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Towards a High-Resolution Real-Time Beam Monitoring Device: Self-Powered Multi-Layered Nano-Porous Aerogel Strip Arrays

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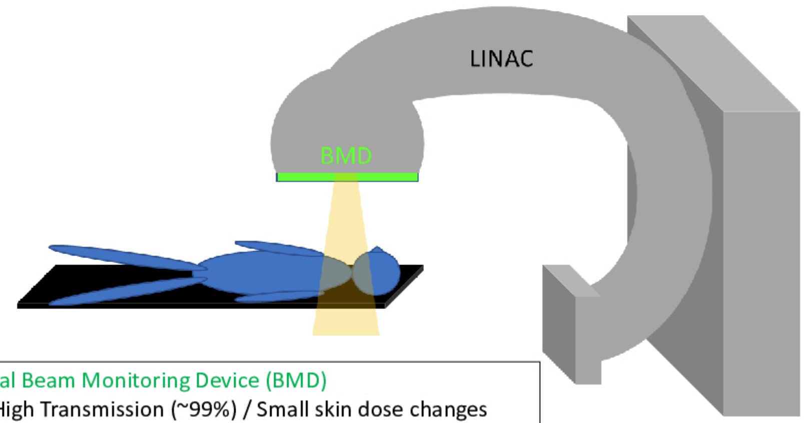
INTRODUCTION

Quality Control of linac performance have been mandated by governmental and non-governmental health and radiation organizations in the US and worldwide (WHO, IAEA, ASTRO, AAPM, etc), in efforts to avoid errors and accidents (from small to catastrophic) in modern Radiotherapy era [1]. Real-time **Beam Monitoring Devices** can provide an important independent check of the planning, calculation and delivery of treatments. For such task, real-time, high-resolution **Transmission Detectors** are needed. Such devices must be based on simple physics and engineering of operation, must possess high-transparency, radiation resistance, stability of performance, flexibility and low-cost of iterative design and fabrication.



Ideal Beam Monitoring Device (BMD)
- High Transmission (~99%) / Small skin dose changes
- High resolution (~1mm)
- Real-time (~10ms)
- Based on simple physics / engineering
- Radioresistant
- Stability of performance
- Integration into existing equipment
- Flexibility and low cost

Figure 1: A Beam monitoring device mounted on linac head can provide an independent check of the planning, calculation and delivery of treatments. A summary of main ideal feature a BMD must possess is reported in the box.

Commercial transmission detectors employ sparse ionization chamber or diode arrays which have limited spatial resolution. These arrays are prone to radiation damage and necessitate re-calibration when continually exposed to MV beams. Integral Monitor Chamber possesses the required simplicity and reliability of operation but provides only a single valued signal that is difficult to interpret when dynamic MLC segments are used.

BMD technology needs further basic science developments and new solutions to satisfy all or most of the aforementioned ideal features.

AIM

We are developing a Beam monitoring device based on a **novel technology** which employs **fast electrons generated in multilayered micro-structures** upon X-ray interaction.

Electrodes are thin and separated by low-density nanoporous aerogel films, therefore the total attenuation is small. Polyimide aerogel material is an ideal interlayer since it is low-Z, low-density, radioresistant and it does not significantly slow down the fast electrons.

METHOD

THE TECHNOLOGY: HIGH ENERGY CURRENT (HEC) DETECTOR

- Fast electrons, 0 Volt, High-Z/Low-Z-junctions,
- Nano-porous aerogel (low-Z, low-density, radioresistant, small electron attenuation)
- Multiple layers (3-100s)
- Nano-micro thick layers (small absorption)
- Conforming to curved surfaces /Covering large areas
- Horizontal or vertical design arrays (multichannel)
- Platform technology for several applications

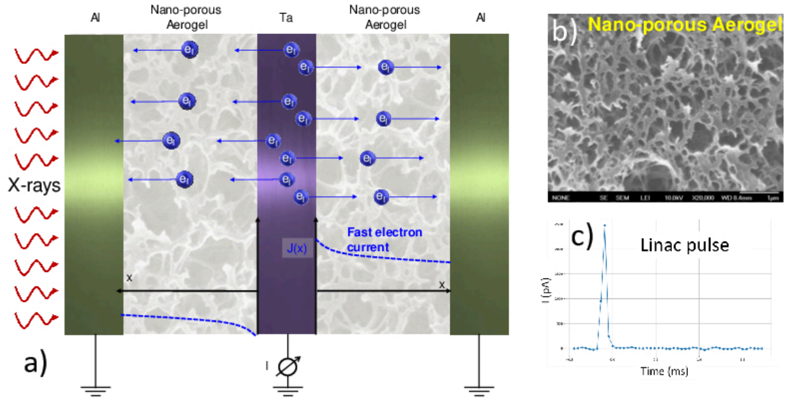


Figure 2: a) principle of operation of an aerogel based fast electron current detector depicted for a single module Al-Aerogel-Ta-Aerogel-Al. High-energy electrons are generated upon interaction of X-rays with the multilayered structure are leaking from the high-Z electrode (Ta) towards the low-Z electrode (Al). b) SEM image of the nano-porous aerogel surface. c) Linac pulse detected with an aerogel based HEC detector.

THE PROTOTYPE DESIGNS

Our sensor is a multilayer structure with N basic elements composed of 3-electrodes: N x (Al-aerogel-Ta-aerogel-Al). 10µm-Ta and 16µm-Al thin-film electrodes are separated by low density nano-porous aerogel 125µm-thick. We performed radiation transport simulations to optimize the geometry and we fabricated single pixel and few elements detector array prototypes to demonstrate the feasibility of monitoring beam profiles in X -/Y-directions with mm resolution, and to track MLC motion in real-time. Stacked and planar strip arrays (Fig. 3) have been prototyped and tested using a Varian True Beam Linac 6MV/6FFF. In the stacked geometry 5mm-wide 20cm-long strip electrodes were parallel to the beam, while in the planar geometry the electrodes were side by side.

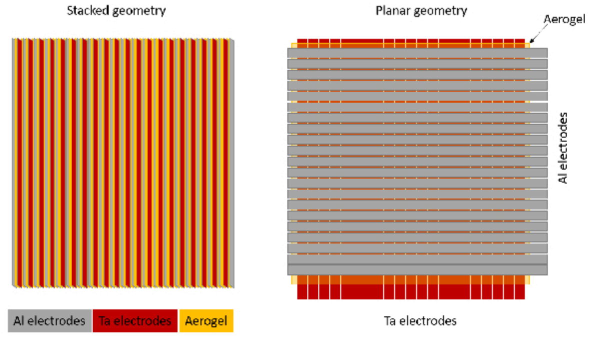


Figure 3: Beams eye view of the architecture of the strip arrays. 5mm-wide, 20cm-long strips of thin electrodes assembled in a stacked geometry (left) or planar geometry (right).

RESULTS

- Linearity to MU and MU/min was established and x-ray beam profiles were acquired with ~1 mm of spatial resolution.
- Beam attenuation by detector arrays is about 1-2% for 6MV/6FFF.
- The device can monitor each linac pulse (few µs) or integrate over few pulses (~10ms) at each control point.
- MLC segments are monitored by acquisition of signal integrated along the x- and y-strips.
- From the raw x-/y-signals the beam output and MLC leaf positions can be extracted for each control point using a custom MLC beam model.

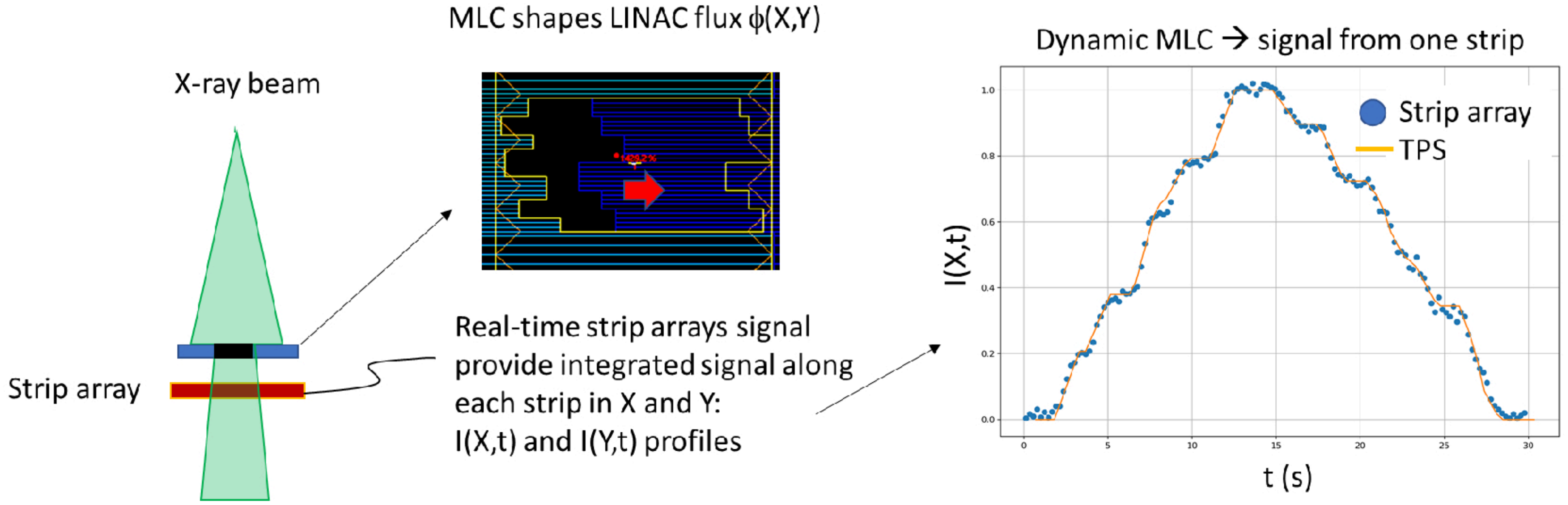


Figure 4: Real-time beam monitoring with a transmission detector strip array.

CONCLUSIONS

The **nano-porous aerogel based HEC strip arrays are suitable** for **high spatial resolution real-time** measurements required **for beam monitoring**. The simplicity of operation of these arrays opens possibilities for novel ways to verify MLC leaf positions in real-time. This technology is also suitable for monitoring of very high dose rate beams such those used in FLASH-RT.

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