physics in Medicine and Biology 61, 7484.
3. **Ahmed, M.**, Shrestha, N., Ahmad, S., Schnell, E., Akselrod, A., Yukihiro, E.G., 2017. *Demonstration of 2D dosimetry using Al₂O₃ optically stimulated luminescence films for therapeutic megavoltage x-ray and ion beams*. Radiation Measurements accepted for publication.
4. **Ahmed, M.**, Shrestha, N., Schnell, E., Ahmad, S., Akselrod, M., Yukihiro, E., 2016b. *Characterization of Al₂O₃ optically stimulated luminescence films for 2D dosimetry using a 6 MV photon beam*. Physics in Medicine and Biology 61, 7551.
5. **Ahmed, M.F.**, 2016. *Development and demonstration of 2D dosimetry using optically stimulated luminescence from new Al₂O₃ films for radiotherapy applications*. Oklahoma State University.
6. Yukihiro, E.G., **Ahmed, M.F.**, 2015. *Pixel bleeding correction in laser scanning luminescence imaging demonstrated using optically stimulated luminescence*. IEEE transactions on medical imaging 34, 2506-2517.