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Dosimetry systems based on Gallium Nitride probe for radiotherapy, brachytherapy and interventional radiology

P. Pittet [a,*], P. Jalade [b], J. Balosso [c], L. Gindraux [d], P. Guiral [b], R. Wang [a], A. Chaikh [c], A. Gaudu [e], J. Ribouton [b], J. Rousseau [e], J.-M. Galvan [a], A. Rivoire [d], J.-Y. Giraud [c], G.-N. Lu [a]

[a] *Institut des Nanotechnologies de Lyon INL, CNRS UMR5270, Université Lyon 1, Villeurbanne, France*
[b] *Service de Radiophysique et Radiovigilance, Centre Hospitalier Lyon Sud, Pierre-Bénite, France*
[c] *Department of Radiation Oncology and Medical Physics, Grenoble University Hospital, France*
[d] *DOSILAB SARL, 66 boulevard Niels Bohr, Villeurbanne, France*
[e] *Department of Radioprotection, Grenoble University Hospital, France*

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Abstract

Our studies focus on dedicated dosimetry systems based on the Gallium Nitride (GaN) probe for Quality Assurance and patient safety in radiotherapy, brachytherapy and interventional radiology. The small size GaN transducer in the probe has high radioluminescence (RL) yield and rapid RL signal response for real time measurements. Preliminary prototypes of dedicated systems were tested in clinical conditions for external beam radiotherapy, brachytherapy and interventional radiology. The obtained pre-clinical results appear favorable and encouraging: in radiotherapy, GaN RL response has not significant dependence on the main influence parameters, excepted for the field size. In brachytherapy, using an instrumented phantom with integration of GaN probes allows real time verification of planned treatments. In interventional radiology, skin dose measurements using GaN probe based dosimeters show consistent results with those from a reference dosimeter.

1. Introduction

For enhancing the quality assurance and safety in radiotherapy, brachytherapy and interventional radiology, there is a strong need to develop new dedicated dosimetry systems.

In radiotherapy, in vivo dosimetry should be used to improve the quality assurance of the treatments. Several types of dosimeters are currently available for in vivo dosimetry [1,2] such as Thermo Luminescent Dosimeters (TLD), Metal oxide semiconductor field effect transistors (MOSFET), diamond detector, semiconductor diodes, films and optical fiber dosimeters [3]. These dosimeters can be used to measure the entrance dose at the skin as an assessment of the delivered dose to the patient.

In radiology, the role of in vivo dosimetry is to prevent the over irradiation of the skin in case of a prolonged procedure. Ionization chambers and diodes are widely used for quality assurance and for measuring the kerma area product and other similar quantities [4]. These are alternative measurement methods for skin dose assessment. However, both dosimeter types have major drawbacks: the chamber has a relatively large size to be placed on the skin of the patient and the diodes are visible on the image and can interfere with the diagnosis.

In High Dose Rate BrachyTherapy (HDR-BT), mainly used to treat gynecologic, anal, prostate, head and neck and breast cancers, treatments are typically administered in large doses per fraction (>5 Gy) and with high-gradient-dose-distributions, with serious consequences in case of a treatment delivery error (e.g. on dwell time and dwell position). Thus, Quality Assurance (QA) and in vivo Dosimetry (IVD) should be systematically and independently implemented [2].

* Corresponding author.
E-mail address: Patrick.Pittet@univ-lyon1.fr (P. Pittet).

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In this context, the DorGaN project funded by the French National Research Agency, ANR-11-TECS-0018, is aimed to develop dedicated dosimetry systems based on the recently developed GaN probe [5].

The GaN probe is less invasive compared to existing solutions; it provides real-time monitoring of dose and dose rate. Previous studies have shown that it has interesting characteristics such as excellent linear RL response with no dose rate dependence [6]. Nevertheless, significant challenges associated with the material properties and its implementation in dosimetry systems need to be solved for targeted applications before it can be routinely used.

GaN is not a tissue equivalent material with energy dependence in its RL response. Its energy mass attenuation coefficient is much higher than for water for low photon energy due to its higher atomic number which increases the cross section for photoelectric effect. This leads to an over-response for beam spectrum with significant scattered components. To address this issue and for different clinical applications involving specific radiation sources (LINAC, ^{60}Co, ^{192}Ir), we carried out the following studies: i) Modeling of GaN RL response for megavoltage photons beams (for radiotherapy) [7,8]; ii) Development of a bi-media measuring method for compensation of GaN RL over-response [9].

On the other hand, for system operation, we have proposed a failure detection method by UV excitation and analyzing the probe's optical path signal, for several failure cases such as absence of GaN RL response and poor optical fiber connection [10]. This paper reports our studies on testing of dedicated dosimetry systems for external beam radiotherapy, brachytherapy and interventional radiology.

2. Testing for external beam radiotherapy

For EBRT (External Beam Radiotherapy), the goal of our studies was to make possible a direct, *in-situ*, real time measurement of the delivered dose.

The measurements were acquired with a GaN dosimeter and two reference ionization chambers. The GaN dosimeter consisted of a solid state GaN crystal ($V \sim 0.1$ mm^3) coupled with an optical fiber. In EBRT, the system of measurement included an advanced signal processing method for parasitic fiber background rejection, Cerenkov light and intrinsic RL, and crystal over-response compensation [7]. The GaN dosimeter was connected to the photo-detection system via a 15 m long optical fiber. The ionization chambers were a PTW Pinpoint (15 mm^3) and a cylindrical chamber (125 mm^3). The Pinpoint chamber was used to characterize the GaN response under clinically representative conditions. The cylindrical chamber was used for Percent Depth Dose (PDD) and beam profile for reference measurements. The experimentation was carried out using a water tank or a multi-plate $30 \times 30 \times 15$ cm^3 PMMA phantom.

The photon beam energies used for this study were 6 MV and 18 MV (Clinac 2100 or 600, Varian Medical system). The GaN transducer was placed at the beam isocenter with a Source Skin Distance (SSD) = 95 cm and a depth of 5 cm of PMMA. A 10 cm thick PMMA plate was placed between the probe GaN and the couch according to TRS-398 backscattering requirements, as shown on Fig. 1. The reference beam setting was: 5×5 cm^2, with normal beam incidence. The delivered dose in monitor unit (MU) was 200 MU and the dose rate was set at 300 MU/min.

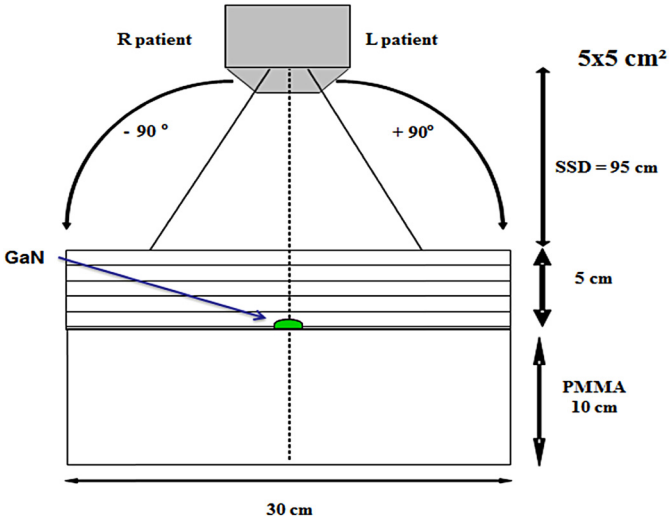

Fig. 1. Experimental setup.

The testing in clinical conditions included variations of the following parameters: field size, Source Skin Distance SSD, beam incidence and wedge filter.

We evaluated correction factors CF_i defined and proposed in the ESTRO booklet n°5 [16]:

$$CF_i = \frac{(\frac{R_{IC}}{R_{GaN}})Clinical\ condition}{(\frac{R_{IC}}{R_{GaN}})Reference\ condition} \quad (1)$$

where R_{IC} and R_{GaN} are IC and GaN probe readouts, respectively.

CF_{field} was determined for field size varying from 5×5 to 25×25 cm^2, $CF_{incidence}$ on the range $[-60°, +60°]$, and CF_{SSD} for SSD between 85 cm and 115 cm. We characterized the influence of the wedge filter on the GaN RL response by using successively 15, 30, 45 and 60° filters. The short term and long term reproducibilities were evaluated by measuring dose for 10 successive 200 MU radiation runs and 20 successive days with two probes irradiated at 50 and 200 MU for each run, respectively. Dose rate ranging from 0.83 to 7.47 Gy/min and accumulated dose from 1 to 10 Gy were tested to quantify accuracy of measurements compared to planned dose as a reference. Wilcoxon signed rank test was used for assessing the statically significance of dose difference and language R® was used to calculate p-value at alpha error equal to 5% [11].

Table 1 summarizes the main characteristics of the GaN probe measured with a 18 MV photon beam (see [12] for 6 MV characterization). It can be seen in Table 1 that, short term and long term reproducibility of GaN probe RL measurements were estimated to be better than 0.4% and 1% at 1 SD respectively. The correction factors for SSD, beam incidence and wedge filter were close to the unity. GaN dependence on field size shows the need to implement an efficient method for compensating GaN over-response in the dosimetry system [8]. The accuracy