Novel dual single sided silicon strip detector chip for radiotherapy verification

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A novel dual single sided silicon strip detector (SSSSD) chip was designed to meet clinical requirements in radiotherapy verification. An available design from Micron Semiconductor Ltd. (BB7, 500 μm thick) was the base of a two-dimensional detector adapted into a special configuration with the aim of uniforming and minimizing foreing materials around the active area (64×64 mm^2). With this purpose, two independent BB7 SSSSDs were mounted in a perpendicular configuration, separated by a 500 μm kapton dielectric film with the same dimensions as the silicon wafers, thus minimizing air gaps in between. This new configuration, called the dual SSSSD chip design, was mounted on kapton printed circuit board (PCB). Both silicon wafers were divided into 32 strips, 2 mm width each. The aim of developing this detector was to allow 2D dose measurements, improve spatial resolution and perform radiotherapy treatment verification faster than with a previous prototype. Characteristics and performance of the novel detector are presented.

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1. Introduction

Many efforts have been done to develop silicon detectors for medical applications, taking advantage of the experience and advances earned in detector technology from nuclear physics research (i.e. tracking silicon detectors, electronics and data acquisition systems) [1]. In particular, research is oriented towards silicon strip/pixel technology to improve spatial resolution for complex radiotherapy verification [2, 3]. As a matter of fact, silicon pixel detectors were developed to obtain good spatial resolutions, such as MAESTRO, DOSI, and CMRP DMG detectors [4, 5, 6, 7, 8, 9]. They require a high number of allocated channels and complex multichannel readout electronics based on application specific integrated circuits (ASIC) coupled directly to the detection system. This can produce some inconveniences due to the sensitivity of ASICs to radiation. In addition, these systems are not suitable to obtain dose maps in axial planes, which are generally oriented parallel to the beam axis. In fact, many of them are designed to be irradiated only perpendicularly with respect to detector active area. This means that they are useful for verifying separately each treatment field but not the full plan.

Within this scenario, we developed a novel solution and studied its feasibility to obtain two-dimensional (2D) axial dose maps in radiotherapy treatments using a single sided silicon strip detector (SSSSD) [10, 11, 12]; concretely, we used the 16-strip design W1-SS 500 from Micron Semiconductor Ltd. [13] The detector was placed at the axial plane of a cylindrical rotating phantom and the whole system was irradiated under clinical conditions by a Siemens linear accelerator (linac) installed at the Virgen Macarena Hospital in Seville (Spain). After successful results using the W1-SS 500, we present the development of an advanced prototype. The aim is to improve the traditional devices and to verify in a simple, fast and correct way, a complete radiotherapy treatment.

2. The Detector

The new detector concept was designed, developed and built within the context of RADIA collaboration (University of Seville, the National Accelerator Centre (CNA) and Virgen Macarena Hospital), with the support of the companies ATI sistemas S. L. and Micron Semiconductor Ltd. [13]; the latter was also responsible for its construction. Characteristics of the W1-SS 500 detector, used previously, are summarized in references [10, 13]. The detectors are shown in figure 1. In the new design, based on the same silicon strip technology, we decided to modify four key elements for improving complex radiotherapy treatment verification:

1) Bigger **active area (64x64 mm^2)** to allow measurements of larger dose maps.

2) Smaller **strip width (2 mm)**, i.e. 32 strips per wafer, to improve the spatial resolution.

3) **Two perpendicular strip orientations** to allow simultaneous measurements in two different orientations, hence reducing considerably the acquisition time.

4) The **packaging** of the detector, minimizing it and improving the density uniformity of materials with respect to the previous design.

We chose an already existing silicon wafer model from Micron Semiconductor Ltd., usually employed for the manufacturing of the 500 μm single sided BB7 model. In addition, we wanted to

implement the ability to perform simultaneous measurements with two different strip orientations. Due to this assembly, we have called this new detector the dual SSSSD chip design.
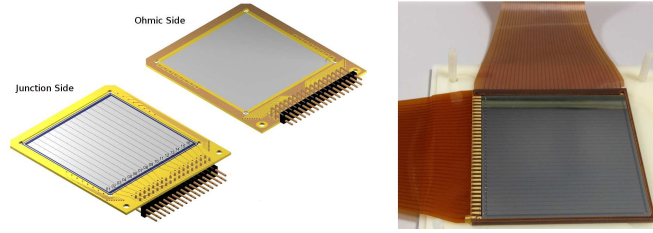
Figure 1: Single sided silicon strip W1-SS 500 model detector (on the left) provided by Micron Semiconductor Ltd.[13], compared to the novel dual SSSSD chip design (on the right).

Another goal of the new setup is to minimize the perturbation due to placing the detector in the medium (similar to water) where absorbed dose is to be measured. This can be achieved by uniforming detector composition with material densities as close as possible to 1 g/cm^3 (water density). Thus, for the frame of the new detector (67×67 mm^2), we chose 1200 μm Kapton (Arlon 85N polyimide laminate from DuPont), with a density of 1.6 g/cm^3. Besides, the frame dimensions were decreased from ~1 cm to 1.5 mm. Since Kapton presents very low thermal conductivity and very good insulating properties, we used a 500 μm Kapton film as dielectric separator between both silicon wafers, avoiding air gaps between them. Following the idea of minimizing foreign material around the detecting volume, we replaced the pin connector found on the W1-SS 500 design by two 200 mm length thin flat Kapton cables; at the end of which we installed pin connectors for the strips (Samtec TSW-117-7-L-D), thus keeping away the copper connectors from the detector (fig. 1). The flat cables directly connected to the silicon strips are made of 50 μm DuPont AP8525R ($\rho = 1.43$ g/cm^3) core, with 18 μm of copper on each side ($\rho = 8.2$ g/cm^3).
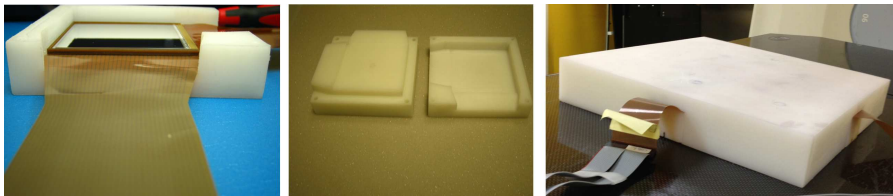
Figure 2: The final version of the dual SSSSD chip (on the left) for radiotherapy verification, placed in a polyethylene box (in the middle), which is designed to be coupled to different phantoms (on the right).

In summary, our dual SSSSD chip prototype consisted of the two SSSSDs with serial numbers 2958-2 (BB7-SS with 500 μm thickness) and 2958-6 (BB7-SS, 504 μm), mounted together (separated by Kapton as explained above) with the detector strips perpendicular to each other. The prototype was installed in a polyethylene box, for protection, before being placed in a slab phantom (fig. 2) for the first measurements.

3. Measurements

The system was irradiated in the Radiotherapy Unit of Virgen Macarena Hospital (Sevilla,

Spain) by a Siemens PRIMUS clinical linac (Figure 3) in 6 MV photon mode. As it is well known, clinical linacs used for X-ray radiotherapy, accelerate electrons which generate bremsstrahlung radiation when colliding with a tungsten target placed at the beam entrance of the treatment head. Typical energies of the primary electron beam are 6 MeV and 15 MeV (commonly referred to as 6 MV or 15 MV mode). The photon fields are shaped by means of a multileaf collimator (MLC) moving along the X-axis, and jaws moving along the Y-axis (provided the radiation beam axis is Z-axis), both systems installed within the linac treatment head. At therapy energies, photons interact with water equivalent material of the phantoms (or the human body tissue) mainly by Compton interaction releasing electrons into medium. As these electrons travel through the detector, they lose kinetic energy by exciting and ionizing atoms of the material, creating carriers which generate a charge (or voltage) output. In order to validate and characterize the system as a dosimeter for radiotherapy irradiations one, first of all, has to find a relation between this output and the dose absorbed in the medium if the detector were not present.

To do that, we have performed several measurements with the detector hosted inside a slab phantom and irradiated with the beam axis perpendicular to its active area (Figure 3), following closely a clinical protocol for quality assurance purposes.


Figure 3: Dual SSSSD chip placed into a slab phantom and positioned on the treatment couch to be irradiated by the linac at the Hospital.

Fig. 4 shows preliminary results of the detector response characterization:

1. Plot (a) shows the behavior of one detector strip under irradiation as a function of time. The strip collects the electrons generated by Compton scattering with a linear response that allows to calibrate the system as a dosimeter.

2. In plot (b), the response of individual strips when irradiated by a uniform field is represented. Different responses of the upper and lower detector can be observed. The red points represent the raw signal from each strip, while the blue ones show the average response of each detector, that leads to the uniformity factor calculation.

3. The study of the percentage depth dose is shown at (c). The results of the dose deposited at 10 and 15 cm in solid water depth (red points) are compared with those measured by an ion-

ization chamber (blue dots) at Virgen Macarena Hospital under clinical reference conditions (10×10 cm^2 field, water phantom surface at the isocenter plane).

4. Plot (d) shows the penumbra, defined as the region located between 20% and 80% of the maximum dose level, along the X (red squares) and Y (blue squares) directions. This study has been carried out by irradiating the system with asymmetric fields of 5×10 cm^2 and 10×5 cm^2 respectively.
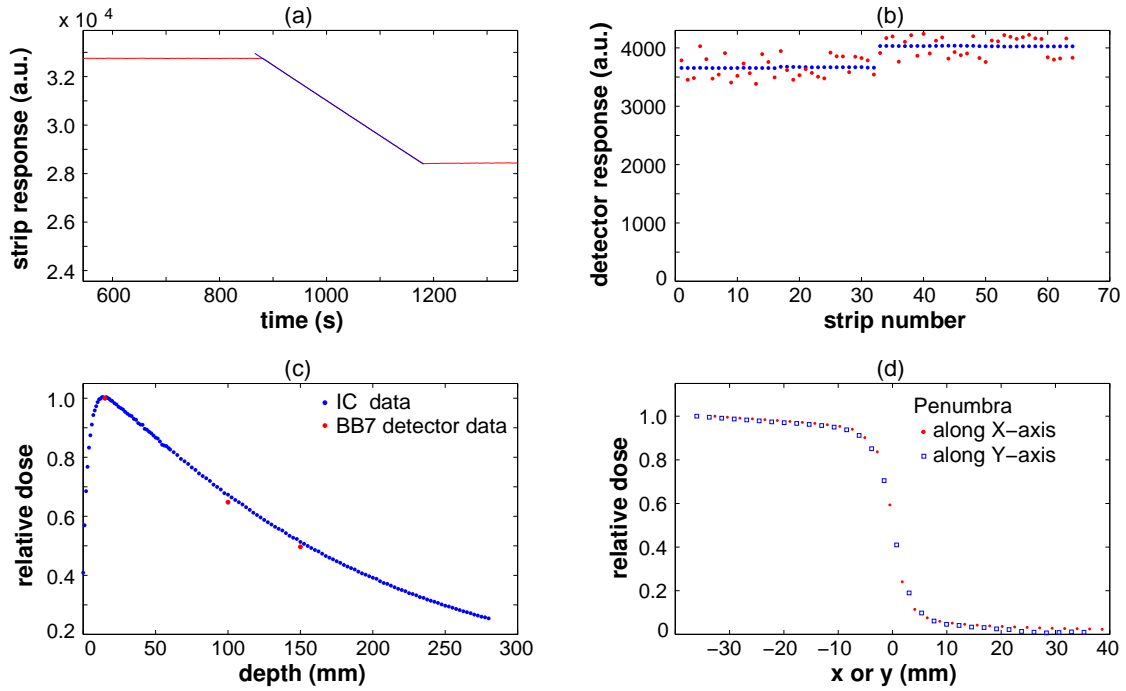
Figure 4: Preliminary tests of the detector responses in terms of: silicon strip uniformity, linearity, PDD and penumbra.

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