LANDAUER®

microSTAR ii
medical dosimetry system

LANDAUER® TECHNOLOGY WHITE PAPER

microSTAR®ii – A System for Medical Dosimetry

Executive Summary

The microSTARii dosimetry system from LANDAUER provides fast, accurate, and repeatable point-dose measurements for secondary verification of dose for the Quality Assurance (QA) of patient therapy. The microSTARii features innovations in electro-optical, mechanical, and software design; including new technology developed for the U.S. Army RadWatch® Optically Stimulated Luminescence (OSL) dosimetry system, which was designed to monitor radiation exposure to battlefield personnel.

The microSTARii uses state-of-the-art manufacturing techniques and aerospace-grade materials and coatings to improve durability and to increase dosimeter positioning accuracy. The system is exceptionally stable and measurements are highly repeatable. The intrinsic stability was measured using a photomultiplier tube (PMT) and photodiode, and the coefficients of variation were 0.017 and 0.008 respectively. Precision was evaluated using static and dynamic repeatability measurements. Repeat measurements of the same nanoDot™ without removing it from the reader were within 0.53% and repeat measurements of the same nanoDot after removing it from the reader tray were within 0.59%. With this, the lower limit of detection (LLD) is less than 0.020 mGy. The microSTARii software is user friendly dramatically improving workflow and quality assurance process.

This paper describes the new opto-mechanical design solutions and measurement techniques used in the microSTARii providing next-level of performance for medical dosimetry.

Rev. 1

Introduction

The purpose of this paper is to describe the improved workflow, technological innovations, and enhanced performance of the microSTARii compared to the original Microstar® and other products on the market.

The microSTARii system for medical dosimetry is intended for use with LANDAUER's OSL-based nanoDot dosimeters. The system was designed for secondary verification of dose for QA of patient dose.

Figure 1: microSTARii Medical Dosimetry System

The microSTARii system uses a redesigned, state-of-the-art electro-optical engine and embedded microprocessor for pulsed LED stimulation, luminescent light collection, and on-board data collection for improved accuracy and repeatability [U.S. patents #8,633,455 and #9,000,381]. The reader utilizes a readout technique based on Pulsed Optically Stimulated Luminescence (POSL) technology [Akselrod and McKeever, 1998] to improve the signal-to-noise ratio of measurements, accuracy, and reproducibility. With this, the mechanical design was optimized for accurate and precise measurements of nanoDot dosimeters, and measurement precision was further improved through custom optimization of each reader's measurement settings. Lastly, aerospace-grade coatings and self-lubricating plastics were also used to further enhance the durability and performance of the system.

The microSTARii also features improved software and hardware design, such as an optimized drawer for the quick loading of nanoDot dosimeters. The drawer slides into position with ease, enabling faster, smoother dosimeter reading process and was designed such that the dosimeter is opened and positioned consistently each time, improving the precision of repeat measurements. The reader and software were designed in tandem to complement one other and enable automatic reading features that were not previously possible. In addition, the microSTARii software allows for the analysis of multiple measurements without disturbing the position of the nanoDot. This provides better dose measurement accuracy than the original Microstar and enhances the workflow by eliminating the need to manually initiate a read process each time. Lastly, the software now recognizes repeat readings of the same nanoDot, eliminating the need to rescan a dosimeter serial number for each reading.

Technology Innovations

New Intrinsic Measurements for Improved Quality Assurance

The automation features of the microSTARii facilitate the collection and analysis of data for clinical quality assurance programs. The updated software automates the collection of measurements required for daily QA. In the original Microstar this required the physicist to turn a mechanical knob as many as 80 times, but the new microSTARii software accomplishes this with one mouse click. After the automatic intrinsic measurements and multi-read QC analysis have been completed, the average reading and coefficients of variation are automatically calculated and checked against the performance specifications. This feature eliminates the need to export measured data, and to manually perform spreadsheet calculations in order to track the intrinsic stability of the reader as part of an ongoing clinical quality assurance program.

The optical design, combined with the optical filtration, allows for spatial separation of the excitation light from the luminescence light. The change in the readout from Continuous Wave Optically Stimulation Luminescence (CW-OSL) to Pulsed Optically Stimulated Luminescence (POSL) reduces the background noise to a level approaching the dark counts of a photomultiplier tube (PMT).

In the microSTARii, the PMT and the photodiode are used to measure the intensity of LED light, which provides the indication of intrinsic stability of both the PMT and the LED over time. The microSTARii offers three such intrinsic performance measurements (formerly known as standard measurements). The intrinsic performance measurements include the Dark Count, the PMT Count, and the Photodiode Count measurements.

Lastly, the Optical Engine used in the microSTARii has no moving parts, which further improves reliability and reproducibility.

State-of-the-Art Optics and Pulsed Measurement

The microSTARii uses advanced optical technology and an improved readout technique to improve the signal-to-noise ratio of the luminescence measurement. The advanced optical design combines focusing lenses with a shorter optical path to increase luminescence collection efficiency. The design, combined with improved optical filtration, allows for spectral discrimination of the excitation light from the luminescence. The change in the readout process from CW-OSL to POSL reduces the background down to the level of dark counts of the PMT. Another innovation in measurement technique is utilization of a reflective geometry. POSL mode of readout and the optical engine with reflective geometry were originally developed by LANDAUER as part of the RadWatch OSL dosimetry system that is now used by the U.S. Army for monitoring the radiation exposure of almost one million personnel.

Mechanical Innovations

The microSTARii was designed using contemporary industrial production methods, such as 3D printing, rapid-prototyping, and state-of-the-art technology originally developed for the U.S. Army, to design and develop a reader that was smaller and more lightweight than the original Microstar. The case has a contemporary look-and-feel that compliments the high performance internal electro-optics and precision mechanical components, while reducing the number of moving parts in the reader by a factor of 5 relative to the original Microstar.

microSTARii Drawer and nanoDot Positioning

One of the most significant mechanical improvements to the system is the microSTARii drawer, constructed from precision-machined aluminum with an aerospace-grade, hard anodized coating for smooth operation and high durability.

Figure 2: microSTARii Drawer

The microSTARii drawer is a removable part that can be easily extracted for field cleaning and maintenance. As shown in Figure 2, the drawer is modular and contains the only moving parts of the reader, which result in increased measurement accuracy and precision, greater reliability, improved ease-of-use, and improved serviceability. With this, the design also ensures there is no variability in positioning of the nanoDot dosimeter during the read. The durable construction ensures a long life and reliable operation of both the drawer and nanoDot dosimeters.

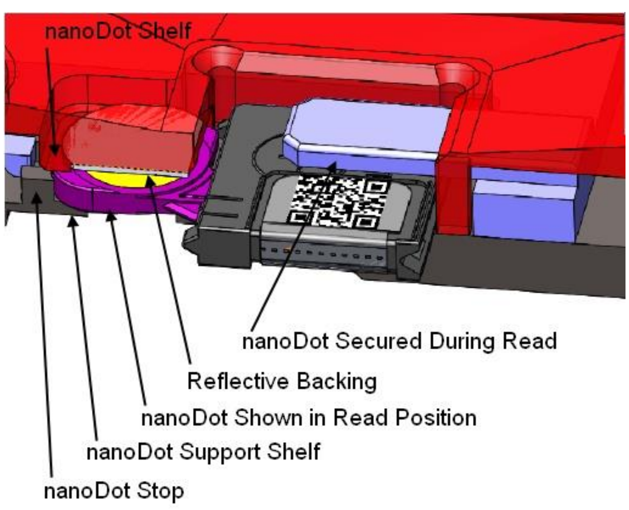

Figure 3: nanoDot Positioning in Drawer

Compact Design

The microSTARii features an improved geometry that allows for a reduction in size of optical components. By placing the PMT and LED on the same side of the dosimeter (instead of opposite sides as with the original Microstar) the optical chain of the reader has significantly decreased in size, resulting in a more compact unit. Figure 4 illustrates the difference between the transmission and reflection geometry.

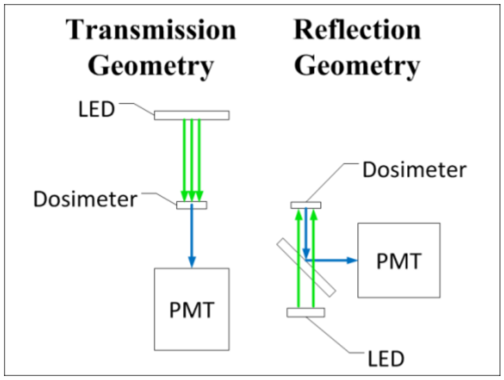

Figure 4: A Comparison of Transmission and Reflection Geometry

Optical Engine

The Optical Engine is a single unit with a reflective geometry OSL readout optical chain that consists of a small, lightweight and robust aluminum housing containing the LED, PMT, photodiode, filters and focusing optics. The Optical Engine introduces several design improvements over the original Microstar optics and electronics. For example, the microSTARii uses a single, high-power LED in place of the 38 LED array of the Microstar. The beam profile of the LED is very consistent from reader to reader. The microSTARii also uses a new PMT that is smaller, more sensitive and has a higher dynamic range than the PMT from the original Microstar. The microSTARii also introduces a new photodiode to monitor the stability of the LED.

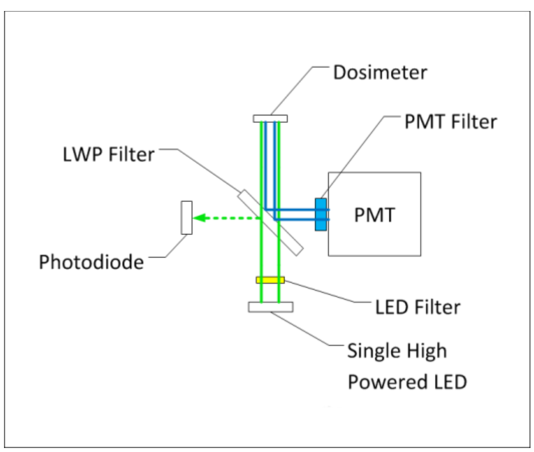

Figure 5: Photo-Optical Engine Layout

Figure 5 illustrates the optical chain and operation of the Optical Engine. During the LED pulse, light is emitted from the single, high-power green LED. That light from the LED is collimated by a lens and directed through a long-wavelength-pass filter that blocks out the blue tail of the LED emission spectrum. The LED light then passes through a dichroic mirror with a long-wavelength-pass transmission coating positioned at a 45 degrees angle. This dichroic mirror is designed to transmit the green LED stimulation light and to reflect the blue luminescent emission from the OSL dosimeter sensor in direction of the PMT. During the LED pulse, the dosimeter immediately begins luminescing, however the luminescence is not recorded until the LED illumination pulse has terminated. The radiation-induced blue luminescence collected from the OSL sensor is reflected by the dichroic mirror into the PMT. Even though the PMT is not in a direct line with the LED, the optical filtration is still needed to protect the PMT from stray LED light during the pulse. The photodiode positioned on the opposite (left) side from the dichroic mirror detects partially reflected LED lights for QC purposes.

Results

The microSTARii demonstrates stable and reproducible performance. The intrinsic stability of the reader was evaluated using intrinsic measurements of the PMT and Photodiode counts from nine readers. The average coefficients of variation of the PMT and Photodiode counts measured using nine different readers were 0.017 and 0.008 respectively. In contrast, the coefficient of variation for LED standard measurements of the original Microstar were 0.028 on average, and the coefficient of variation for PMT standard measurements were 0.022 on average.

The precision of the new reader was evaluated using tests of stationary and moving repeatability. The stationary repeatability test measures a reader’s ability to reproduce a reading without removing the dosimeter from the drawer. This is important because the microSTARii software can make multiple measurements of the same nanoDot without moving the dosimeter. The moving repeatability test measures the precision of reading the same nanoDot after the dosimeter is removed and re-inserted before each read. All repeatability tests were performed using nanoDots exposed to 50 cGy of Cs137. Measurements from nine readers resulted in an average stationary repeatability within 0.53% and an average moving repeatability of 0.59%.

The microSTARii also delivers improved lower limits of detection (LLD) compared to the original Microstar for the low dose measurement mode approaching 0.010 mGy. The average LLD measured using nine microSTARii readers were less than 0.020 mGy for the strong beam (low dose mode) and 0.055 mGy for the weak beam (high dose mode). The original Microstar had a strong beam LLD of approximately 0.040 mGy on average (the weak beam LLD was not normally calculated). These improvements in the LLD are due to the reduction of background signal made possible by the new POSL time discrimination technique and the new optical engine described above.

microSTARii Comparison to the Original Microstar			
	Microstar	microSTARii	
Intrinsic Measurement			
LED	0.028	0.017	PMT
CAL	0.022	0.008	Photodiode
Repeatability (@ 50 cGy Cs137)			
Stationary	NA	0.53%	
Moving	0.67%	0.59%	
Lower Limit of Detection (mGy)			
Low Dose	0.040	0.017	
High Dose	NA	0.054	

Table 1: Comparison of the new microSTARii to the Original Microstar

The performance comparison results, as shown in Table 1, demonstrate a significant improvement in the performance of the microSTARii over the original Microstar. Stationary repeatability measurements are a new feature of the microSTARii that were not possible with the original Microstar.

Tests performed during development demonstrated that the best repeatability for each reader could be obtained by balancing counting statistics with higher signal and increased depletion. Figure 6 illustrates the relationship between depletion and the coefficient of variation of multiple reads for the microSTARii. Each microSTARii has been optimized for the best reader repeatability without depletion correction.

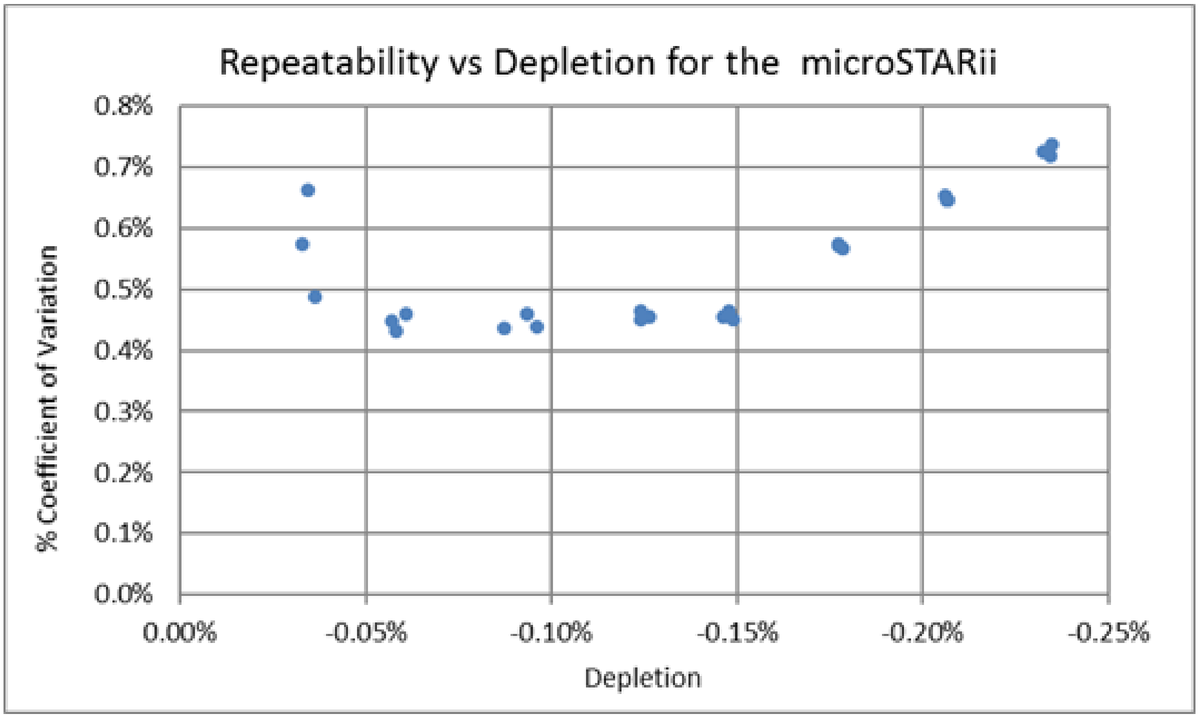

Figure 6: Finding the Optimal Depletion for Minimum Repeatability

The excellent repeatability of the microSTARii was achieved through the innovative mechanical design, material selection and precision machining. The latest modification of the drawer allows for precise positioning of the OSL sensor in front of the Optical Engine. It was achieved with the drawer having multiple spring-loaded ball pushers, a hard stop and an axial spring for the nanoDot sensor element extension. The pin that opens the nanoDot and the spring maintain constant pressure on the sensor element to ensure repeatable placement each time the nanoDot is inserted into the reader. All critical mechanical parts use aerospace-grade anodized aluminum or self-lubricating plastics for a long life and precise movement.

Discussion

Advantages of the microSTARii over the Original Microstar

The first generation Microstar was originally designed to read LANDAUER InLight™ whole body dosimeters for occupational dosimetry and emergency response applications. Medical dosimetry using OSL dosimeters was made possible by the development of the LANDAUER nanoDot OSL dosimeter, and an adaptor that allowed nanoDots to be inserted into the Microstar reader. However, the adaptor was prone to wear and had to be replaced after repeated use.

The microSTARii, in contrast, was designed specifically for medical dosimetry applications using nanoDot OSL dosimeters and was optimized for repeat measurements of the nanoDot.

The original Microstar also used CW-OSL, which resulted in an elevated background signal from the leakage of stimulation light through the PMT filtration. This leakage increased the

LLD. The microSTARii, however, leverages patented, state-of-the-art POSL technology with the new optical engine utilizing reflection geometry that was developed for the U.S. Army in order to eliminate background signal from the LED and achieve superior signal-to-noise characteristics. As a result, the microSTARii provides a higher level of accuracy, precision, reliability, ease-of-use, and cost-effectiveness that was not possible with the original Microstar.

Lastly, the original Microstar software was developed for occupational dosimetry and emergency response applications, and later modified to provide the basic functionality required for medical dosimetry. The microSTARii software was designed and developed specifically for medical dosimetry. The new software introduces many new features that significantly improve the workflow of clinical measurements, while providing automated quality assurance features that facilitate best practices in clinical medical physics.

Advantages of the microSTARii over other Medical Dosimetry Options

Although a number of dosimetry systems have been developed for in vivo radiotherapy dosimetry, including thermoluminescent dosimeters (TLDs), solid-state diodes, and metal-oxide-semiconductor field effect transistors (MOSFETs) [Mijnheer, 2013], few of these systems offer the unique capabilities, performance and value provided by the nanoDot OSL dosimeter and the new microSTARii reader. TLD readers are large and more complex, slow, and often require dry nitrogen gas for operation. TLDs must be reannealed (heated) under controlled conditions after each use for accurate dose measurement and require additional ovens. The TLD readout process also destroys the dosimetric information so that it can only be read once.

Most diode-based and MOSFET dosimeters developed for point-dose measurements have strong energy dependence, greater angular dependence, and are more temperature sensitive than OSL dosimeters. For example, commercially available diode-based systems were found to have ±12% change in sensitivity depending upon the angle of incidence of radiation [Jursinic, 2009]. However, diode and MOSFET leads are prone to breaking, which decreases the reliability of the device and increases the cost of operation. In addition, in all current commercially available diode-based and MOSFET dosimeter systems, the detector leads are attached to wires that must be routed to the readout electronics.

The performance and clinical application of OSL dosimeters for in vivo radiotherapy dosimetry have been extensively reported in the peer-reviewed literature [Jursinic, 2007; Akselrod et al, 2007, Yukihara et al., 2010; Mrčela et al., 2011]. These studies have shown that LANDAUER's nanoDot OSL dosimeters, in contrast to TLDs, MOSFETs and diodes, have little energy dependence in the range of energies used in radiotherapy, have relatively little angular or temperature dependence, can be re-read multiple times, are durable and reliable, and are small and convenient to use.

Conclusion

The microSTARii offers users a faster, more accurate and more precise medical dosimetry system in a compact, contemporary design. The new technology in the microSTARii reader increases the accuracy and repeatability of measurements, improves the LLD, and decreases reader to reader variability. The microSTARii uses fewer moving parts to improve durability and reliability and uses a modular drawer design that decreases service costs. It also includes new features to quickly and easily measure intrinsic reader performance, to improve and streamline measurements, and to implement an improved quality assurance program. The performance test results indicate that the reader is exceptionally stable, measurements are accurate and highly repeatable, and an LLD of less than 0.020 mGy can be achieved. The nanoDot OSL dosimeter and microSTARii reader offer a level of performance, reliability, convenience and cost-effectiveness that is unmatched by existing medical dosimetry systems.

References

Akselrod, M. S. and McKeever S. W. S., *A Radiation Dosimetry Method Using Pulsed Optically Stimulated Luminescence*, Radiat. Prot. Dosim., v. 81, No 3, 167-176 (1999)

Akselrod, M. S., McKeever, S. W. S., and Botter-Jensen, L., *Optically stimulated luminescence and its use in medical dosimetry*, Radiat. Meas. 41 S1 S78-S99 (2007).

Jursinic, P.A., (2007) *Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements*. Medical Physics, 34, 4594.

Jursinic, P.A., (2009) Angular dependence of dose sensitivity of surface diodes. Medical Physics, 36, 2165.

Mijnheer, B., Beddar, S., Izewska, J., Reft, C., (2013) *In-vivo dosimetry in external beam radiotherapy.* Medical Physics, 40.

Mrčela, I., Bokulić, T., Izewska, J., Budanec, M., Fröbe, A., Kusić, Z., (2011) *Optically stimulated luminescence in vivo dosimetry for radiotherapy: physical characterization and clinical measurements in Co-60 beams.* Physics in Medicine and Biology, 56, 6065.

U.S patent #9,000,381 M.S. Akselrod, K. Dillin*, Method and apparatus for fast determination of unknown dose* (April 7, 2015).

U.S. patent #8,633,455 C.R Yoder, M.S. Akselrod, V. Fomenko, *Optical system for dosimeter reader (*Jan 21, 2014)

Yukihara, E.G., Gasparian, P.B.R., Sawakuchi, G.O., Ruan, C., Ahmad, S., Kalavagunta, C., Clouse, W.J., Sahoo, N., Titt, U., (2011) *Medical applications of optically stimulated luminescence dosimeters (OSLDs*). Radiation Measurements, 45, 658-662.