UNIVERSITI PUTRA MALAYSIA

AUTOMATION SYSTEM FOR SINGLE PHOTON GENERATION AND DETECTION

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MASTER OF SCIENCE

UNIVERSITI PUTRA MALAYSIA

2009

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

CHAN KAR TIM

March 2009

Chairman: Ionel Valeriu Grozescu, PhD

Faculty: Science

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

Pengerusi : Ionel Valeriu Grozescu, PhD

Fakulti : Sains

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 mengandungi 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-kekosogan.

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 perisisan LabVIEW 8.2.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Associate Professor Dr. Ionel Valeriu Grozescu for giving me a chance to study and work with him. His encouragement, advice, guidance and technical support have not only making this research possible but also helping me to be a better person. I would also like to thank my co-supervisor, Associate Professor Dr. Hishamuddin Zainuddin for his valuable support and discussions during this period of study.

Thanks and appreciation is also extended to all my friends and colleagues especially Kuan Ya Chin, Suhaila and Kokula who have helped me in countless ways and made these years lots of fun. I would also like to thank Mr. Roslim and Mr. Zulambiar for their generosity in assisting and permitting me to use the Instrumentation Lab.

Last but not least, I wish to express my gratitude to my family especially my wife, Kun Mei Yee, for her support and understanding. Thank you very much.

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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 14 May 2009

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

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LIST OF ABBREVIATIONS

APD	Avalance 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 send 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.

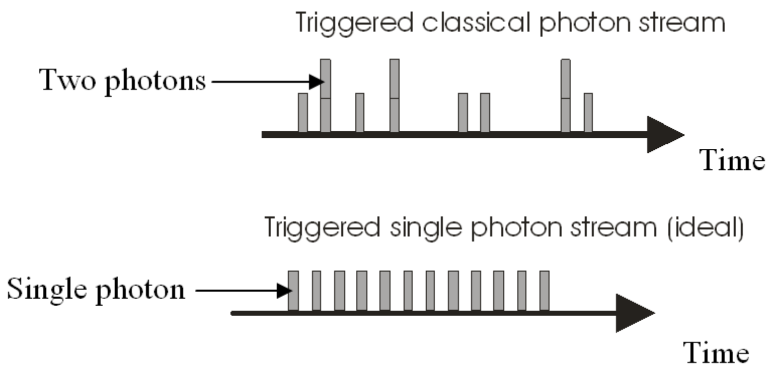

Figure 1.1: A pulsed classical source (top) and a pulsed single photon source (bottom)

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