

**EVALUATION OF RADIATION DETECTOR SYSTEMS FOR  
MAMMOGRAPHY X-RAY UNITS**

**Risimati Dazmen Mavunda**



Submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg,  
South Africa, in fulfillment of the requirement for the degree of  
Doctor of Philosophy

March 2008

## DECLARATION

I declare that this thesis is my own, unaided work and it has not been submitted before for any degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg, South Africa.

---

----- day of ----- 2008

## ABSTRACT

Nine polycrystalline (Detector and Optical Grade) and Single Crystal CVD diamond detectors were characterised in terms of their defects and impurities with the specific aim to provide the much needed tool for selecting materials suitable for use in radiation detectors and in spectroscopy when exposed to alpha particles radiation or mammographic X-rays. The effectiveness of electron spin resonance (ESR), ultra-violet (UV) absorption, Raman broadening and thermo-luminescence (TL) emission as tools for performance evaluation were analyzed. The study has shown that defects (e.g. grain boundaries) and impurities (e.g. single substitution nitrogen concentration) played a role in the performance of CVD diamond wafers when used as dosimeter or spectrometer. In particular the observed higher values of single substitutional nitrogen concentrations, higher UV absorption and Raman broadening but lower TL emission values in the Optical Grade CVD diamond wafers were associated with their improved performance as detectors of alpha particles. The lower ESR, the lower UV absorption, higher TL emission values and lower Raman broadening were related to the better performance of both the Detector and Single Crystal CVD diamond wafers when used for alpha spectroscopy.

An adopted and extended method developed for the correction of the ‘as accumulated’ spectra that takes into account the detector’s efficiency gave rise to an X-ray mammography spectrum that is independent of the detector type. This was used to justify the use the Monte Carlo simulated spectrum to evaluate the comparative responses of

pure diamond to that of the CVD diamonds wafers when exposed to simulated and actual X-ray exposures respectively.

The research has provided an evaluation technique for selecting detectors suitable for different applications. The research furthermore, suggests that for the detection of X-ray photons, using a Detector Grade CVD diamond wafer is best suited for the task but generally the most consistent radiation detector material is the Single Crystal CVD wafer.

*I dedicate this thesis to my parents*

*The late Mzamani and Njhakanjhaka Mavunda*

*Who brought me to this harsh world*

*To my wife, Hilda*

*To my sons Amukelani, Vunwe and Ntila*

*To my brother*

*Samson*

# Acknowledgements

A great many people have contributed in many ways to the success of this thesis, far too many to mention all of them by name and I highly appreciate their contribution and the time they sacrificed during the course of this work. Without the help and the efforts of these mentioned people, this thesis, would not have been successful. I therefore thank God for touching them, and I, personally, wish to express my deepest gratitude and honour by name to some of these outstanding personalities:

My dedicated supervisors; Professor Thomas Leong Nam and Professor Emeritus Rex James Keddy for their relentless commitment through their guidance, coaching, supervision, and motivation to empirically undertake this rigorous investigation on this study, a study that was never done before in this specific area

Dr. Jan Van Wyk from the University of the Witwatersrand-for determination of the single substitutional nitrogen concentration in CVD diamond wafers

Prof Trevor Derry from the University of the Witwatersrand-for simulating the layers on the Co-57 reference source

Mr. Rudolph Erasmus from the University of the Witwatersrand -for Raman Spectral and UV absorption data collection

Dr. Simon Connell from the University of the Witwatersrand-for providing the equipment for current leakage measurements

Professor Hayes from the University of Pretoria-for metallization of CVD diamond wafers

Mr. Kobus Grobbelaar-for designing and checking the electronic problems of the pre-amplifier which was used in the alpha spectroscopy of this study

Mr. Mick Rebak from iThemba Labs-for cleaning and polishing CVD diamond wafers

Mr. Marius Labuschagne from iThemba Labs-for his interest and professional expertise in designing the Sample holders

Mr. Richard Chirwa, Mr Jacek Tomasik from iThemba Labs and Mr. Tonny Voorveldt from the University of the Witwatersrand-for their professional expertise in assisting with the fixing of electronic equipment I was used during this study

Mr. Oleg Pekar from iThemba Labs-for assembling a vacuum chamber in which diamond wafers were place during alpha spectroscopy

Dr Isaac Machi from iThemba Labs-for allowing me to utilize his facilities in the pursuit of this study which effectively enhanced and accelerated the research of this work

Mr. Mpho Mofokeng from NED Bank and Mr Lester Masher from Standard Bank-for signal conditioning during data collection

Ms. Doris Monyamane, Mr. Khaya Radebe, and Ms Mbali Lunga from iThemba Labs staff- for working tirelessly in providing the administrative support which facilitated my work in this study

National Research Foundation (NRF) and the DST/NRF Centre of Excellence in Strong Materials -for financial support

Finally I would like to deliver my sincere gratitude to Dr Yusuf Ibrahim Zakari from Ahmadu Bello University, Zaria, Nigeria, for his supervision and guidance during the final and important stages of this work

## CONTENT

Title page	i
Declaration	ii
Abstract	iii-iv
Dedication	v
Acknowledgement	vi-viii
Table of contents	ix-x
<b>CHAPTER ONE</b>	<b>1-31</b>
General introduction	
<b>CHAPTER TWO</b>	<b>32-70</b>
The presence of defects in and their influence on the performance of, CVD diamond as an $\alpha$ -particle radiation sensing element	
<b>CHAPTER THREE</b>	<b>71-93</b>
Comparative evaluation of the inherent spectrometric performances of CVD diamond detector exposed to $\alpha$ -particles radiation after spectral background subtraction	
<b>CHAPTER FOUR</b>	<b>94-122</b>
Methodology used for the correction of bremsstrahlung X-ray spectra obtained from a Ge(Li) detector and a comparison with spectra generated from the use of the Monte Carlo code PENELOPE	

<b>CHAPTER FIVE</b>	123-150
Evaluation of observed variation in CVD diamond detector response with crystal defects at low energy mammographic X-rays	
<b>CHAPTER SIX</b>	151-169
Analysis of a simulated low energy X-ray mammographic model with Monte Carlo code (PENELOPE) for a validation of the experimental performance of the CVD diamond detectors	
<b>CHAPTER SEVEN</b>	170-174
General conclusion	
<b>APPENDICES</b>	175-197