X-ray microbeam semiconductor dosimetry and modelling

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Rationale and objectives

During the past decade, potential applications of microbeam radiation therapy (MRT) have been studied experimentally at the National Synchrotron Light Source (NSLS) at Upton, New York, USA and at the ESRF in Grenoble, France. At the ESRF, the preclinical MRT program is carried out with ~20-30 µm-wide, ~10 mm-high, parallel array of microbeams of X-rays. Reliable dosimetry for research and clinical MRT treatment is required for beam profiling, verification of the peak-to-valley dose ratio (PVDR) and real-time quality assurance during the MRT delivery, similar to other radiotherapy modalities. Two criteria of experimental and theoretical dosimetry are required for MRT: i) in a phantom single micro beam dosimetry with one-micron resolution ii) real-time dosimetry to monitor the PVDR of microbeam array during the MRT delivery. Both of these criteria are challenging due to requirements of submicron the size of the dosimetric volume, tissue equivalency and real time readout.

Methods

In 1997 we proposed and developed the **edge on MOSFET** (EO MOSFET) detector technique to address the first challenge. The advantage of the MOSFET is in the dosimetric volume (DV) that is less then one micron thick, the simple, real time readout, and the dose rate independence. Multiple detectors on a chip are ideal for precise alignment of the MOSFET with a microbeam. MOSFETs are also the only detector that satisfies the Brag Grey cavity theory for photon energies as low as 10-15 keV, and the electron stoping power ratio of silicon-to-water is almost constant, making them suitable for the 50-600 keV photon spectra used in MRT. The second challenge was addressed by the development of a Si strip detector with 128, 10x500 (1000) μm^2 DVs with a pitch of 200 µm and electronics for the simultaneous dose readout in the peak and valleys and their presentation on a display.

Results

The high spatial resolution of the MOSFET detector was justified initially by profiling of the 0.2 mm X-ray beam in comparison with GaF film and accurate 0.1 mm penumbra measurements on X-ray beam blocked by lead, all carried out on an orthovoltage X-ray machine. First results of the application of EO MOSFET detectors on 35x500 μm^2 single MRT microbeam were obtained with Dr A.Dilmanian at NSLS that confirmed ability of dose mapping with one micron resolution and we found reasonable agreement with EGS MC simulations of a single microbeam [1,2]
The design of the detector is important as the dose deposited in the DV is driven by the immediate surrounding of Si substrate and gate oxide overlayer, which can attenuate photons in different ways to water, and can lead to a measured increase of 10-15% in the PVDR value in comparison with MC simulations and some distortion in the dose profile of a single microbeam in water [3-5]. We designed and produced a new MOSFET detector

(MO*Skin*) which has a reproducible, 20 μm thick, TE cover to avoid encapsulation with non reproducible epoxy bubble build up, simple DV configuration and twice thinner Si substrate to reduce photon attenuation from the back side. Profiling the array of 25 μm microbeams with pitch 200-400 μm have been obtained at different depths in a PMMA phantom with and without magnetic field aiming to measure confining effect of scattered low energy electrons. Response of EO MOSKIN PVDR measurements for monoenergetic MRT X-ray microbeams and pencil beams will be presented.
The Si strip detector instrument was tested with a scanned microbeam at the ESRF ID-17 beamline and demonstrated the ability to measure the relative dose in each peak in real time within the MRT dose delivery time. Detectors have not demonstrated a degradation of performance after accumulation of 10^5 Gy dose on MRT X-ray spectra. To improve the accuracy in PVDR measurements a prototype of a new Si detector for microbeam array detection has been developed and based on silicon on insulator (SOI) 2 μm diameter p-i-n mesa structures array with 5 μm thick for valley dosimetry while 0.5 μm thick array for peak dosimetry on the same chip.

Conclusion

Ten years of comprehensive MRT research has demonstrated the usefulness and advances of silicon detectors for MRT dosimetry. Intensive MC simulations of the EO MOSFET response and microbeam array dosimetry for the real multi slit collimator (MSC) have been carried out using PENELOPE and GEANT 4 codes. The results indicate that the geometry of the both the source and the MSC device can alter the shape of the microbeam profiles, particularly those furthest from the central microbeam in the MRT array.

References

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