UNIVERSITI PUTRA MALAYSIA

AUTOMATION SYSTEM FOR SINGLE PHOTON GENERATION AND DETECTION

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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

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.
PENGAUTOMASIAN SISTEM PENGHASILAN DAN PENGESANAN FOTON TUNGGAL

Oleh

CHAN KAR TIM

March 2009


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


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.
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.

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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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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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<tr>
<td>APD</td>
<td>Avalanche photodiode</td>
</tr>
<tr>
<td>ASCII</td>
<td>American standard for information interchange</td>
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<tr>
<td>DAQ</td>
<td>Data acquisition system</td>
</tr>
<tr>
<td>HBT</td>
<td>Hanbury Brown Twiss</td>
</tr>
<tr>
<td>LabVIEW</td>
<td>Laboratory Virtual Instrument Engineering Workbench</td>
</tr>
<tr>
<td>LSB</td>
<td>Least significant bit</td>
</tr>
<tr>
<td>MSB</td>
<td>Most significant bit</td>
</tr>
<tr>
<td>NA</td>
<td>Numerical aperture</td>
</tr>
<tr>
<td>NI-VISA</td>
<td>National Instrument- Virtual Instrument Software Architecture</td>
</tr>
<tr>
<td>NV</td>
<td>Nitrogen vacancy</td>
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<tr>
<td>PFI</td>
<td>Programmable function interface</td>
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<tr>
<td>PZT</td>
<td>Piezo translation</td>
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<td>QKD</td>
<td>Quantum key distribution</td>
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<tr>
<td>QD</td>
<td>Quantum dot</td>
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<td>SCA</td>
<td>Single channel analyzer</td>
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<td>SPCM</td>
<td>Single photon counting module</td>
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<td>TAC</td>
<td>Time to amplitude converter</td>
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<tr>
<td>TTL</td>
<td>Transistor-transistor logic</td>
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<tr>
<td>VI</td>
<td>Virtual instrument</td>
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<tr>
<td>$n(\tau)$</td>
<td>Number of events</td>
</tr>
<tr>
<td>$P(t, t+\tau)$</td>
<td>Joint photoelectric detection probability density</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Time difference or delay</td>
</tr>
<tr>
<td>$E$</td>
<td>Radiation field</td>
</tr>
<tr>
<td>$I$</td>
<td>Irradiance</td>
</tr>
<tr>
<td>$g^{(1)}$</td>
<td>First order correlation function</td>
</tr>
<tr>
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<td>$N_B$</td>
<td>Number of detections at counter B</td>
</tr>
<tr>
<td>$N_B'$</td>
<td>Number of detections at counter B’</td>
</tr>
<tr>
<td>$N_{BB'}$</td>
<td>Number of coincidence</td>
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<tr>
<td>$P_{act}$</td>
<td>Photons actual count rate</td>
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<td>$X$</td>
<td>Input value in distance (µm) form</td>
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<tr>
<td>$Y$</td>
<td>Input value in distance (µm) form</td>
</tr>
<tr>
<td>$V_X$</td>
<td>Input value in voltage form for X</td>
</tr>
<tr>
<td>$V_Y$</td>
<td>Input value in voltage form for Y</td>
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<tr>
<td>$N_X$</td>
<td>Step input for axis X (in µm)</td>
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<td>$N_Y$</td>
<td>Resolution for axis Y (in µm)</td>
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<td>$S_X$</td>
<td>Total number of scanning points along X axis</td>
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<td>$S_Y$</td>
<td>Total number of scanning points along Y axis</td>
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<tr>
<td>$D_X$</td>
<td>Step input for axis X (in v)</td>
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<tr>
<td>$D_Y$</td>
<td>Step input for axis Y (in v)</td>
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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