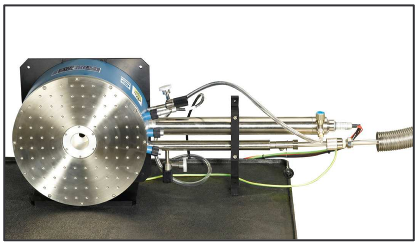
MicrostatMO Evaluation Performed at Oxford University, Clarendon Laboratory



Dr Robert Taylor, Oxford University.

Featured Product: MicrostatMO

Introduction

Dr. Taylor's research is undertaken as part of the Quantum Information Processing IRC (QIPIRC), directed by Prof. Andrew Briggs at the Department of Materials in Oxford. He is looking at InGaN quantum dots, studying dephasing, carrier lifetime and inter-dot interactions. For more details see the project website at www.qipirc.org. He also works on dots made from InGaAs, which emit in the infrared. These dots are registered optically and then placed in cavities formed by using photonic bandgap structures, also as part of the IRC in quantum information processing.

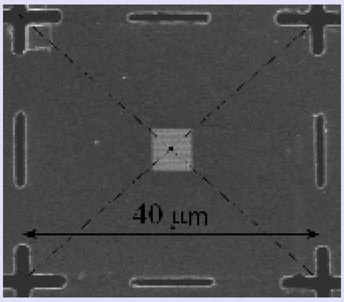


Figure 1: Registered single quantum dots with a photonic crystal cavity written around it.

Typically these experiments involve the use of micro-photoluminescence techniques to investigate the emission of single photons from a variety of quantum dot-like structures. He has looked at properties of InGaN quantum dots in particular using time-integrated and time-resolved spectroscopy. The application of electric and magnetic fields enables a further understanding of the quantum states in these dots.

Dr Taylor has carried out an evaluation of the MicrostatMO system which provides a low temperature/magnetic field sample environment with optical access suitable for quantum dot measurements.

Overview of the MicrostatMO

The MicrostatMO is a compact cryostat, which provides a cryogenic environment ideal for sensitive optical and electrical measurements in magnetic field. This cryostat provides good spacial stability, easy integration with optical components and is also ideal for quick electrical sample characterisation.

Dr Taylor performed a series of measurements to characterise the performance of the MicrostatMO within an optical system designed for quantum dot research. Overall the results are very positive.

Sample Position Stability Measurements:

A) Without magnetic field:

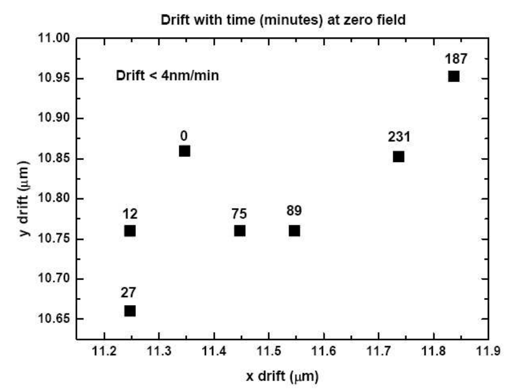


Figure 2

Once stable the sample moved by less than 240 nm/hr.

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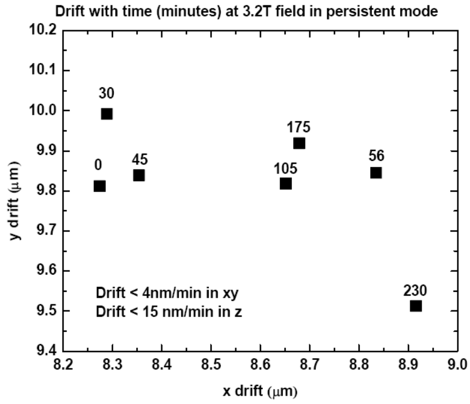


Figure 3

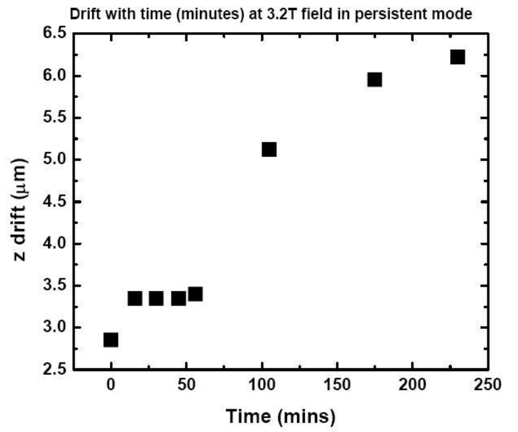


Figure 4

b) With magnetic field

The z axis is defined as the magnetic field direction and optical access direction; therefore the transverse x and y axes are in the plain of the sample mount surface.

In field, with current in the magnet leads:
The measured drift figure was
< 20nm/min in x or y directions
<30nm/min in z directions.

In field, with magnet in persistent mode: (fig 3 and 4)
The drift figure was
4nm/min in x or y direction
<15nm/min in z direction.

The z direction stability tends to be worse as there is a force in the z direction due to magnetic field interaction effects with the surroundings, e.g. steel optical bench. This is less of a problem optically, as the depth of field in the z direction is such that a movement of 300nm or so would be required to see significant differences in this direction.

Drift at these levels did not interfere with the experiments. Measurements with field present were taken ~2hrs after re-cooling sample from ~40K (magnet left overnight with reduced flow).

As can be seen from the measurements sample drift tends to increase when the magnet is held at a given field using the power supply. Sample drift is greater still whilst the magnet field is ramping.

Vibration Measurements:
No adverse effect due to vibration could be observed on an optical scale (within an optical wavelength). All the measurements were made with the vacuum pump and air conditioning switched off.

Details of the measurement technique:
An InGaN masked quantum dot sample was mounted on the sample holder. The mask was illuminated from the back using a white LED. An EPI L-plan APO 50x long working distance objective (11mm working distance, 0.4 NA) was used to image the sample, focus the pump laser and collect the luminescence. An image of the masked sample, showing the dimensions of the mask is shown in figure 5.

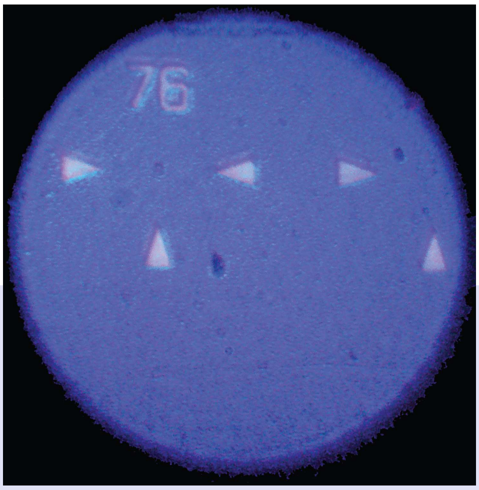


Figure 5. Image of the back-illuminated InGaN dot sample. The Al mask has arrows set in a square of dimension 50 microns from the tip of the arrows. The small feature at the centre is a 1 micron aperture, through which the sample was excited. The objective was a 0.4 NA 50x L-plan APO lens. The sample was in a flux density of 3T and was at nominally 4.5K (measured on the sample platform heat exchanger). A 1 µm hole can be seen at the center of the 3 arrows labelled 76.

The objective was mounted to the magnet cryostat using a Melles Griot piezo-driven xyz stage (17 MAX 301), and the position controlled and monitored by computer using a Melles Griot controller (17PCZ013). These components seemed to operate perfectly well with the magnet set at 5T. The luminescence was focussed into a 0.3m spectrograph and the spectrum measured using a cooled CCD (Andor Shamrock 303i spectrograph and Andor DU420-BR-DD-999 CCD).

Figure 6 shows a spectrum taken of several dots emitting from a 1 micron square aperture on the mask.

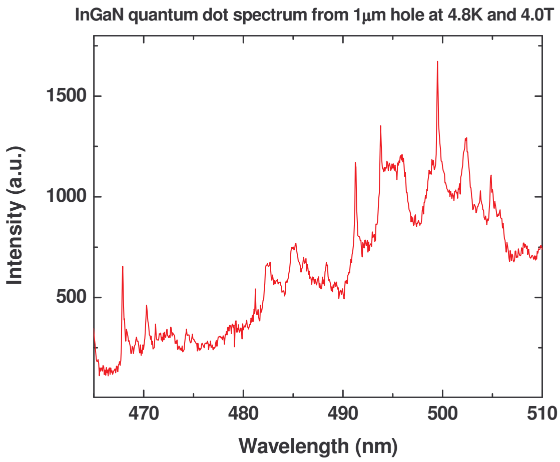


Figure 6. Emission form several single dots in a 1 micron window. The sample was illuminated using two-photon excitation at 810 nm by 1ps Ti:sapphire laser pulses.

The sample was nominally at 4.8K (measured on the sample platform heat exchanger) and the flux density was 4.0T. The exposure took 30s – no measurable drift occurred in this time. The drift was determined by scanning the objective whilst monitoring the emission from a single dot. A Gaussian intensity profile is produced, and the centre can be determined accurately. The position of the centre of the Gaussian as a function of time was then recorded, both at zero field and at 3.27T in persistent mode.

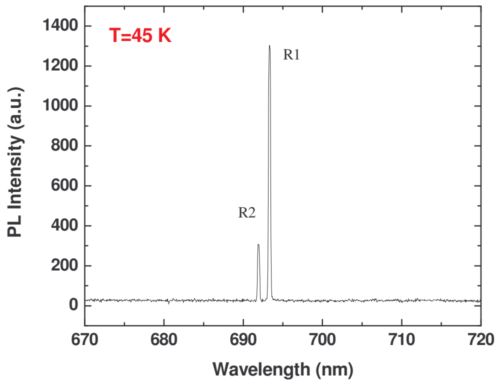
Sample Temperature calibration:

The sample was grown on a sapphire substrate. All sapphire (Al_2O_3) contains some Cr which has a well defined emission line at around 694nm (ruby). The exact location of the line is well characterized as a function of temperature. So this line was used to precisely define the temperature of the sample carrier.

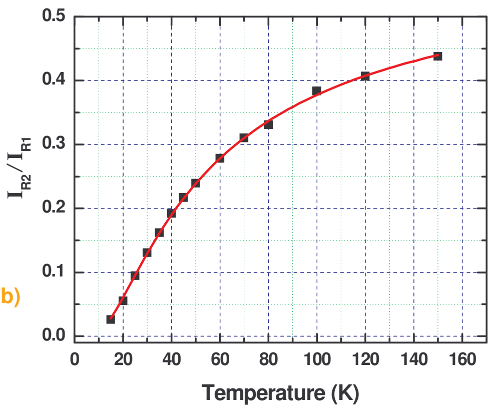
The sample and sensor (at the heat exchanger) temperatures agreed within the uncertainty in the measurement of the chromium intensity - i.e. around 1K above 10K. (absolute calibration not possible below this). Note that the sample that was used had a very good thermal conductivity.

Factory measurements at base temperature suggest sample is ~2K above the heat exchange temperature at 4.5k.

Figure 7a shows the spectrum obtained by illuminating the sapphire substrate of the sample at 45K using a CW 532nm beam. The chromium impurity ions emit on two lines, whose relative intensity is determined via Boltzmann statistics. The relative intensity is shown in figure 7b. Using this data the temperature of the sample was checked and compared it to that read on the temperature controller, no difference was found within the accuracy of the measurement (+/- 1K).



7a)



7b)

Figures 7a: Relative intensity of two chromium lines at 45K. This intensity ratio can be used to measure the sample temperature accurately as shown in the curve in **Figure 7b**.

General Comments:

- It took 6 hours to get the system cold and stable. But then the system was left cold overnight which hardly used any helium, by reducing the flow to a minimum, and was able to get to base temperature the next morning in less than an hour.
- It takes less than 2 hours to change the helium Dewar if necessary.
- A pump was used to reach temperatures down to 50K faster, then the system was used in push mode; i.e. with just a pressurised 4He storage dewar.
- Only 8 minutes were spent realigning the optics between temperature and magnetic field set points.

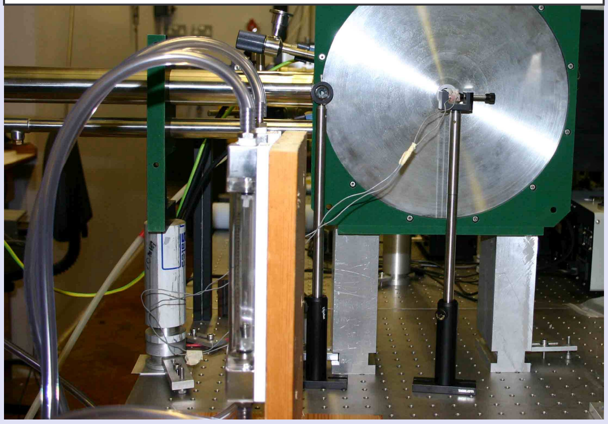
Conclusion

The results were very positive. The drift/vibration measured was very low. In magnetic field, the figures were higher but still low enough not to cause any problems during measurements. The system was very easy to use.

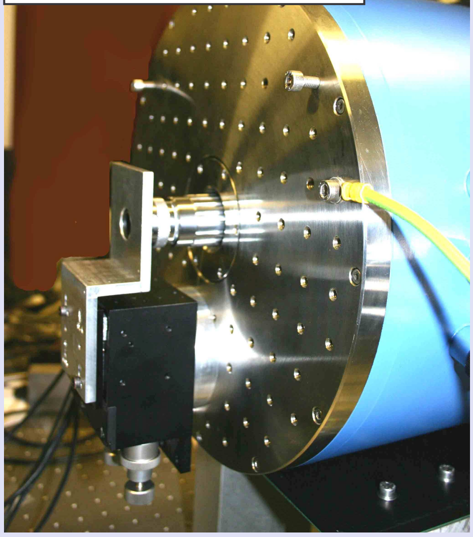
The MicrostatMO was used in the z axis horizontal orientation as it is easier to set-up the optical components this way. The sample holder equipped with electrical connections would be suitable for a wide range of applications.

The system was used in push mode and the lowest temperature observed on the sample platform heat exchanger was 4.5K.

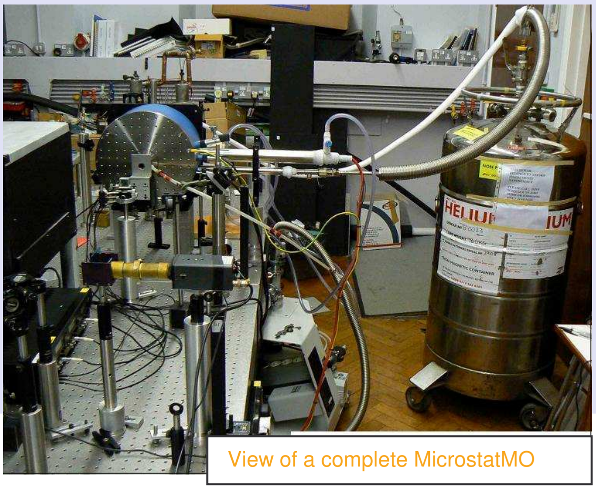
Pictures of the Optical Set-up:



View of the MicrostatMO from the back. The aluminium stands were made by Robert Taylor himself in a workshop. Note the white LED used for illumination.



Close up of the MicrostatMO top plate fitted with microscope objective and piezo.



View of a complete MicrostatMO

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