



UNIVERSITI PUTRA MALAYSIA

**AUTOMATION SYSTEM FOR SINGLE PHOTON GENERATION AND
DETECTION**

CHAN KAR TIM

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GENERATION AND DETECTION**

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**MASTER OF SCIENCE
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**AUTOMATION SYSTEM FOR SINGLE PHOTON GENERATION AND
DETECTION**

By

CHAN KAR TIM

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
In Fulfilment of the Requirements for the Degree of Master of Science**

March 2009



TO ALL THE LOVED ONES IN MY LIFE.....



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

**AUTOMATION SYSTEM FOR SINGLE PHOTON GENERATION AND
DETECTION**

By

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March 2009

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Single photon source can be produced by using spontaneous parametric down conversion or quantum emitter such as ions, molecules, atoms, quantum dots and colour centres. Main objective of current research is to automate single photon generation module and detection module based on nitrogen vacancy colour centre in diamond into one system. In single photon generation, diamond sample is held at a holder mounted on a 3D piezo translation stage. Laser source with wavelength 527nm is focused using a standard microscope objective to a spot size at the nitrogen vacancy centre to produce fluorescence.

Since a single photon is generated by exciting an isolated nitrogen vacancy in a diamond crystal, it is critical that position of nitrogen vacancies in the crystal to be known. For this purpose, a scanning system was designed and constructed to determine the 3D position of nitrogen vacancy and identified their coordinates for



later use. The system consists of a high precision 3D piezo translation stage and was controlled by a scanning programme built using LabVIEW. This programme will map the location of the vacancies in an intensity graph where axis X and Y show the scanning position while the bright colour spots determine the position of the vacancies.

In single photon detection which is based on the Hanbury-Brown-Twiss setup, the fluorescence emitted from the nitrogen vacancy is split by a beamsplitter and directed to single photon detectors. A digital pulse is produced for each photocount detected. At the same time, output from the detectors is fed into a time to amplitude converter/single channel analyzer to produce coincidence counts. In order to read and record the number of photon counts and number of coincidences, a detection system was designed and built. This detection system interfaces a series of high performance single photon detectors to the same computer that controls the scanning system via a detection programme. Besides reading and recording data, the detection programme can also calculate the second order correlation function, $g^2(\tau)$ from a subVI written in LabVIEW 8.2.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

**PENGAUTOMASIAN SISTEM PENGHASILAN DAN PENGESANAN
FOTON TUNGGAL**

Oleh

CHAN KAR TIM

March 2009

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Sumber foton tunggal boleh dihasilkan dengan menggunakan *spontaneous parametric down conversion* atau pemancar kuantum seperti ion, molekul, atom, dot kuantum dan pusat berwarna. Objectif utama penyelidikan ini adalah untuk mengautomasikan modul penghasilan dan pengesanan foton tunggal yang berasaskan pusat berwarna nitrogen-kekosongan pada permata dalam satu sistem. Dalam penghasilan foton tunggal, sampel permata diletakkan pada pemegang atas pentas translasi piezo tiga dimensi. Sumber laser yang mempunyai panjang gelombang 527nm difokuskan dengan menggunakan objektif mikroskop kepada satu saiz tompok pada pusat nitrogen-kekosongan bagi menghasikan pendarflour.

Memandangkan foton tunggal terhasil apabila nitrogen-kekosongan dalam permata diujakan, adalah kritis kedudukan nitrogen-kekosongan diketahui. Bagi tujuan ini, satu sistem pengimbas telah direka dan dibina untuk menentukan kedudukan dan

koordinat setiap nitrogen-kekosongan. Sistem ini mengandung satu pentas translasi piezo tiga dimensi dan dikawal oleh program pengimbas yang dibina dengan menggunakan perisian LabVIEW. Program ini mampu memetakan lokasi nitrogen-kekosongan dalam satu graf keamatan. Paksi X dan Y pada graf menunjukkan posisi pengimbasan manakala tompok berwarna terang menunjukkan kedudukan nitrogen-kekosongan.

Bagi pengesanan foton tunggal yang berasaskan susunatur Hanbury-Brown-Twiss, pendarflour yang dipancarkan oleh nitrogen-kekosongan akan pisahkan oleh kiub pemisah sinaran dan ditujukan kepada alat pengesan foton tunggal. Satu isyarat digital terhasil apabila satu foton dikesan oleh alat pengesan. Hasil keluaran dari alat pengesan akan disambungkan kepada alat penukar masa-amplitut/penganalisis saluran tunggal untuk menghasilkan bilangan kebetulan.

Demi membaca dan merekod bilangan foton dan kebetulan, satu sistem pengesanan telah direka dan dibina. Sistem ini mengantaramukakan beberapa alat pengesan foton tunggal pada komputer yang mengawal sistem pengimbasan melalui program pengesanan. Selain membaca dan merekod data, program pengesanan ini juga boleh menghitung fungsi korelasi tertib kedua $g^2(\tau)$ melalui satu *subVI* yang ditulis menggunakan perisian LabVIEW 8.2.

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I certify that an Examination Committee met on 3 March 2009 to conduct the final examination of Chan Kar Tim on his master thesis entitled “Automation System for Single Photon Generation and Detection” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Master of Science.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

CHAN KAR TIM

Date: 12 March 2009

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xx
LIST OF SYMBOLS	xxi
CHAPTER	
1 INTRODUCTION	1
1.1 A Brief History	1
1.2 What is Single Photon Source?	1
1.3 Application of Single Photon Source	2
1.4 Automation for Single Photon Generation and Detection System	4
1.5 Objectives	5
1.6 Outline of the Present Work	6
2 LITERATURE REVIEW	8
2.1 Single Quantum Emitter	8
2.1.1 Atoms and Trapped Ions as Quantum Emitter	9
2.1.2 Colour Centre as Quantum Emitter	11
2.1.3 Molecules as Quantum Emitter	14
2.1.4 Quantum Dots as Quantum Emitter	18
2.2 Hanbury Brown Twiss (HBT) Detection Technique	21
2.3 Confocal Scanning Technique	23
2.4 Application Based on LabVIEW Programming	24
3 THEORIES	26
3.1 Coherence Theory	26
3.2 Correlation Function	28
3.2.1 First Order Correlation Function	28
3.2.2 Second Order Correlation Function	30
3.2.3 Different Flavours of Light	32
3.3 Theory of Photodetection	35
3.3.1 Quantum Efficiency of a Detector	35
3.3.2 Dark Noise	35
3.3.3 Speed and Saturation	35
3.3.4 Theory of Photoelectric Detectors	36
3.4 Theory of Timing and Coincidence Counting	38
3.5 Theory of Optical Components	40
3.5.1 Resolving Power and Numerical Aperture	40



3.5.2	Depth of Focus	42
3.5.3	Aberrations	43
3.5.4	Lenses	44
3.6	Serial Communication	46
4	METHODOLOGY	51
4.1	Single Photon Generation System	51
4.1.1	Scanning System	53
4.1.2	Single Photon Detection System for Nitrogen Vacancy Mapping	55
4.1.3	Standard Microscope Objective	56
4.1.4	Piezo Controller	57
4.1.5	Single Photon Counting Module	58
4.2	Single Photon Detection System	59
4.2.1	Detection Measurement Setup	61
4.2.2	Time to Amplitude Converter/ Single Channel Analyzer	62
4.2.3	Time to Amplitude Converter/ Single Channel Analyzer Setting	63
4.2.4	Testing Operation of Time to Amplitude Converter/ Single Channel Analyzer	65
4.2.5	Setting Coincidence Window for Single Channel Analyzer	67
4.2.6	Testing Operation to Verify the Function of Detection Programme	69
4.3	Data Acquisition System	70
4.3.1	Data Acquisition for Scanning System	71
4.3.2	Data Acquisition for Detection System	72
4.3.3	Signal Connections	73
4.3.4	Data Acquisition Hardware and Driver	75
5	RESULT AND DISCUSSION	80
5.1	Algorithm for Positioning Programme	80
5.2	Positioning Programme	82
5.2.1	Piezo Controller Setting	83
5.2.2	Positioning Operation Block Diagram	84
5.2.3	Positioning Selection	88
5.2.4	User Interface for Positioning Programme	91
5.3	Algorithm for Scanning Programme	94
5.4	Scanning Programme	97
5.4.1	Raster Scan	98
5.4.2	Counter Setting	104
5.4.3	Data Saving for Scanning Programme	105
5.4.4	Mapping of Vacancies	106
5.4.5	User Interface for Scanning Programme	109
5.5	Algorithm for Detection Programme	113
5.6	Detection Programme	115
5.6.1	Counter Initialization	116
5.6.2	Counting and Data Acquisition Process	117
5.6.3	Timing Process	120

5.6.4	Second Order Correlation Function g^2 Calculation Process	120
5.6.5	Data Saving for Detection Programme	122
5.6.6	Number of Counts and Coincidences from Testing Operation	124
5.6.7	User Interface for Detection Programme	125
6	CONCLUSION AND SUGGESTIONS	127
6.1	Automation of Piezo Controller via LabVIEW Programming	127
6.2	Automation of Scanning System	127
6.3	Automation of Detection System	128
6.4	Suggestion for Improvement and Future Works	129
	REFERENCES	130
	APPENDICES	134
	BIODATA OF STUDENT	149
	LIST OF PUBLICATIONS	150

LIST OF TABLES

Table		Page
4.1	Setting of the front panel	66
4.2	Electrical connection for the counters and ground	75
5.1	Serial Communication Setting	80
5.2	Looping process in Frame 2 for scanning distance 20 μm and $N_x(\text{step}) = 1\mu\text{m}$	103
5.3	Conditional output from the logical programming	119
5.4	Number of counts from START (B), STOP (B') and coincidences (BB')	124

LIST OF FIGURES

Figure		Page
1.1	A pulsed classical source (top) and a pulsed single photon source (bottom)	2
2.1	Typical optical excitation scheme for a 3 level quantum emitter. (Lukishova et al., 2003)	8
2.2	Outline of the principal elements of the experiment. L represents convex lenses (Kimble et al., 1977).	9
2.3	Radio frequency trap.	10
2.4	Seven-level model of NV centre by Nizovtsev et al., 2003	14
2.5	Collision pulse mode locked laser exciting microcavity.	15
2.6	Schematic diagram of the optical setup used to excite single molecules and to collect their fluorescence (Brunel et al., 1999).	17
2.7	Growth of self-assembled quantum dots: a) A thin layer of InAs is grown on top of GaAs. After a critical thickness is reached, b) quantum dots form to relieve mechanical strain. c) The dots are then capped with GaAs.	19
2.8	Experimental setup using InAs quantum dot (Robert et al., 2001).	20
2.9	a) Radio interferometer while b) modified radio interferometer (Brown et al., 1956)	21
2.10	A Hanbury-Brown and Twiss interferometer, used to determine the degree of second order temporal coherence of a light source.	22
2.11	Confocal scanning technique	23
2.12	Block diagram of a typical automated system by R. N. Roy (2002)	24
3.1	Generalized light paths in an interference experiment	27
3.2	Plot of g^2 as a function of delay normalized to the coherence length τ/τ_C for $g^2(\tau) = 1$ (blue line) and $g^2(\tau) > 1$ (red and green line)	32
3.3	Plot of g^2 as a function of delay normalized to the coherence length τ/τ_C for $g^2(\tau) < 1$	33
3.4	Photon detection as a function of time for a) antibunched b) random c) bunched light	34

3.5	Functional diagram of a time to amplitude converter (Canberra, 2005).	38
3.6	Delay and pulse height measurement by the TAC/SCA	40
3.7	Numerical aperture of a standard microscope objective	41
3.8	Depth of focus of a lens	42
3.9	Formation of an image by a thin lens. The points marked F is equal to the focal length f.	45
3.10	Order of the binary code for an 8-bit data	48
3.11	A start bit (Space state) and a stop bit (Mark state)	48
3.12	RS232 serial waveform transmission	49
4.1	Single photon generation setup and detection	51
4.2	Transmission and reflection of the dichroic mirror (Edmund Optics, N47-268) used in the experimental setup (Edmund Optics, 2004, pp. 82)	52
4.3	Part of scanning system and delivery system	54
4.4	Differential micrometer drive	55
4.5	Schematic diagram of single photon detection system for nitrogen vacancy mapping	56
4.6	Standard microscope objective	57
4.7	Piezo controller MDT693A	58
4.8	Single photon counting module	59
4.9	Schematic diagram of single photon detection system	59
4.10	50/50 Beam splitter	60
4.11	Detection measurement setup	61
4.12	Time to amplitude converter / single channel analyzer	63
4.13	Internal control of TAC/SCA. Marked jumper plugs can be used to change the polarity of the input/ output terminals.	64
4.14	Typical setup for testing the operation of the TAC	65

4.15	TAC verification output	66
4.16	Upper and lower limit for TAC output	67
4.17	Minimum and maximum value of the voltage window	68
4.18	SCA output based on the voltage window	69
4.19	Testing setup to verify the function of detection programme	70
4.20	Data acquisition system for scanning	71
4.21	Data acquisition for detection setup	72
4.22	Signal connections for a) scanning system and b) detection system	74
4.23	Connector block and shielded cable	76
4.24	Counter / timer Data Acquisition Card	77
4.25	Simple event counting	78
4.26	Gated-event counting	78
5.1	Algorithm for positioning	81
5.2	Overall block diagram for positioning programme	82
5.3	a) sub VI for serial port setting b) Block diagram for piezo controller setting	83
5.4	a) Micron to voltage subVI b) Micron to voltage block diagram	84
5.5	a) Positioning subVI b) Block diagram for positioning subVI	85
5.6	Number to fractional string function	86
5.7	Concatenate string function	87
5.8	Frac/exp string to number function	87
5.9	a) voltage to micron subVI b) voltage to micron block diagram	88
5.10	Block diagram for three axes or single axis function selector	89
5.11	Sequential programming for three axes	90
5.12	Case structure used for selection of different axis in single axis selector	91

5.13	User interface for piezo controller setting	92
5.14	LabVIEW positioning operation front panel	93
5.15	Single axis folder showing the knob control	93
5.16	Algorithm for two dimension scanning	95
5.17	Algorithm for line scanning	96
5.18	Overall block diagram for the scanning programme	97
5.19	Division of the scanning area	98
5.20	Set scan subVI block diagram and the connection terminal	99
5.21	Initialize array function	100
5.22	Connection of two dimension array to a shift register	101
5.23	Scanning sequence from Frame 0 to 3	102
5.24	Replace array subset	104
5.25	Block diagram of counter used in scanning programme	105
5.26	Data saving for scanning programme	106
5.27	Simulated data displayed in an intensity graph for pane Z=1. Circled areas are spots with high counts.	107
5.28	Simulated data displayed in an intensity graph for pane Z=2. Circled areas are spots with high counts.	107
5.29	Three dimensions graph plotted using ORIGIN software to determine the bright spot for plane Z=1.	108
5.30	Three dimensions graph plotted using ORIGIN software to determine the bright spot for plane Z=2.	109
5.31	Front panel for counter setting	110
5.32	Front panel for scan setting	111
5.33	Front panel for scanning programme in the graph folder	111
5.34	Front panel for displaying collected data	112
5.35	Algorithm for detection process	114



5.36	Algorithm for reading counters and calculating second order correlation function procedure	115
5.37	Overall block diagram of the detection programme	116
5.38	Polymorphic VI selector from Create task function	117
5.39	Read task and its polymorphic VI selector	118
5.40	Logical programming to create a conditional output	119
5.41	a) Connection of the elapsed time function b) Elapsed time function	120
5.42	Connection of data to the G2 CALC subVI	121
5.43	$g^2(\tau)$ calculation subVI	122
5.44	Data saving for detection programme	123
5.45	Front panel of detection programme for setting	125
5.46	Front panel for data display	126

LIST OF ABBREVIATIONS

APD	Avalanche photodiode
ASCII	American standard for information interchange
DAQ	Data acquisition system
HBT	Hanbury Brown Twiss
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
LSB	Least significant bit
MSB	Most significant bit
NA	Numerical aperture
NI-VISA	National Instrument- Virtual Instrument Software Architecture
NV	Nitrogen vacancy
PFI	Programmable function interface
PZT	Piezo translation
QKD	Quantum key distribution
QD	Quantum dot
SCA	Single channel analyzer
SPCM	Single photon counting module
TAC	Time to amplitude converter
TTL	Transistor-transistor logic
VI	Virtual instrument

LIST OF SYMBOLS

$n(\tau)$	Number of events
$P(t, t+\tau)$	Joint photoelectric detection probability density
τ	Time difference or delay
E	Radiation field
I	Irradiance
$g^{(1)}$	First order correlation function
$g^{(2)}$	Second order correlation function
N_B	Number of detections at counter B
$N_{B'}$	Number of detections at counter B'
$N_{BB'}$	Number of coincidence
P_{act}	Photons actual count rate
X	Input value in distance (μm) form
Y	Input value in distance (μm) form
V_X	Input value in voltage form for X
V_Y	Input value in voltage form for Y
N_X	Step input for axis X (in μm)
N_Y	Resolution for axis Y (in μm)
S_X	Total number of scanning points along X axis
S_Y	Total number of scanning points along Y axis
D_X	Step input for axis X (in v)
D_Y	Step input for axis Y (in v)



CHAPTER 1

INTRODUCTION

1.1 A Brief History

In 1905, Albert Einstein published the theory of photoelectric effect which gave the idea of photons to describe light as composed of discrete quanta rather than continuous waves. This theory plays an important role in the photoelectric detection of light and its experimental application has led to a clearly point of view of the statistical properties of light (Bachor et al., 2004, pp. 1-2). The understanding of the interaction between light and matter following from these developments formed the basis of quantum optics.

After the introduction of the correlation experiment in 1956 and also the forming of quantum formulation of optical coherence by R. J. Glauber, quantum optics started to flourish. Many experiments based on entangled photon pairs and quantum emitter such as using trap ions, quantum dots, molecules and colour centre have been studied intensively to realize their potential as a single photon source.

1.2 What is Single Photon Source?

A single photon source is a source that can emit one photon at a time. In general, each photon emitted has antibunching characteristic. This characteristic is a quantum state of light where the photon statistics deviate strongly from the classical



distribution. For example, if one photon was sent to a beam splitter and photon counting detectors were placed at the transmitted and reflected beams position, no coincidence will be observed. From the principle of quantum mechanics, the wavefunction of the photon has to collapse onto either one of the two detectors. The probability of obtaining two or more photons at the same time is negligible. Figure 1.1 shows the difference between a triggered classical photon stream and the triggered single photon stream (ideal). An ideal single photon source emits one and only one photon in each pulse as shown in Figure 1.1.

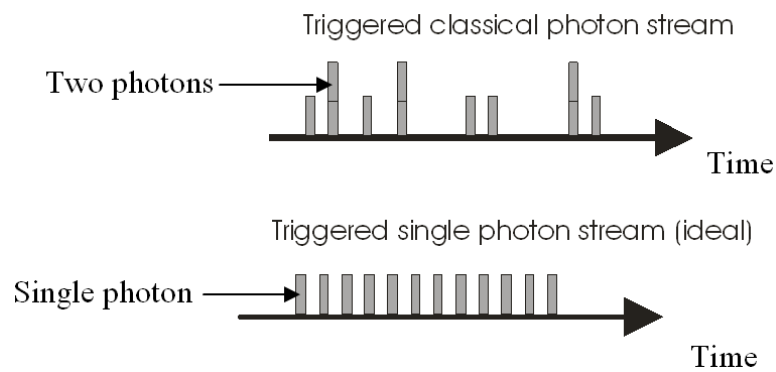


Figure 1.1: A pulsed classical source (top) and a pulsed single photon source (bottom)

1.3 Applications of Single Photon Source

Quantum cryptography more precisely as Quantum Key Distribution (QKD) is one of the first major application proposed for single photon source (M. Oxborrow et al., 2005). In this application, a sender (Alice) sends information to the receiver (Bob) through a channel. Each bit of their information is coded on a single quantum state or qubit. If a third party, a potential eavesdropper (Eve) tries to eavesdrop on the transmission, Eve will alter some of the states of these photons. Quantum mechanics