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奈米結構超物質之新穎特性研究(3/3)
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行政院國家科學委員會補助專題研究計畫

■成果報告
□期中進度報告

奈米結構超物質之新穎特性研究

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中文摘要

在這裡我們提出的計畫是奈米科技中一個極富挑戰性的新課題---「奈米結構的群體效應(Collective behavior)和崁入人造奈米物件後的新材料研究」。**超物質(metamaterial)是一種人造結構的混合材料。這種材料具有許多自然界中沒的特性。結合了奈米科技，超物質將更能展現其優異的性質。**這些特質包括負折射係數，包括負折射係數、電磁波和聲波的傳輸間隙、電漿頻率的巨大減少、磁性材料的異常電磁響應，…等。結合奈米結構的超物質是一項新的研究領域。它存在著很大的挑戰。如何將理論的設計整合到實際的應用中，是一個極待解決的課題。我們的挑戰，包括：(1)結構與特性的關係和光譜響應的測定，特別是當超物質的基本構成物質是小到奈米尺寸的結構時(2)在可選用的設計中，確認可以快速製造和標準化的設計，(3)測定控制效能(損耗)的因素。

最近半導體科技的發展使得製造人工半導體超物質成為可能。這些新的材料可以由非常小的奈米結構所構成。奈米結構半導體超物質可以使其電磁響應的範圍落在可見光的區域。這對於實際的元件應用有很大的好處。超物質的發展有趣但是困難的原因在於它本身位於物理與技術的十字路口。需要兩者密切的搭配才能達成；最終的成功不僅需仰賴對於材料本身及其結構的全盤了解並且同時需要一個結合奈米科技及當代最先進的特殊技術的科技。我們這裡所提出的計畫就是要抓住利用奈米結構所建構的超物質的最關鍵議題。

我們提出的半導體超物質計畫是一個結合理論學者、物理學家和技術工程人員的共同研究計畫。我們的研究團隊，將不同領域、不同才能的人結合在一起，從不同的角度探討問題的所在。這個計畫由四個分離但息息相關的部分所組成：(1)由奈米結構所成長與製造的超物質，(2)在微波和光學系統中，材料的特性和新穎的應用，(3)在低溫高磁環境下超物質的光學研究，(4)崁入奈米物件系統之光學響應的理論研究。我們的計畫，建構在數個本世紀最重要的奈米、材料、及光學技術之上。 理論上我們已經預測半導體量子環有可能成為在可見光範圍的左手物質。藉由此計畫我們將嘗試在實驗上予以實現。

本計畫的實驗將得到交大奈米科技中心的全力支援。許多研究將在奈米科技中心的實驗室完成。交大奈米科技中心已承諾在儀器的使用，新技術的開發以及人力與物力上全力的配合。它的commitment將是本計畫成功的一大關鍵。

我們計畫中的一些重要的技術目標有：

- 演驛砷化銦、銻化銦和銻化鎵結構的量子點和量子環崁入到各式不同的主材料中。
- 針對由半導體奈米物件所製成的人工超物質做多角化的研究。
- 了解並控制半導體奈米物件結合於半導體奈米結構超物質系統之電、磁和磁光特性。
- 對於由半導體奈米物件所製成之新的超物質發展包括量子和光學非局化效應的量化描述。
- 發展並完成橢圓儀量測、直接的磁性量測和利用近場顯微鏡在低溫高磁系統中針對超物質的光學研究。
- 發展積體雷射和利用於慢速光元件的光子晶體結構。
- 藉由半導體奈米結構研發可見光範圍之左手物質(left handed material)。

(KEYWORD：超物質，光子晶體，磁光)

計畫英文摘要

Executive Summary

The proposed program presented here targets one of the most exciting and challenging fields in nanotechnology – the collective behavior and functionality of materials with embedded artificial nano-objects. Artificial semiconductor metamaterials can be constructed from very small objects, typically a few tens of nanometers in size. Unlike some the metamaterials that have been developed, nano-structured semiconductor metamaterials, because of the small size of the nano-objects, potentially can manipulate electromagnetic fields in the optical regime. The proposed program is designed to tackle the most critical issues of metamaterials built from nanostructures.

Here we proposed a tightly coupled multidisciplinary investigation of metamaterials. The combined and diverse talents of this team will enable us to tackle the problem from different angles. This project is made up of four separate but strongly related parts: (1) the growth and fabrication of metamaterials from nanostructures (2) material properties and novel applications in the areas of RF and optical systems (3) optical study of metamaterials at low temperature and high magnetic field environment (4) theoretical investigation of optical response of systems with embedded nano-objects.

Some key technical goals and operational features of our plan are:

- Demonstration of growth of InAs, InSb and GaSb quantum structures like quantum dots and quantum rings embedded in various kinds of host materials
- Perform a multilateral study of artificial metamaterials made from semiconductor nano-objects
- Understand and control electrical, magnetic and magneto-optical properties of systems of semiconductor nano-objects combined in semiconductor nano-structured metamaterials
- Develop quantitative description of new metamaterials built from semiconductor nano-objects including quantum and optical non-locality effects
- Perform and develop ellipsometry measurement, direct magnetism measurement and optical study with SNOM for the metamaterials in the cryogenic system
- Development of integrated QD laser and photonic crystal structure for slow light devices
- A team of researchers who have substantial research experience in their respective fields and have a demonstrated commitment to collaborative research

(KEYWORD：Metal Material, Photonic Crystal, Magneto-Optical)

前言

What is a “metamaterial’? In recent years, there has been a growing interest in the fabricated structures and composited materials that either mimic known material responses or qualitatively have new, physically realizable response function that do not occur or may not be readily available in nature. The unconventional response functions of these metamaterials are often generated by artificially fabricated inclusions or inhomogeneities embedded in a host medium or connected to or embedded on a host surface. Exotic properties for such metamaterials have been predicated; many experiments have confirmed our basic understanding of many of them. The underlying interest in metamaterials is the potential to have the ability to engineer the electromagnetic and optical properties of materials for a variety of applications. The impact of metamaterials may be enormous: If one can tailor and manipulate the wave properties, significant decreases in the size and weight of components, devices, and systems along with enhancements in their performance appear to realizable.

Recent technological progress in semiconductor technology made it possible to fabricate artificial semiconductor metamaterials. Those new materials can be constructed from very small objects, typically a few tens of nanometers in size. Nano-structured semiconductor metamaterials potentially can manipulate electromagnetic fields in optical range, which is particularly beneficial for potential applications and devices, as well as for new basic science. The reason that metamaterials development is interesting but difficult is that it is at the cross road of physics and technology. Its eventual success is dependent upon our thorough understanding on material itself and at the same time a viable technology that combines the nanotechnology with state-of-the-art characterization techniques. The proposed program is designed to tackle the most critical issues of metamaterials built from nanostructures.

研究目的及文獻探討

The pursuit of artificial materials for electromagnetic applications is not new; this activity has a long history which dates back to Jadagis Chunder Bose in 1898 when he worked and experimented on the constructed twisted elements that exhibit properties nowadays known as chiral characteristics. In the early part of the twentieth century, Karl Ferdinand Lindman studied wave interaction with collections of metallic helices as artificial chiral media. Articificial dielectrics were explored, for example, in the 1950s and 1960s for lightweight microwave antenna lenses. Artificial chiral materials were investigated extensively in the 1980s and 1990s for microwave radar absorbers and other applications. The development of electromagnetic bandgap (EBG) structured materials and single-negative (SNG) and double-negative (NDG) materials and their fascinating properties have driven the recent explosive interest in metamaterials.

The proposed program presented here targets one of the most exciting and challenging fields in nanotechnology – the collective behavior and functionality of materials with embedded artificial nano-objects. Examples of such properties include negative refractive index and transmission gaps for electromagnetic and acoustic waves, colossal reductions in the plasmon frequencies, and magnetic responses in composites made out of nonmagnetic constituents, etc.. The aim of metamaterials development is to propose, fabricate and characterize novel periodic configurations of available materials for achieving new media with desired figures of merit. However, most of the designs are still in the stage of theory and there is a big challenge to integrate them in real applications. Some of the challenges that lie ahead are: (1) determination of the structure-property relationships and spectral responses, particularly as the metamaterial building-block sizes shrink to the nanoscale, (2) identification of options for rapid fabrication and prototyping, and (3) determination of the factors that control the performance (losses).

研究方法

In the following we divided our research approaches into five major classes of metamaterials: **A.** Ellipsomery measurements on embedded semiconductor nanostructures, **B.** Temperature dependence of time-resolved photoluminescence spectroscopy in InAs/GaAs quantum ring, **C.** Spectroscopy of single quantum dot **D.** Nanocavity with square lattice photonic crystal **E.** Magneto-optics of layers of double quantum dot molecules

A. Ellipsomery measurements on embedded semiconductor nanostructures

I. Low Temperature and High Magnetic Field Spectroscopic Ellipsometry System (system design)

Ia. Description of the complete system

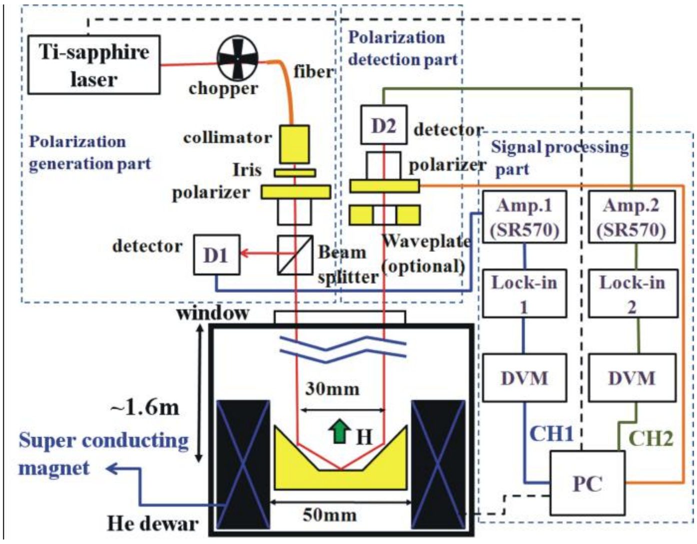
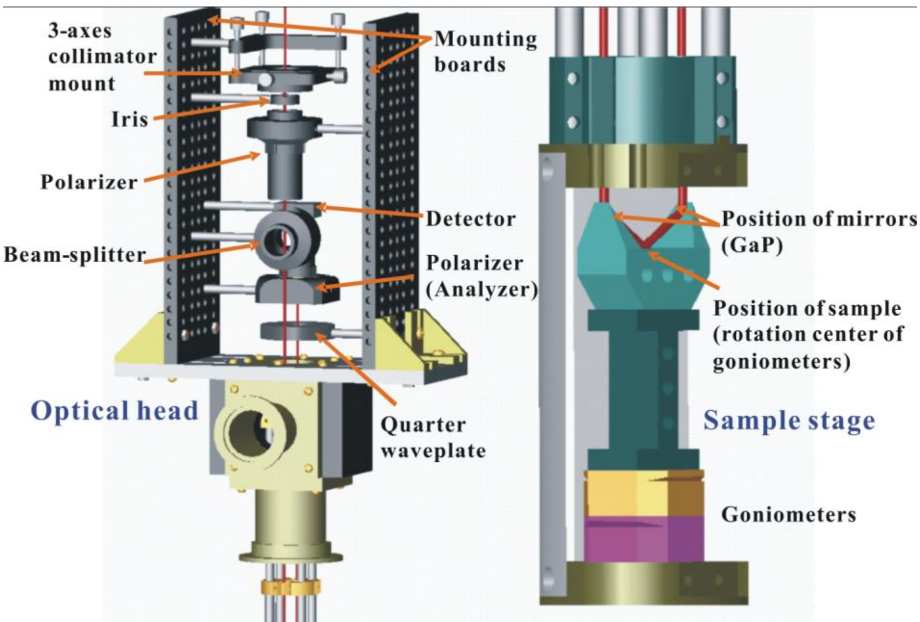


FIG 1

Figure 1 shows the complete schematic diagram of the ellipsometry system, consisting of the polarization generation part, the polarization detection part, the signal processing part, and the cryogenic dewar together with the sample and two dielectric mirrors in a low temperature environment. We use a Ti-sapphire laser as the optical source which operates in the wavelength range of 700nm to 1000nm. The laser is coupled into a 10-m long single mode fiber with a collimator attached at the end. The light out of the collimator having a deviation angle less than 0.03 degree passes through a Glan-Laser calcite polarizer to generate a known linear polarization state. One of the laser beams being branched out by the beamsplitter is detected by a silicon photodiode detector (D1) to monitor the polarization and intensity fluctuation, and the other beam is guided into the cryogenic dewar through a window. The incident beam is reflected by a dielectric mirror (GaP) before reaching the sample. The outgoing beam is also reflected by another dielectric mirror and then goes to the polarization detection part, which includes a quarter waveplate, a rotating analyzer, and a silicon photodiode detector (D2). The photocurrents are measured by current pre-amplifiers and lock-in amplifiers in the signal processing part. All the three reflections, two from the GaP mirrors and one from the sample, have a 60° incident angle and share the same incident plane, making the ingoing beam and outgoing beam be exactly parallel to each other.



Ib. Mechanical design

FIG 2

Our ellipsometer designed as an insert for the Oxford dewar is shown in Fig.2. Here, we focus on the mechanical design for the purpose of light path alignment at low temperature and in high magnetic fields. Due to the geometry of the Oxford dewar, the space of the center of the magnet is only 5cm, which limits the distance between incoming and reflected beam and the size of sample stage. Because the length from the top of the dewar to the magnet center is 135cm, very long light path is demanded. The subject, therefore, has been to make a small, long and rigid structure without any magnetism material used. The mechanical support structure of this insert was made by four thin wall stainless steel tubes fixed by screws from different directions through the holes of designed plates. This structure could avoid bending of steel tubes and suppress vibration.

The bottom of insert, shown in Fig2., includs housing, sample stage, and two-axes piezoelectric goniometers which are all made by titanium due to its small expansion coefficient. At the boundary of two different materials, we use beryllium-copper spacer as the buffer to reduce deformation due to non-equivalent shrink at low temperature. Because this very long light path, we need to tilt the sample stage very precisely and instantaneously. We mount our sample stage on the controllable goniometer and the location of sample is just at the center of rotation of these two axes goniometers to avoid displacement.

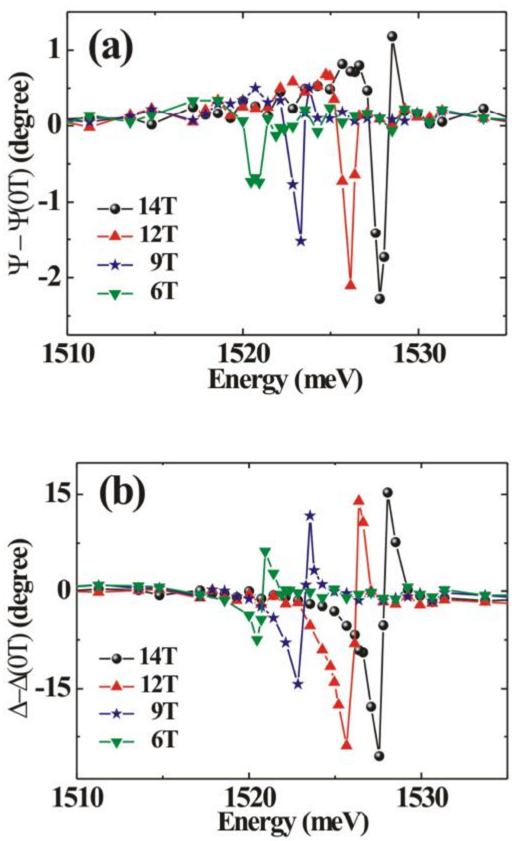
In a real measurement, a thin wall stainless steel jacket was added to form a close space. For connection the insert and the outer jacket, we used screws and nuts to fine tune the skew of jacket relative to the insert and made sure no contact between them.

II. Measurements and Discussions

We have first applied the low temperature and high magnetic field ellipsometry system to characterize the properties of intrinsic GaAs near band edge and to focus on the variation under different magnetic fields. For this measurement, we choice semi-insulating GaP as the dielectric mirrors duo to the larger band gap than GaAs, not very small refractive index, and no significant response when magnetic field applied. These two GaP side mirrors and GaAs sample was mount to sample stage carefully by N-grease. Because of the different thickness of GaP and GaAs, a slide was put in the bottom of GaAs.

After sample preparation, the alignment procedure was carried out by fine tuning the three axis collimator mount on the top of the optical head (see Fig.2) for input light and the two axes piezoelectric goniometers in the bottom of sample stage (see Fig. 2) for reflected light. Then, the insert was sealed by outer jacket with o-ring and screws. Before inserting into low temperature dewar, the pressure inside the jacket was pumped to $\sim 5\times10^{-5}$ mbar and inflated a little Helium gas (~25mbar) as exchange gas. The insert was put into low temperature dewar slowly and the reflected light signal was adjusted instantaneously by goniometers during lower temperature.

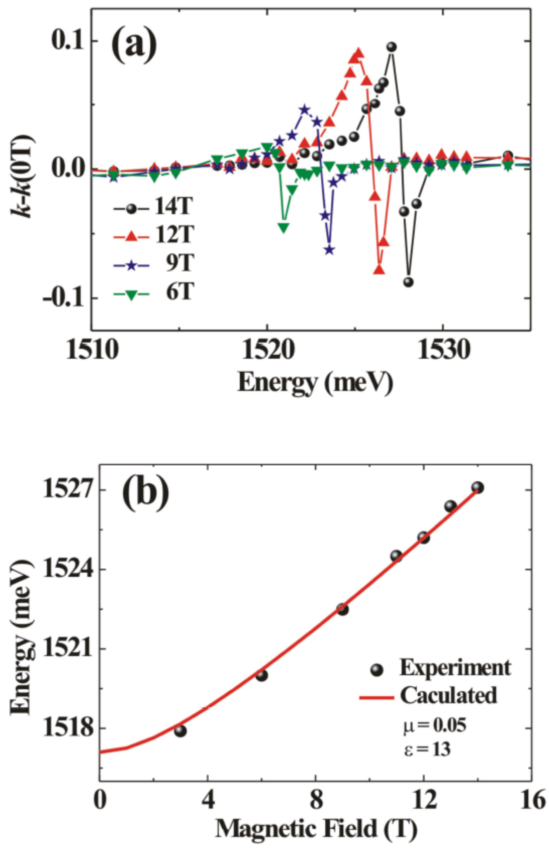
The performance of this system at low temperature was test for 100 times, and the standard deviation of Ψ and Δ were about 0.1° and 0.2°. This test ensured acceptable stability of sample stage at low temperature, although the helium level was not invariant for a long time measurement.



The obtained Ψ and Δ at stable temperature 4.2K from 0 to 14 Tesla in the energy range 1.510 to 1.535 eV are shown in Fig.3 (a) and (b) for taking 0 T data as reference. The peaks shift to higher energies and become stronger when the magnetic field is increased. This is due to the diamagnetic effect of the excitons and the increased oscillation strength with larger magnetic field confinement.

The real part and the imaginary part of the refractive index, *n* and *k*, can be converted from the obtained Ψ and Δ using equation:

$$N_1 = N_0 \tan\varphi_0[1 - \frac{4\rho}{(1+\rho)^2}\sin^2\varphi_0]^{1/2}, N_i = n_i - jk_i \qquad (1)$$



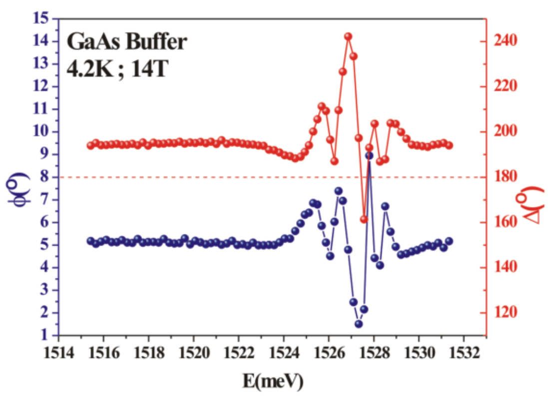
Here, i=0 represents real space, i=1 represents GaAs. φ_0 is the incident angle. Equation (1) can be derived directly from Snell's law. Fig.4 (a) shows the k value as a function of energy from 0T to 14T (0T as reference). Fig.4 (b) shows the position of the observed peaks as a function of the magnetic field. Very nice diamagnetic shift behavior was observed. The amount of diamagnetic shift depends on the radius of the magneto-excitons and can be obtained by simply solving the Schrödinger equation for a ground state exciton under magnetic field

$$\{\frac{-\hbar^2}{2\mu}\nabla^2 - \frac{e^2}{4\pi\varepsilon|\vec{r}_e - \vec{r}_h|} + \frac{e^2B^2}{8\mu}(x^2+y^2)\}\Phi_{ex} = E\Phi_{ex}$$

(2)

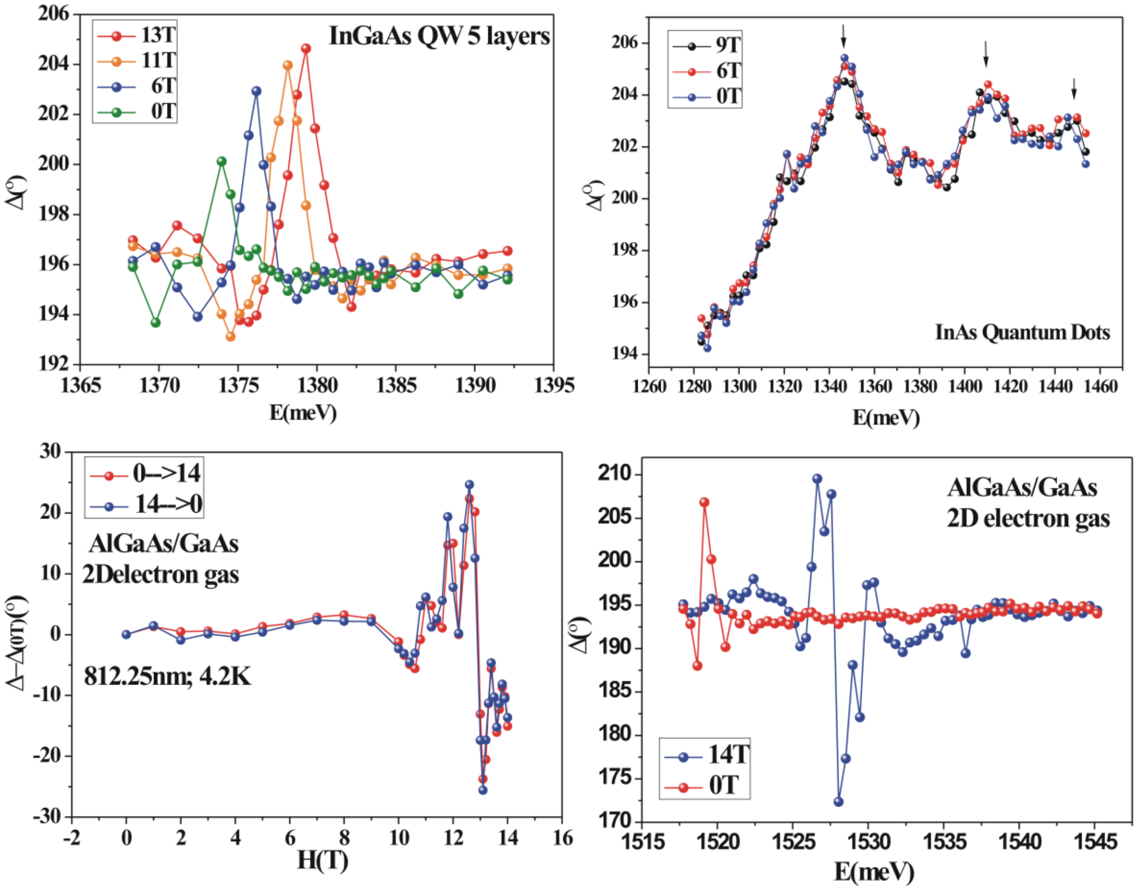
Here μ is the electron-hole reduced mass of the exciton. The calculated ground state energy as a function of the magnetic field along with the experimental data is shown in Fig.4 (b). The reduced mass used was 0.05me and the dielectric constant was 13. Excellent agreement was obtained between the calculated and the experimental results. It is suggest that this observed transition peak is the electron/heavy hole ground state exciton. However, the difference of ellipsometry technique between other measurements is that ellipsometer measures a region very close to the surface, the surface states are expected to show up in the absorption spectrum. The asymmetric shapes of these transitions are likely due to the Fano resonances which caused by the interference of discrete exciton state and the continuum suface states. The background absorption tails into band gap showing no sharp absorption difference at the band edge, which is also given rise to the surface states.

Besides intrinsic GaAs substrate, we have also measured 1 μm undoped GaAs buffer layer growth on the intrinsic substrate by MBE. The multi-peaks configuration has been observed when high magnetic field applied, however, it is not clear for the physics of multi-peaks now.



We have also measured nanostructures, for example, InGaAs quantum wells, InAs quantum dots, and AlGaAs/GaAs two dimension electron gas. The data are shown in figure. More theoretical work will be put in for investigating the physical meaning behind these measurements.

In



summary, we have developed and demonstrated the first ellipsometry system that can be manipulated at 4.2K and in magnetic fields up to 14 Tesla. This system provides a means of studying the collective optical behavior of bulk, layered, nano-structured material under high magnetic fields and at low temperatures.

B. Temperature dependence of time-resolved photoluminescence spectroscopy in InAs/GaAs quantum ring

We observe the strong dependence of photoluminescence decay time on the temperature in both the excited and ground states of QRs. A rate equation model is proposed and is found to agree well with the PL dynamics observed.

The GaAs QDs sample studied in this work were grown on GaAs (001) substrates by molecular beam epitaxy. The QDs were formed by depositing 2.6 monolayers of InAs with a growth rate of 0.056 μm/hr at a growth temperature of 520 ℃ under As_2 atmosphere. QDs have an average base diameter of about 20 nm and a height of 2 nm. For the preparation of QR samples, after dot growth was completed, a thin partially capping layer of 2 nm was deposited on the dots with a 1 μm/hr growth rate at 520 ℃. Followed by an annealing process under As_2 flux from 5 seconds to 30 seconds at the same temperature, the QD structures can be transformed into ring (QR) structures after the annealing processes. Figure 1 (a) and (b) shows the AFM images of samples with nanostructures of QDs and QRs. The QD and QR samples have areal densities of ~ $3.4\text{x}10^{10}$ cm^{-2} and $2\text{x}10^{10}$ cm^{-2}, respectively. The final QR shape has a base with of ~ 60 nm, a height of ~ 1nm, and an inner diameter of 30 nm. Figure 1(c) shows the XTEM image of the QR sample. The QR appears as two dark-gray lobes (InAs rich) corresponding to a cut through the middle of the ring. The sizes determined by XTEM matched AFM results.

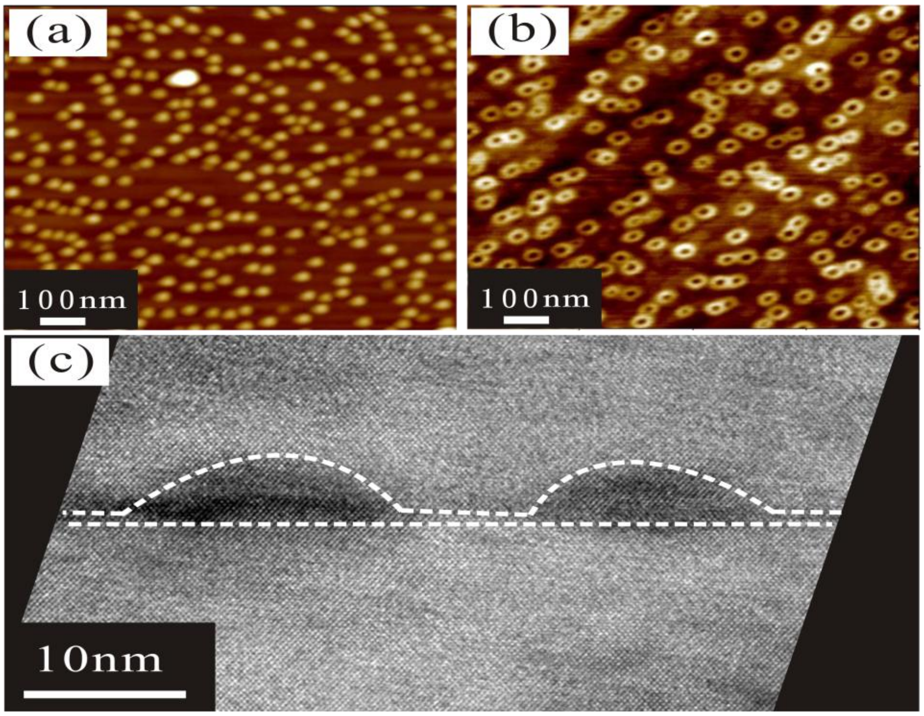


Figure 1 Atomic force microscopy images of (a) QD, (b) QR and (c) cross-section transmission electron microscopy image of QR.

We performed time-resolved measurements for the above samples under nonresonant excitation in the GaAs barrier. The sample was placed in a closed-cycled helium dewar. A diode-pumped Ti:sapphire laser was used to excite steady-state photoluminescence (PL). The signal was dispersed by a 0.18 m double spectrometer and detected by a TE-cooled InGaAs photodetector. For the time-resolved measurements, a pulsed diode laser was used as the excitation source at a wavelength of 635 nm. The pulse duration was 50 picosecond with a repetition rate of 5 MHz and an excitation density in the range of 1-100 W/cm^2. The time-resolved PL signal was analyzed with a 0.55 m spectrometer and detected by a micro-channel photomultiplier with a time correlated single photon counting setup. The overall spectral resolution and system response were 0.1 meV and 300 picosecond.

The ground state energies of the QD and QR are 1.21 and 1.25 eV at 15 K, respectively, as shown in Figure 2(a) and 2(c). The barrier and wetting layer emission are observed clearly at around 1.51 eV and 1.43 eV for both samples. More information can be obtained following the PL excitation density dependence for each sample. The state filling of the excited state transition can be observed for the QRs by increasing the pumping power. We can identify the contributions to the PL of QR's first and second excited states at 51.5 meV and 94.6 meV above the ground state, respectively.

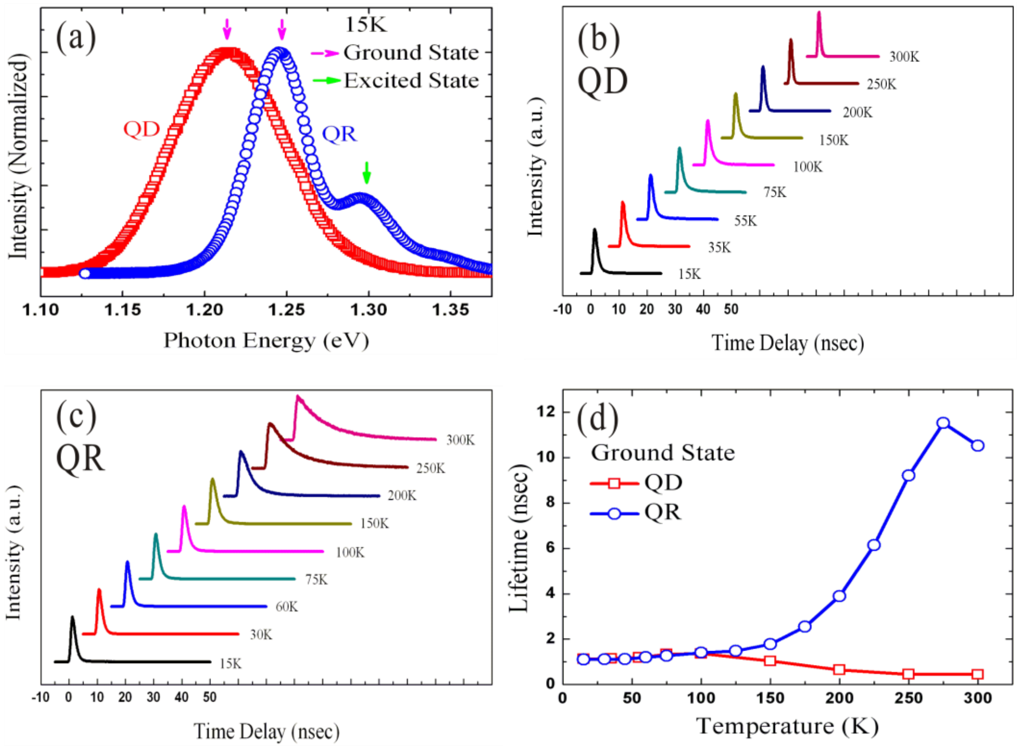


Figure 2 CW PL spectra of (a) QDs and (c) QRs from T = 15 K to T = 300K. PL transient from T = 15 K to 300 K at ground state energy of (b) QDs and (d) QRs. Detection energies of time-resolved spectra were fixed at PL peaks indicated by the dots shown in (a) and (c) at all temperatures.

Figures 2 (b) and 2(d) show the temperature evolution of the PL transient at ground state energy from T = 15 K to T = 300K for the QD and QR samples, respectively. The detection energies were always fixed at the PL peaks at different temperatures, as indicated by dots shown in Figure 2(a) and 2(c). A fast rise time of the order of instrumental resolution indicates that there is no phonon bottleneck effect in both samples. The experimental transient decay curves do not reveal saturation effects at a low excitation power as used here and can be described by single exponential functions. The decay time of the QD ground state was about 1.1 ns at a low temperature, which dropped to less than 0.5 ns when the temperature reached 300 K. Surprisingly, the temperature dependence of the decay time behaved quite differently for QR structures. For example, the decay lifetime of QRs became longer with the increasing temperature and reached 10.5 ns at room temperature. In Figure 3(a), we plotted the temperature dependence of the decay time for both samples. It is clear that at temperature above 150 K, the exciton dynamics change dramatically in the QRs. In Figure 3(b) the temperature evolution of the PL transient at the excited states of QRs also shows similar behavior.

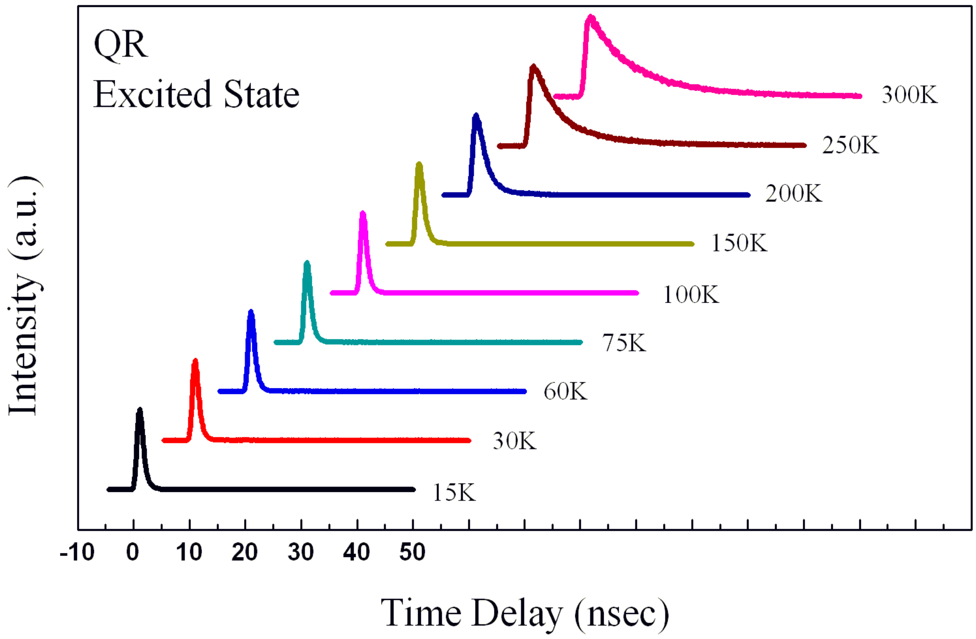


Figure 3 (a) Temperature dependence of the photoluminescence decay time of QD and QR ground states. (b) PL transients from T = 15 K to 300 K at first excite state energy of QRs. Detection energies were fixed at excited state peaks as indicated by the dots shown in Figure 2(c) at all temperatures.

The behavior of the excitons at a high temperature deserves greater attention. Its origin is possibly due to the thermal population of dark states (states that can neither be accessed by absorbing photons nor relax to other energy states non-radiatively), competing with the exciton radiative recombination ground state. It has been argued that due to the presence of piezoelectric/strain potential and a large asymmetry in the ring profiles, there is reduction in the overlap between the electron and hole wave functions [18, 21]. Such separation causes a reduction in exciton oscillator strength, and a longer decay time is expected for ring structures. We speculate that, at a temperature above 150 K, the electrons and holes tend to occupy states with reduced wavefunction overlapping, which leads to the slowing down of PL decay time in QRs.

The energy level scheme representative of our proposed model is depicted in Figure 4. By using a simplified two-level model (as shown in the inset of Figure 4), the temperature dependence of the decay time curve of QR can be fitted quite well with parameters ΔE = 13.5 meV and τ' = 0.7 ns (energy separation and relaxation time between the dark state and ground state, respectively). The temperature dependence of the PL lifetime agrees well with the proposed rate equation model of the dark state and exciton ground state. At present, an explanation for the dark excited states is still missing and more experiments and detail calculations are required to clarify the issue.

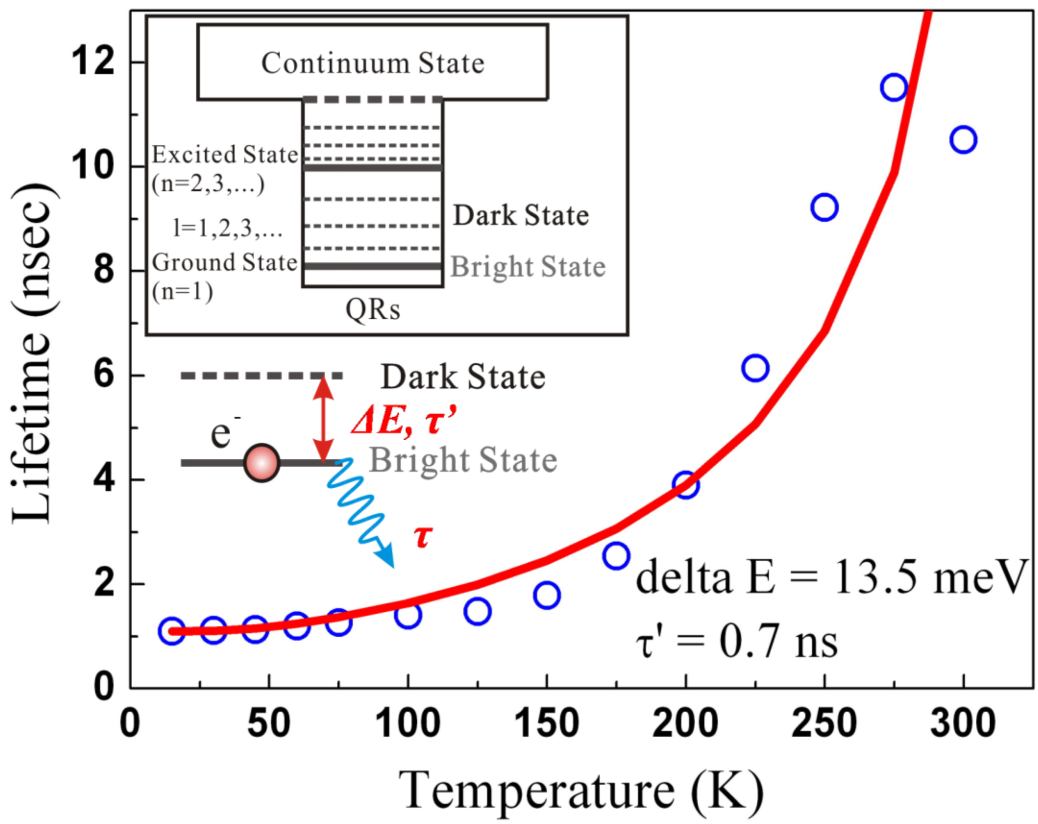


Figure 4 Schematic of the dark states and ground states model and the fitting of QR's decay time curve with a state energy separation of 13.5 meV and relaxation time of 0.7 ns.

C. Spectroscopy of single quantum dot

Unlike single QDs, the *XX* confined in single QRs shows a considerably larger diamagnetic coefficient than the *X*. Guided by numerical model calculations, we found that the inherent structural asymmetry and imperfection, combined with the interparticle Coulomb interactions, play a crucial role in the distribution of *X* and *XX* wave function in self-assembled QRs. Our results suggest that the phase coherence of neutral excitons in QRs will be smeared out by the wave function localization due to the structural asymmetry and imperfections. The InAs QRs were fabricated by Varian Gen-II molecular-beam epitaxy on a GaAs _001_ substrate. Low density QDs were first grown by depositing two monolayers of InAs at 520 ℃ as QR precursors. The substrate temperature was then lowered to 500 ℃. A thin GaAs layer of 1.7 nm was deposited to cover the QD sidewalls, and a 50 s growth interruption was performed for a dewetting process which expels the indium atoms from the center of the QDs to move outwards for the QR formation. Surface topography of uncapped QRs has been investigated by atomic force microscopy. The area density of surface QRs is estimated to be about 1_10^7 cm^{-2}. As shown in Fig. 1, the surface QR has a rim diameter of 35 nm, a height of ~ 1.3 nm, and a center dip of about 2 nm. The realistic dimension of the embedded QRs is expected to be much smaller. We also found that the QR is anisotropic; the rim of the surface QR is highe along.

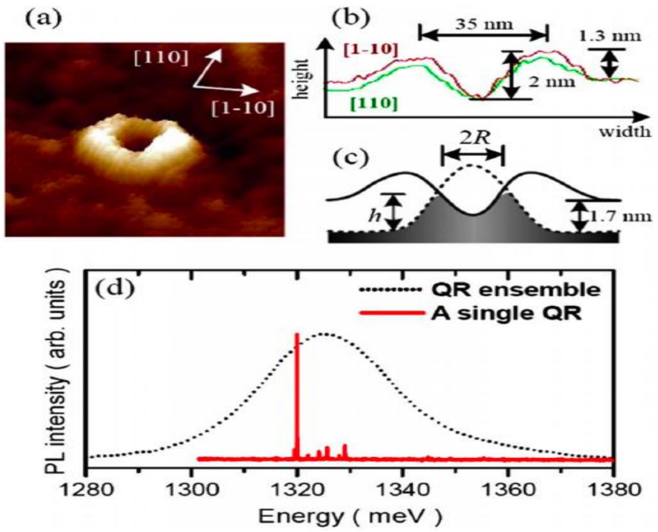


FIG. 1. (Color online) (a) The AFM image of the surface QR. (b) Topographical line scans along the [110] and the [1-10] directions. (c) A schematic for the surface QR profile (solid line), the precursor QD (dash line), and the indium-rich part of the embedded QR (gray part). (d) PL spectra taken from the QR ensemble and from a representative single QR.

The single QR emissions were measured by a lowtemperature microphotoluminescence μ-PL setup combined with a 6 T superconducting magnet. The PL was excited by a 633 nm He-Ne laser, dispersed by a 750 mm monochromator and detected by a silicon charge coupled device camera. An aluminum metal shadow mask with arrays of 300 nm diameter apertures were used to isolate single QR emissions. A comparison between the PL spectra for the QR ensemble and a single QR is displayed in Fig. 1(d). The QR ensemble shows an emission peak at 1329 meV with a line width of 26 meV due to size fluctuations. For the single QR, the spectrum is dominated by a sharp emission line near 1320 meV with a resolution limited line width of 50 μeV.

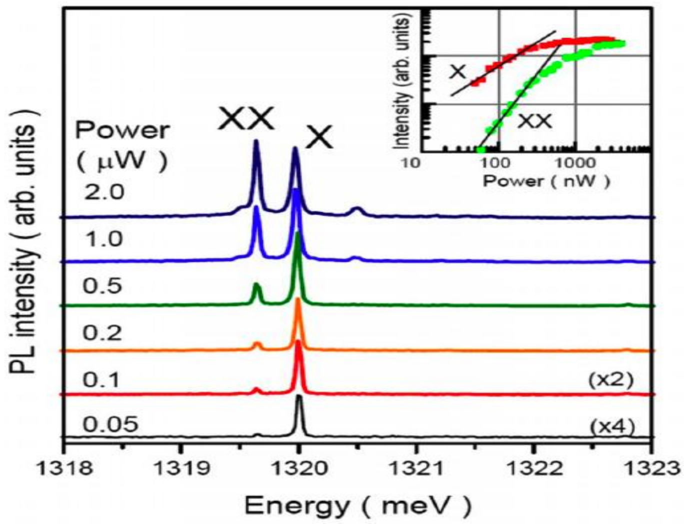


FIG. 2. (Color online) Power-dependent PL spectra of a single QR. The inset shows the integrated intensity of *X* and *XX* lines as a function excitation power.

Figure 2 shows the PL spectra taken from a representative single QR under different excitation powers. Two emission lines associated with the recombination from exciton (*X*) and biexciton (*XX*) states can be observed, which have been identified according to linear and quadratic power dependence of intensity as shown in the inset of Fig. 2. The samemeasurement has been performed on a total of seven QRs. The emission energies of *X* are in the range of 1320–1328 meV, while the biexciton binding energies _defined as ($EX-EXX$) are varying from 0.2 to 0.7 meV for different QRs.

When an external magnetic field is applied along thegrowth direction, each of *X* and *XX* lines splits into a cross circularly polarized doublet due to the spin Zeeman effect, as presented in Fig. 3. Because the exciton state is the final state of the spin-singlet biexciton state, both *X* and *XX* show an identical energy splitting of 131 μeV/T, corresponding to an excitonic *g* factor of |*g*|=2.3, a reasonable value for the InAs nanostructures embedded in GaAs matrix. The average energy of each Zeeman doublet shows a quadratic dependence on *B*, i.e., the diamagnetic shift, which can be fitted to γB^2, where γ is the diamagnetic coefficient. The average diamagnetic coefficient of *X* for all the investigated QRs is γ*X*=6.8 γeV/T2. Interestingly, we found that the *XX* shows a considerably larger diamagnetic coefficient with an average value of γ*XX*=14.8 γeV/T2, which is more than the double of the γ*X* value. The diamagnetic coefficient is proportional to the area of the excitonic wave function. Our results suggest that the *XX* wave function is more extended than that of *X* in a QR. This is different from the case of QDs, where the diamagnetic response of *XX* is usually similar to, or somewhat smaller than, that of *X* due to the different spatial extents of the electron and hole wave functions and their responses to the applied *B*.

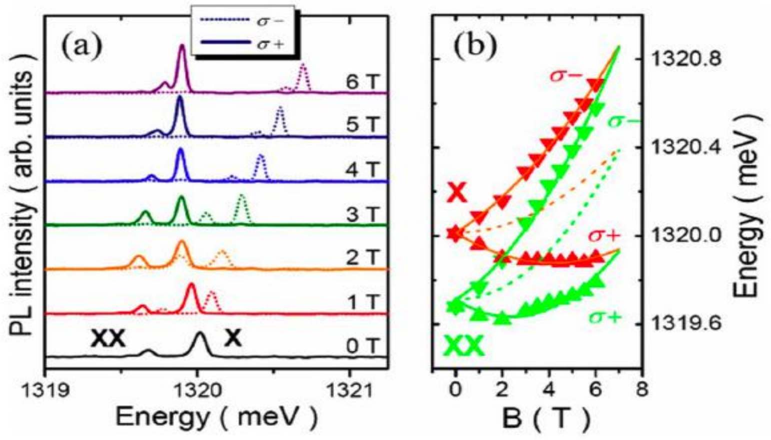


FIG. 3. (Color online) (a) Magneto-PL spectra for *X* and *XX* lines under different magnetic fields. (b) Emission peak energies of the *X* and *XX* Zeeman doublets as a function of magnetic field. Dash lines are quadratic fits to the averages of the Zeeman doublets.

Here we argue that the more sensitive diamagnetic response of *XX* is a consequence of the fact that self-assembled QRs do not have perfect azimuthal symmetry. It has been reported that the structure of buried self-assembled QRs shows an asymmetric craterlike shape, with a diameter substantially smaller than the ring-shaped islands on the surface of uncapped QR structures. In addition, due to the preferential out diffusion of dot material along the direction, the embedded rim height is higher along the [110] direction, resulting in two separate potential valleys along the [110] direction, resembling a pair of connected QDs. The lack of rotational symmetry in the potential of embedded QRs is expected to have significant impacts on the diamagnetic responses of *X* and *XX*. For a neutral *X*, the height variation strongly localizes the hole inside one of the potential valleys due to the large effective mass. Consequently, the electron will be bound to the same valley by the electron-hole Coulomb attraction. This means that the wave-function extent of *X* is determined mainly by the confinement of the potential valley and the Coulomb interaction. Therefore, the diamagnetic response of *X* is similar to an elliptic QD.

For a neutral *XX* confined in the QR, the two holes may be separately localized in different valleys due to the strong hole-hole Coulomb repulsion and the negligible coupling of hole states between the two valleys. Due to the Coulomb attractions of the two separately localized holes, the electron wave functions of *XX* are more likely to spread over the two valleys and become more extended than that of *X*. Unlike *X*, the wave-function extent *XX* is determined mainly by the diameter of the embedded QRs.

In order to further attest our assertions, we performed calculations of the *X* and *XX* states in our QRs based on structural information obtained from our atomic force microscopy topography and the proposed shape of embedded QRs. A one-band effective mass Hamiltonian was used to calculate the single-particle states. The Coulomb interaction between the electron and hole was then treated self-consistently. We model the QR as a nanoscale crater with an azimuthal asymmetric potential $V_H(\rho,\varphi)$ deduced from the *z*-axis quantization energy variation arising from the height anisotropy. The potential can be further simplified to $V_H(\rho,\varphi)= V_0(\rho)\cos 2\varphi$, where $V_0(\rho)$ is proportional to the height anisotropy factor _*h*. Figures 4(b) and 4(c) depict the QR height profile and the corresponding radial potential $V_0(\rho)$ for the electron for a rim radius of *R*=7 nm, an average rim height of h_M=2.5 nm, and an anisotropy factor of ξ_h=0.15. The corresponding maximum V_0 is 19.5 and 9.8 meV at the rim

for the electron and hole, respectively. The calculated electron wave functions for the lowest energy states of *X* and *XX* are plotted in Figs. 4(d) and 4(e), respectively. It can be seen that *X* is well confined in one side of the QR with a less extended wave function. By contrast, the electron wave function of *XX* spreads over both sides of the QR. The diamagnetic response of *X* and *XX* can be further calculated by superimposing a magnetic confining potential to the QR potential. By fitting the calculated energy shift to the quadratic energy dependence _*B*2 as depicted in Fig. 4(f), the diamagnetic coefficients of *X* and *XX* are found to be _*X*=10.7 _eV/T2 and _*XX*=23.0 _eV/T2, respectively. Although the model QR shape may be different from the actual shape of our QRs, our simulations demonstrate unambiguously that the asymmetric potential indeed impacts the diamagnetic response of *X* and *XX*, which agrees very well with
our experimental finding.

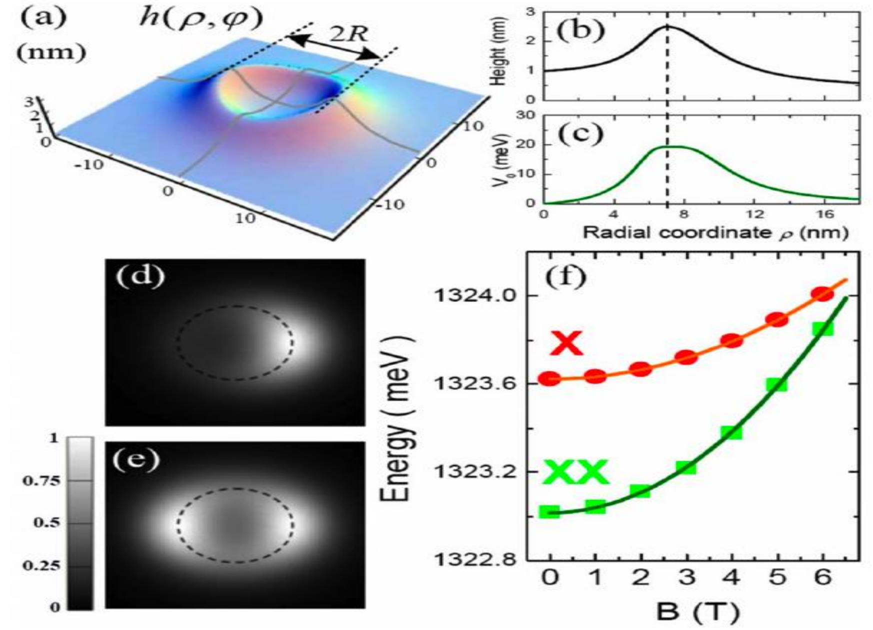


FIG. 4. (Color online) (a) A schematic for the QR geometry with an anisotropy factor ξ_h=0.15 used in our model calculations. (b) and (c) are the height profile $h(\rho)$ and the electron radial potential $V_0(\rho)$ of the model QR. (d) and (e) are the calculated electron wave functions of the lowest *X* and *XX* states. The dash circle represents the rim diameter of 14 nm. (f) The emission energies of *X* and *XX* as a function of *B*. γ_X and γ_{XX} are found to be 10.7 μeV/T^2 and 23.0 μeV/T^2 by fitting to $E=\gamma B^2$.

In brief, the diamagnetic responses of excitons and biexcitons confined in single self-assembled QRs have been investigated. Unlike single QDs, the biexciton confined in single QRs shows a considerably larger diamagnetic coefficient than the exciton, implying the more extended biexciton wave functions in the ring. The lack of perfect rotational symmetry in the potential of embedded QRs due to the inherent structural asymmetry is the fundamental cause of the more extende biexciton wave function. The strongly localized holes in potential valleys of QRs leads to a localized exciton wave function due to the electron-hole Coulomb attraction, while makes the biexciton wave function being able to spread over the ring due to the hole-hole Coulomb repulsion. In other words, the Coulomb interactions combined with the reduced azimuthal symmetry caused by inherent structural imperfection could destroy any of the expected magnetic response that relies on the rotational symmetry of exciton and biexciton wave functions confined in self-assembled QRs.

D. Nanocavity with square lattice photonic crystal

We proposed and demonstrated a point-shifted nanocavity which can sustain a lowest-order WG mode based on square-PhCs. Although the lowest-order WG mode also exists in square-PhC single-defect (*D1*) nanocavity, we show the WG mode in our proposed design here can be with smaller mode volume but larger nano-post tolerance than that in square-PhC *D1* nanocavity.

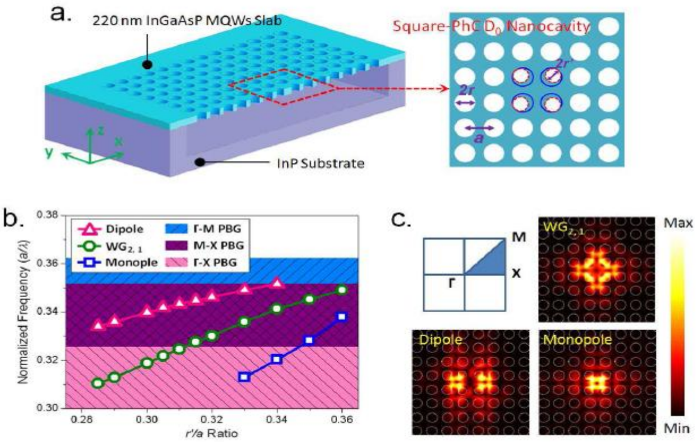


Fig. 1. (a) Scheme of square-PhC D_0 nanocavity on a suspended dielectric slab. (b) The plot of FDTD simulated defect modes frequency versus *r'/a* ratio in square-PhC D_0 nanocavity under fixed *r/a* ratio = 0.38, including dipole (open triangle), $WG_{2,1}$ (open circle), and monopole (open square) modes. *Γ-M* (blue shadow) direction PBG, *Γ-X* (pink shadow) direction PBG, and their overlapped region *M-X* direction PBG (purple shadow) are also shown. (c) FDTD simulated mode profiles in electric field of dipole, $WG_{2,1}$, and monopole modes, which are obtained under *r'/a* ratios of 0.30, 0.30, and 0.35, respectively.

Generally, square-PhC has smaller photonic band gap (PBG) comparing with triangular one. To make sure that the defect modes will be well-confined by the PBG effect, we calculate the band diagram of square-PhC dielectric slab by three-dimensional (3D) plane wave expansion method. The slab thickness and refractive index are set to be 220 nm and 3.4, respectively. The structure scheme is shown in Fig. 1(a). The simulated results indicate that the PBG width increases with *r/a* ratio, where *r* and *a* represent air-hole radius and lattice constant, respectively. For example, the PBG region is ranged from 0.326 to 0.352 in normalized frequency (*a/*λ) under *r/a* ratio = 0.38, which corresponds to a sufficient large spectral width of 110 nm when *a* = 500 nm. Although wider PBG range can be obtained when *r/a* ratio is larger than 0.38, the PhC structure becomes fragile in fabrication due to the enlarged air-hole radius. Thus, the *r/a* ratio of square-PhC will be chosen and fixed to be 0.38 from now on. A simple square-PhC nanocavity design is the *D1* nanocavity by removing an air-hole and a lowest-order WG2, 1 (the former and latter sub-number represent the azimuthal number and radial order, respectively) mode will be sustained in this nanocavity design.

Recently, it has been reported that local lattice shifts in 1D or 2D PhCs can create nanocavities well sustaining various ultra-small defect modes. Here we propose a nanocavity design using similar approach based on square-PhCs. As shown in Fig. 1(a), the square PhCs are defined by air holes on a suspended dielectric slab. Four central air holes are shrunk to be
r' in radius and the positions are shifted outward to form a nanocavity region, named pointshifted *D0* nanocavity. First, we perform 3D finite-difference time-domain (FDTD) simulations to obtain the defect modes in this nanocavity design. In the simulation setup, the lattice constant, *r/a* ratio, slab thickness, and refractive index are set to be 500 nm, 0.38, 220 nm, and 3.4, respectively. The *r'/a* ratio is varied from 0.285 to 0.36, and the number of lattice periods is set to be 14 in both *x*- and *y*-directions to provide sufficient PBG confinement. From the simulation results, three defect modes exist in *D0* nanocavity under different *r'/a* ratios, including dipole, WG2, 1, and monopole modes. The relationship between the simulated defect mode frequency and *r'/a* ratio of square-PhC *D0* nanocavity are shown in Fig. 1(b). All the defect modes lie inside the PBG region. As shown in Fig. 1(b), we also find that WG2, 1 and monopole modes can be confined only by Γ-X direction PBG effect. This is possible because the in-plane radiations of WG2, 1 and monopole modes are mainly along Γ-X direction, which can be observed from the FDTD simulated mode profiles in electrical field shown in Fig. 1(c). Thus, for both WG2, 1 and monopole modes, the available design range will be larger than the expected *M-X* direction PBG region. It should be noted that WG2, 1 mode in *D0* nanocavity is different from WG2, 1 mode in *D1* nanocavity with in-plane radiation along Γ-*M* direction.

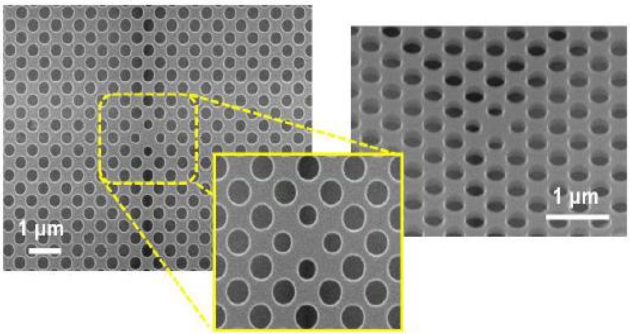


Fig. 3. Top-, zoom-in, and tilted-view SEM pictures of fabricated square-PhC D_0 nanocavity from left to right. The fabricated lattice constant, *r/a*, and *r'/a* ratios are 500 nm, 0.38, and 0.30, respectively.

Real devices are fabricated on InGaAsP multi-quantum-wells (MQWs) by electron-beam lithography and a series of inductively coupled plasma / reactive ion etching dry-etching process. Then the suspended slab is formed by HCl selective wet-etching process [17,19]. Top-, zoom-in, and tilted-view scanning electron microscope (SEM) pictures of fabricated square-PhC *D0* nanocavity are shown in Fig. 3. The fabricated square-PhC *D0* nanocavities are optically pumped at room temperature. To avoid thermal problems, the duty cycle and width of optical pulse are set to be 0.2% and 40 ns, respectively. And the pump spot size is focused to be around 3.5 μm in diameter. From nanocavity with fabricated *a* = 500 nm, *r/a* ~0.38, and *r'/a* = 0.30, we obtain single-mode lasing at 1560 nm, which can be identified as WG2, 1 mode by comparing with the simulation results in Fig. 1(b). The measured light-in light-out (*L-L*) curve and spectrum of single-mode lasing action are shown in Fig. 4(a) and (b). The thresholdis estimated to be 160 μW from the *L-L* curve, which corresponds to an effective threshold as low as 8 μW when taking the power absorbed by the nanocavity into account only. This low threshold is attributed to the small mode volume and high *Q* factor of WG2, 1 mode in *D0* nanocavity, which directly indicates the potential in achieving thresholdless nanolaser. We also obtain the spectrum below threshold (at 100 μW, ~0.7 times threshold), as shown in the inset of Fig. 4(a). The estimated spectral line-width by Lorentzian fitting is 0.38 nm, which corresponds to a *Q* factor of 4,100. And the measured side-mode suppression-ratio (SMSR) is larger than 20 dB as shown in the inset spectrum of Fig. 4(b).

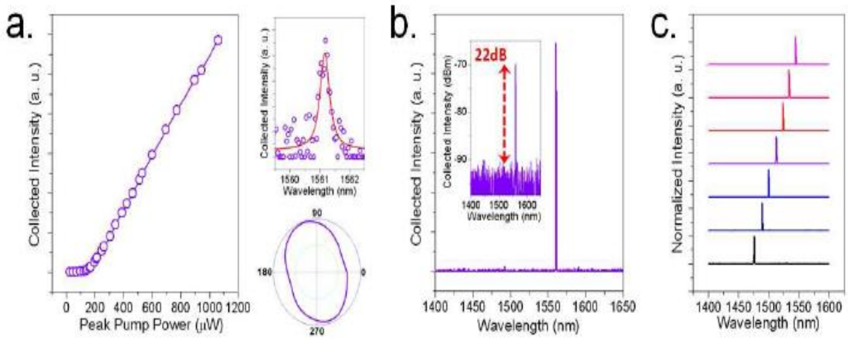


Fig. 4. (a) The measured *L-L* curve and (b) lasing spectrum of WG$_{2,1}$ mode at wavelength of 1560 nm from square-PhC D_0 nanocavity. The measured WG mode polarization and spectrum below threshold are shown in the insets of (a). The lasing spectrum in logarithm scale is shown in the inset of (b). The *r/a* ratio, *r'/a* ratio, and lattice constant of the measured device are 0.38, 0.30, and 500 nm, respectively. (c) WG$_{2,1}$ mode lasing spectra from square-PhC D_0 nanocavities with increased *r'/a* ratio from 0.285 (top curve) to 0.315 (bottom curve) under lattice constant of 480 nm. The intensity of each spectrum has been normalized.

E. Magneto-optics of layers of double quantum dot molecules

We formulate a computational method which allows us to monitor the coherent manipulation of the quantum states of electrons and holes in embedded semiconductor nano objects by means of the magnetoellipsometry. The influence of the surrounding semiconducting matrix on the polarizability of the nano objects has been imposed using a generalization of the hybrid discrete-continuum model. The generalization allows us to simulate the nano objects of arbitrary shapes. We show that parameters of the electron and hole quantum states localized in the nano objects can be retrieved from the collective magneto-optical response of systems of such nano objects. As an example of the method implementation we consider impact of the coherent manipulation of electronic states in the double vertical lens-shaped circular QDM on the collective magneto-optical response from a layer of those nano objects. The manipulation is performed by an external magnetic field applied upon InAs/GaAs quantum dot molecules assembled from the dots with substantially different lateral radii. Recently it was demonstrated that in the asymmetrical QDM the nonuniform diamagnetic shifts of the lowest electron-energy levels lead to their anticrossing which yields in a positive peak of the differential magnetic susceptibility of the system. In this paper we show unusual consequences of the nonuniform diamagnetic shifts for the magneto-optics of layers of asymmetrical QDMs. We treat the semiconductor QDMs within complete three-dimensional description which allows us to simulate arbitrary directions of the external magnetic field (Fig. 1) in contrast to most of the calculations done before. It brings up much wider opportunities to dynamically manipulate electron and hole states in QDMs. As it was already mentioned changes in magneto-optical response of a layer of QDMs emerge from the changes in the quantum-mechanical configuration of the QDMs. In this paper we demonstrate in detail that the magnetoellipsometric data can reproduce an important and clear information on the quantum mechanics of the molecules.

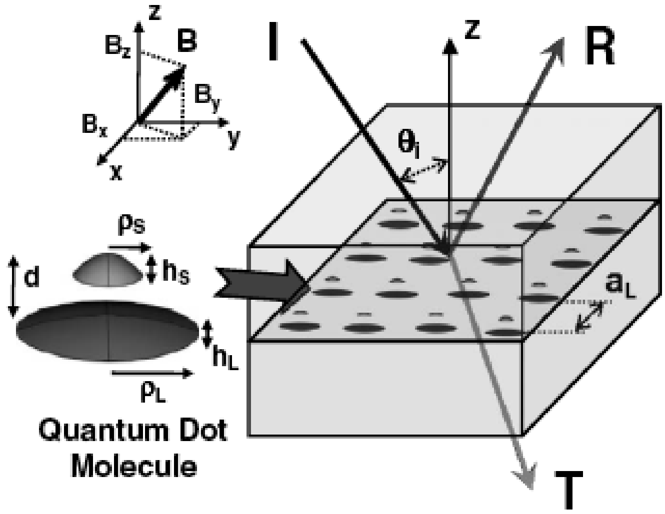


FIG. 1. Schematic of the magneto-optics of a layer of embedded semiconductor quantum dot molecules.

For systems of semiconductor embedded nano objects ofarbitrary shapes we have formulated a modification of the hybrid discrete dipole approximation. The modification allows us to describe the collective magneto-optical response of systems of such objects. As an example of the theory implementation we have performed a comparative study of the magneto-optical response functions _absorbance and the ellipsometric angles_ for a layer of asymmetrical InAs quantum dot molecules arranged in a square two-dimensional lattice and embedded into GaAs matrix. The response of individual embedded QDMs is presented in terms of the excess polarizability. Static and dynamic parts of the polarizability _and the self-interaction tensor as well_ are determined. Using the Veliger's derivation we simulated the ellipsometric angles of the layer embedded QDMs for a wide range of the system configuration. We emphasize that the magnetoellipsometric data reproduce important information on the quantum mechanics of the molecules. Varying magnetic field and the distance between quantum dots within the layer we can investigate optically the transition from molecular to "atomic" behavior of the system. This general conclusion remains valid when excitonic effects are taken into consideration. Our simulation results clearly suggest measurable values for the ellipsometric data for any modern ellipsometric setup. The approach can be potentially useful for simulation and characterization of new all-semiconductor nanostructured metamaterials.

結果與討論

Publications resulted from this grant:

國外期刊

1.Edge magnetoplasma excitations in quantum wire arrays , Hsieh WH, Suen YW, Lee BC, Li LC, Lee CP , PHYSICA E-LOW-DIMENSIONAL SYSTEMS & NANOSTRUCTURES , Volume: 40 Issue: 5 Pages: 1681-1683 Published: MAR 2008

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3.High quantum efficiency dots-in-a-well quantum dot infrared photodetectors with AlGaAs confinement enhancing layer , Ling HS, Wang SY, Lee CP, Lo MC , APPLIED PHYSICS LETTERS , Volume: 92 Issue: 19 Article Number: 193506 Published: MAY 12 2008

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中　華　民　國 99 年 10 月 20 日

附件二

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□　未達成目標（請說明，以 100 字為限）

□　實驗失敗

□　因故實驗中斷

□　其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：■已獲得 □申請中 □無

技轉：□已技轉 □洽談中 □無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

在此計劃中，最重要的一項成果是我們完成了低溫強磁場下的橢圓儀設備。它是世界第一個可在如此環境下操作的橢圓儀。在發展這一套系統過程中，我們以特殊設計克服了長光程及低溫的環境限制，成功的量測到樣品的偏極光光學參數，並且正在對量子點及量子環等奈米結構組成的超物質光學性質進行分析量測。由於這是目前唯一可以在 4 K 低溫及 14T 高磁場環境下進行偏極光量測的系統，對於奈米光電研究的學者，這會是一個很理想的工作平台，為台灣的學術發展加入嶄新的活力。

針對量子環變溫下的光譜研究成果，我們進一步了解到其由量子點結構漸進演變至量子環過程中電子能態之變化及於不同結構中能量弛緩之不同過程。

在光子晶體元件上我們實現可作為電激發結構之光子晶體共振腔奈米柱，利用雙異質結構光子晶體波導設計並製作具有平面輻射特性之奈米雷射，並且設計並製作具高靈敏度的光子晶體感測元件。

我們也進行了關於單一量子點的光激光研究，利用在磁場下的光激光量測，首次觀察到各種激子之間不同的反磁係數，並且用一個解析模型來定量地解釋此一差異的物理原因，此一工作深化了我們對量子點對磁場響應行為的理解，激發了此系統的應用可能性。

附件四

國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：99 年 10 月 20 日

計畫編號	NSC 97-2120－M－009-004		
計畫名稱	奈米結構超物質之新穎特性研究		
出國人員姓名		服務機構及職稱	
會議時間	年 月 日至 年 月 日	會議地點	
會議名稱	(中文) (英文)		
發表論文題目	(中文) (英文)		

一、參加會議經過

二、與會心得

三、考察參觀活動(無是項活動者略)

四、建議

五、攜回資料名稱及內容

六、其他

國際會議出席報告

會議名稱: Trends in Nano-Technology
出國人員: 林大鈞　交通大學電子所　博五
地點　　: 西班牙 巴塞隆納
日期　　: 2009/09/07-2009/09/11

今年第 10 屆 Trends in NanoTechnology 在西班牙巴塞隆納舉行，九月七號到十一號，為期五天的會議，會議的主要內容包含奈米尺度的科技發展應用與物理探討，邀請各個領域頂尖的專家學者演講，更邀請奈米科技的業界人士介紹各種先進並且已經商業化的最新科技，這次 conference 有十個討論的主題,如下:

- Graphene / Carbon nanotubes based nanoelectronics and field emission
- Low dimensional materials (nanowires, clusters, quantum dots, etc.)
- Nanobiotechnologies
- NanoChemistry
- Nanofabrication tools & nanoscale integration
- Nanomagnetism and Spintronics
- NanoOptics & NanoPhotonics
- Nanostructured and nanoparticle based materials
- SPM
- Theory and modelling at the nanoscale

半導體奈米材料是我國研究的大宗，包含奈米碳管、直接能隙半導體材料(如 GaAs、GaN 或者 InP) 的奈米光學，而國外的研究團隊，不僅僅在半導體奈米元件上著重，對金屬的奈米薄膜或粒子也有很深的探討，另外他們在 SPM 上也下了不少功夫，讓我增長了不少視野。此外生物跟化學相關的奈米材料，還有自旋物理或者磁性物質也是我平常很少接觸的，這次參觀確實大開眼界。

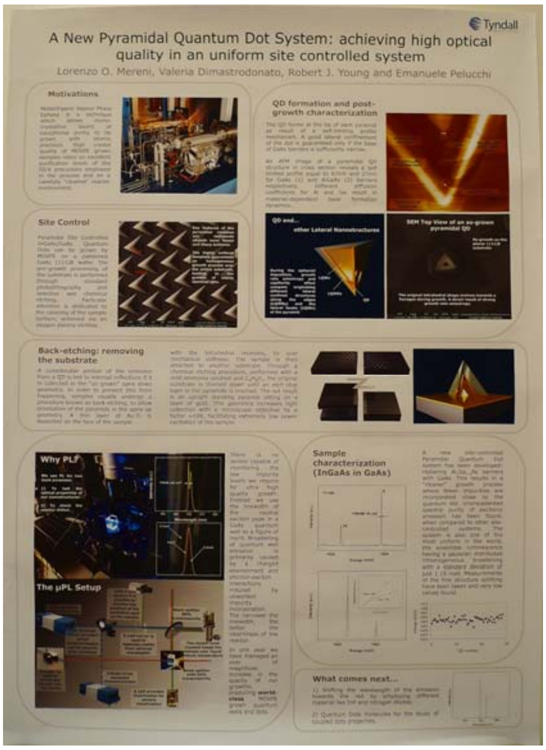
Poster 分成兩個組別，平均一組約有 200 個 Poster，其研究成果的質量品質有好有壞，少數很優秀的，就會在參考資料裡放上自己曾經發表的優良期刊，例如 PRL、PRB，甚至是 Nature 的論文發表，讓人很佩服，不過也有品質很差的發表，不只內容不佳，甚至只用許多 A4 紙拼湊出一張海報。

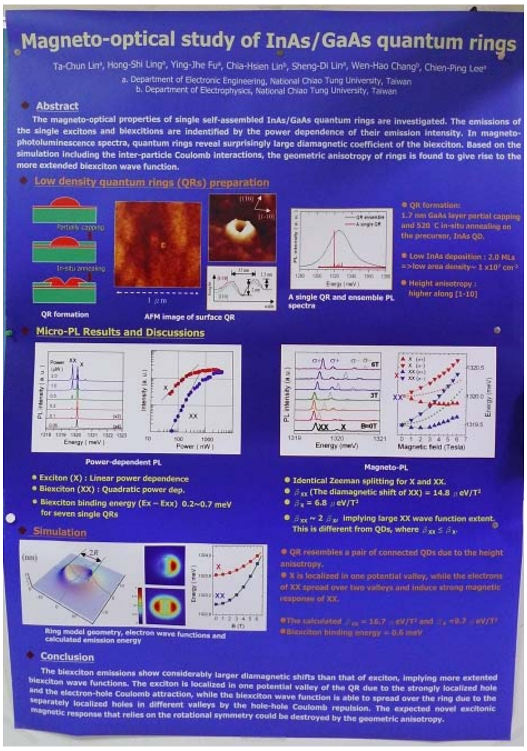
其中讓我印象比較深的海報(如圖一)，是利用 MOVPE 成長在 GaAs(111)平面上的金字塔形堆積，中間累積一層薄的 InGaAs layer 當主動層，在金字塔尖端會形成類似量子點的量子三維侷限系統，他們量測了單量子點的 exciton 跟 biexciton 的發光，並跟據發光能量推算 biexcition binding energy，因為題目與我

相仿，我特別有印象。

另外一個有強烈印象的海報則是模擬奈米碳管，在充電時的靜電荷分佈，他利用了 Maxwell 方程式跟薛丁格方程式。此外也計算了電場中，奈米探管上的感應電荷跟電場作用導致碳管彎曲的量。由於得到 PRL 跟 PRB 的發表，所以我特別有印象，他也是唯一有上台做口頭報告(Oral presentation)的年輕華裔研究員。

Oral 中有一個人用掃描探針顯微鏡(SPM)去量測試片的局部電位能，雖然不是新技術，可是他能成功量測出激態能階(excited state)，相當令人印象深刻。





圖一. MOVPE 成長的金字塔形量子點　　圖二. 我的 poster presentation

結論:

此次參加 TNT2009 得到相當大的收穫，不只是瞭解不同領域的研究成果，繼而拓展我的視野，更在 poster 時與不同國籍的人溝通指教，更增加我的世界觀，此次參加研討會收益良多。

Report on the 22^{nd} Annual Meeting of the IEEE Photonics Society.

Belek, Antalya, Turkey, October 4^{th} - 8^{th} 2009.

Project Account	
Project Name	
Student	Dai Van Truong / 交通大學電子工程系所 / Ph. D Candidate
Conference Name	LEOS 2009
Address and Time	4^{th} – 8^{th} October 2009 @ Antalya, Turkey
Paper Title	Modeling the Simultaneous Two Ground-State Lasing Emissions in Chirped Quantum Dot Lasers

22^{nd} Annual Meeting of the IEEE Photonics Society was held at Belek, Antalya, Turkey, October, 4^{th} – 8^{th} 2009. This year's Annual Meeting features a broad spectrum of activities including plenary, invited and contributed papers, special symposia, short courses and special sessions on Creative Teaching Methods and on Careers in Research. The program sub-committees have put together an excellent program consisting of about 135 invited talks and 320 contributed papers. The conference has 21 topics and divided into 8 rooms. The conference topics are as follows:

- Bio-photonics
- Display
- Electro-optic sensors and systems
- Integrated optics and optoelectronics
- High power and short wavelength lasers
- Microwave photonics
- Nano-photonics
- Nonlinear optics
- Optical communications
- Optical fiber and planer waveguide technology
- Optical interconnects and processing systems
- Optical material and processing
- Optical network and systems
- Semiconductor lasers
- Optoelectronic packaging, manufacturing and reliability
- Photo-detectors and imaging
- Solid State Lasers
- SPECIAL SYMPOSIUM ON The Convergence of Wired and Wireless Services in In-Building and Access Networks
- SPECIAL SYMPOSIUM ON New Materials for Photonics
- SPECIAL SYMPOSIUM ON Optical Networks and Devices for Data Centers
- Ultrafast Optics and Electronics

The conference brings to the participants opportunity to present their works in different research branches in photonics society. Especially, this is the good opportunity for young researchers to learn a lot of things from experienced researchers in the photonics field. The first day, there are three short courses. These courses not only informed about fundamental of these fields, but also about hot research topics today. Especially, in the evening photonics society leaders gave their talks about creative teaching and research career. The second, third and fourth day, the conference began from 8h30 to 17h00. All presentations at the conference are oral. These talks provided much effective information for participants discuss and share their experience in science and technology. Our paper about "Modelling the Simultaneous Two Ground-State Lasing Emissions in Chirped Quantum Dot Lasers" was presented on "Inter-band and Quantum Dot Lasers" section (9h45-10h00, 8th October).

In summary, the conference not only gave me a big chance to present my work but also opened in my mind many directions in my future research. I also learnt many things in science as well as in education from the conference.

Advisor: Prof. C. P. Lee ***Hsinchu, October, 24th 2009***

***Student*: Dai van Truong**

國際會議出席報告

會議名稱: North American Molecular Beam Epitaxy
出國人員: 林仕偉　交通大學電子所　博一
地點　　: 美國普林斯頓大學
日期　　: 2009/08/09-2009/08/12

今年第 18 屆 NAMBE 在美國普林斯頓舉行,會議所包含的議題包括磊晶技術、氧化物成長、光電元件，以及低維量子結構的研究，並請各領域的專家學者前來演講。這次 conference 有十六個討論的主題，如下:

- ✧ Fundamentals of MBE growth
- ✧ MBE growth modifications
- ✧ Materials characterization
- ✧ MBE technology
- ✧ III-Nitrides and dilute nitrides
- ✧ Oxides
- ✧ II-VI materials
- ✧ ZnO
- ✧ III-V materials and structures
- ✧ Si MBE
- ✧ Hybrid materials
- ✧ Photonic devices
- ✧ Electronic devices
- ✧ Spintronics
- ✧ Low dimensional structures
- ✧ Novel materials and device physics

由於個人因素無法全程參加，僅對 8/11、12 所進行的議題, 做大概的描述:

08/11:

主要研究大致分為兩個主題，中波段(3~5μm)紅外光雷射以及三五族 FET 元件製作。中長波段雷射的研究主要集中在利用 type II 量子井結構以及使用 intra band (Conduction Band) transition 取代傳統 type I 結構，發光波長受限於材料特性的缺點，以達到更長波長的雷射光輸出，看到不少 group 都成功的在 3μm 的波段實現室溫雷射。而三五族 FET 元件則注重於高品質閘極氧化層的成長，以及與 Si 現有製程的結合。

下午是 poster session，內容涵蓋了非常廣的領域，其中有個很特別的研究是將 GaN 成長在 Al 基板上，使用化合物的 source 在較低溫(650℃)成長 GaN。實際

去詢問的結果,這個 topic 他們也還在研究當中,目前 GaN 薄膜還沒有十分平整。而其他的因為主題眾多，無法全部去詢問細節，因此沒有辦法詳細的描述。

08/12:

上午的 session 主要著重於新材料的研究，其中單層碳(Graphene)成長於 Si 或 SiC 基板上的研究有不少 Group 發表。由於非多層堆疊的原因，導致單層碳的 band diagram 與一般 graphite(石墨)有所不同，近而產生許多有趣的電子傳輸效應，在特定條件下可形成無 bandgap 之材料。這方面的研究目前還是主要在於高品質且單一原子層的薄膜成長。另外也有 group 報告了在傳統 GaAs 中摻雜 Bi 的研究，由於 Bi 的摻入，可使得發光波長推向更長波長方向，且 lattice constant 並不會增加太多，但由於 Bi 的成長必須要在相對低溫(300℃)下，所以這方面的研究也是還在進行中。

下午的 poster session 一樣是包含了各種主題，我的研究也有在這個 session 中發表，目前我的研究是單晶鋁薄膜在 GaAs 基板上的成長及特性，其中比較困難的地方在於接面處的控制，要避免多餘的 As 原子累積在 GaAs 上面，導致成長 Al 時與 Al 原子混合在一起，目前可以控制在 60nm 的厚度下，能有相當良好的結晶特性。而其他 group 的研究因為我要解說自己的 poster 就沒有太多時間去了解。

結論:

此次參加 NAMBE 是我第一次參加國際性的會議,不管是聽各個 group 的成果發表，或是自己在 poster session 與其他人的交流，都讓我獲益良多。各式各樣有趣的研究，對拓廣見聞以及更深入的了解 MBE 磊晶的領域都有相當大的幫助。而在 poster session 與他人的交流，一方面可以深入了解其他不同的研究，也可以在自己的研究中聽到其他人不同的看法，很多是自己沒有去想到的。很感謝實驗室的協助能有這次機會去參加這樣的會議，實驗室的齊全的設備有目共睹，也希望我能努力研究，能有機會再參加類似的會議。

附件 1

國立交通大學博士班研究生

出席國際會議報告

98 年 11 月 24 日

報告人姓名	陳政元	申請單位 （學生請加註系級）	應用化學所 博士班 1 年級	職稱	博士生
				電話	0953136822
出國類別	□考察 □訪問 □進修 □研究 ■國際會議 □其他：________				
會議/出國計畫名稱	(中文) 2009 微米製程與奈米科技國際研討會 (英文) 2009 International Microprocesses and Nanotechnology Conference				
出國期間	自 98 年 11 月 17 日 至 98 年 11 月 21 日		出國地點	日本-札幌	
出國目的/發表論文題目	(中文) 利用奈米壓印製作抗反射層並應用於太陽能電池 (英文) Enhancement in Light Conversion Efficiency of Silicon Solar Cell by using Nanoimprint Anti-Reflection Layer				
補助金額			經費來源 （校內會計編號）		

報告內容應包括下列各項：

一、參加經過

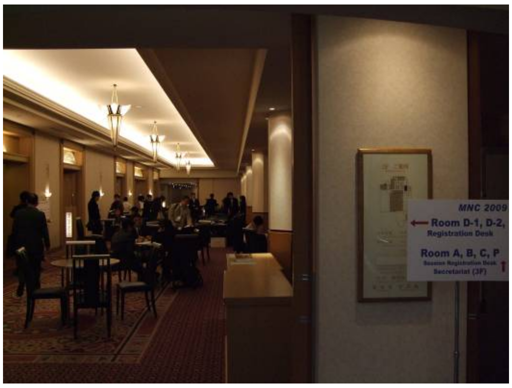
此會議今年已是第二十二屆舉辦，這次選擇於日本札幌喜來登飯店舉行，由日本應用理學會主辦。會議時間訂於 11 月 16 日至 19 日，由於 16 日當天僅安排報到程序，於是我選擇於 17 日搭飛機轉火車抵達會場報到，領取會議行程表。17 日的主要演講內容分為三個部份；DUV, EUV Lithography、Graphene Growth & Characterization、Nanoimprint, Nanoprint and Rising Lithography。18 號的演講主題有：Computatuinal Lithography、Nanomaterials、Microsystem、Nano Tool。並且於下午時間安排 Poster Session，我也於此時段進行海報的展出。發表論文題目為：Enhancement of the Light Conversion Efficiency of Silicon Solar Cell by using Nanoimprint Anti-reflection Layer，屬於 Nanoimprint, Nanoprint and Rising Lithography 主題。19 號的演講主題有：Nano-Carbon Devices、Nanofabrication、Electron & Ion Beam Lithography、Nanowire Device、Resist Materials and Processing。下午則是安排 Poster Session 作為結束。而 20 號則由與會者自由活動，認識當地的風土人情，並於隔日 21 號下午搭機返國。

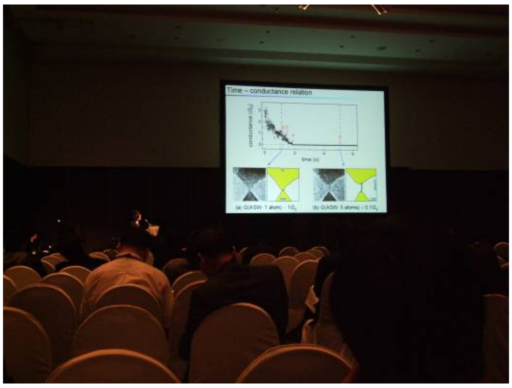
在本次的會議中，依據不同的主題共有數個 session，投稿論文或摘要約 300 餘篇，為日本相當重要且舉辦多年的奈米科技相關之學術研討會。本人所發表之論文為利用奈米壓印所製作出來的抗反射結構，並且應用於矽太陽能電池。此次會議過程中，我也向一些學者進行研究上的討教與交流。且在此次會議中所發表之最近最新的研究成果中得到相當多的啟發。

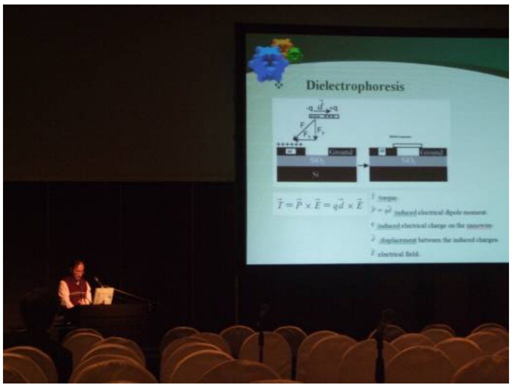
二、心得（可含照片）

此次會議分為許多議題，與我研究相關的奈米壓印部分有相當多的研究成果，在海報展出的期間，也與許多教授以及學生進行討論，接收到許多相關的資訊與問題，讓我會深入想想一些之前沒有考慮到的問題及方法，也藉由其他學者的想法得到一些啟發。大會演講中也有許多讓我印象深刻且感到興趣的題目。Superhydrophobic ZnO surface: Chemical Modification and Effects of UV irradiation，藉由 UV 的照射，可將氧化鋅奈米柱表面的親水性大大提升。除此之外也有許多對於氧化鋅材料的相關研究與應用，讓我得到許多相關的知識。還有像是 Alignment of size-homogeneous Ge dots on Si(001) substrate with two-dimension hole array，利用微影以及蝕刻在基材表面形成洞陣列，再用沉積的方式在表面形成 Ge 的 nanodots，發現 nanodots 會有特定的排列方式，與洞的大小、深度、方向、排列方式都有關係，是一個非常有趣的研究主題。奈米壓印相關的部份，In-situ error estimation of microstructure patterning on glass substrate by imprinting process 這個研究成功將微米結構轉印至軟化溫度較低的玻璃基板上，省去了使用阻劑的步驟，大大降低了微影製程的成本與時間。Enhanced Transmittance of Fresnel Lens for Concentrated Photovoltaic Device using Nano-Imprint Lithography 這個研究與我的部份有很大的相關性，是利用轉印的方式在透鏡表面形成奈米結構，用來增加光穿透的比例，並以此透鏡做為太陽能電池的聚光鏡，藉由提升光的穿透比例來增加效率，並且有相當好的程度上提升。其他還有許多有趣、新穎、甚至可以說是令人意想不到的研究，這對於研究者在之後的研究上有廣泛的幫助，也增加了視野以及思考的方向。

此次能參與大型的國際會議，得先感謝老師給我出國並學習的機會。由於是一場國際性的學術交流，我認識了很多不同領域的研究學者、和更多的文化或想法。很高興在就讀博士班初期就給我這樣的機會，對於日後的方向以及想法都有所幫助。當專注於某個領域時，也許也是將自己侷限在某些層面，而不懂得藉由其他角度來思考或更進一步解決問題，藉由與其他教授、學者、學生的交流；藉由看到更多、更豐富的研究；相信能增長見識並且有助於多方面的思考，也能在研究的路上有所精進。另外，藉由這次參加國際研討會的機會，深刻的感覺的語言的重要，認識與接收外來文化是必然的趨勢，結交不同國家的朋友，彼此間互相交流是極為重要的，而溝通表達更有賴良好的語言能力來達成，這些都是讓我體驗到哪些部份是自己極需加強的。







三、考察參觀活動(無是項活動者，或前已敘述者可省略此項)
無事項活動

四、攜回資料名稱及內容
一本會議流程、一本國際會議報名論文

五、建議
能夠出國參加此種大型的國際會議，是一件很難得的機會，而我也確實獲益良多，在此更感謝貴單位在經費上的補助。
未來，寄望能有更多對學子們的補助、或機會。相信對國內學術視野有正面的發展。

六、其他

大會行程表

MNC 2009 Session Schedule

Monday, November 16, 2009

Room A (3F)
13:00-17:50 MNC 2009 Technical Seiminar in Japanese MNC 2009 技術セミナー北大GCOE企画「ナノ・バイオ・ITの融合」「ナノインプリント技術」
Room D-1 (2F)
18:00-20:00 MNC 2009 Get Together Party (Free for every participants)

Tuesday, November 17

Room P (3F)		
17P-1:Opening Session *Page 5* 9:30-9:50: Opening Remark and 2008 Award Presentation 9:50-10:30 S. Wurm (SEMATEC, USA) 10:30-11:10 A. Neureuter (Univ. of CA, Berkeley, USA) 11:10-11:50 T. Fukui (Hokkaido Univ.)		
Lunch		
Room A (3F)	Room B (3F)	Room C (3F)
17A-2: 13:30-15:20 Page 6 DUV, EUV Lithography and Metrology	17B-2: 13:30-15:10 Page 5 Symp. B. Graphene: Growth & Characterization I	17C-2: 13:30-15:20 Page 5 Nanoimprint, Nanoprint and Rising Lithography I
17A-2: 15:20-15:35, Author's Interview		
Room D-1 and D-2 (2F)		
Coffee Break		
Room A (3F)	Room B (3F)	Room C (3F)
17A-3: 15:40-17:50 Page 6 Bio MEMS, Lab on a Chip	17B-3: 15:30-17:10 Page 6 Symp. B. Graphene: Growth & Characterization II	17C-3: 15:40-17:30 Page 6 Nanoimprint, Nanoprint and Rising Lithography II
17A-3: 17:50-18:05, Author's Interview	17B-2, 3: 17:10-17:25, Author's Interview	17C-2, 3: 17:30-17:45, Author's Interview

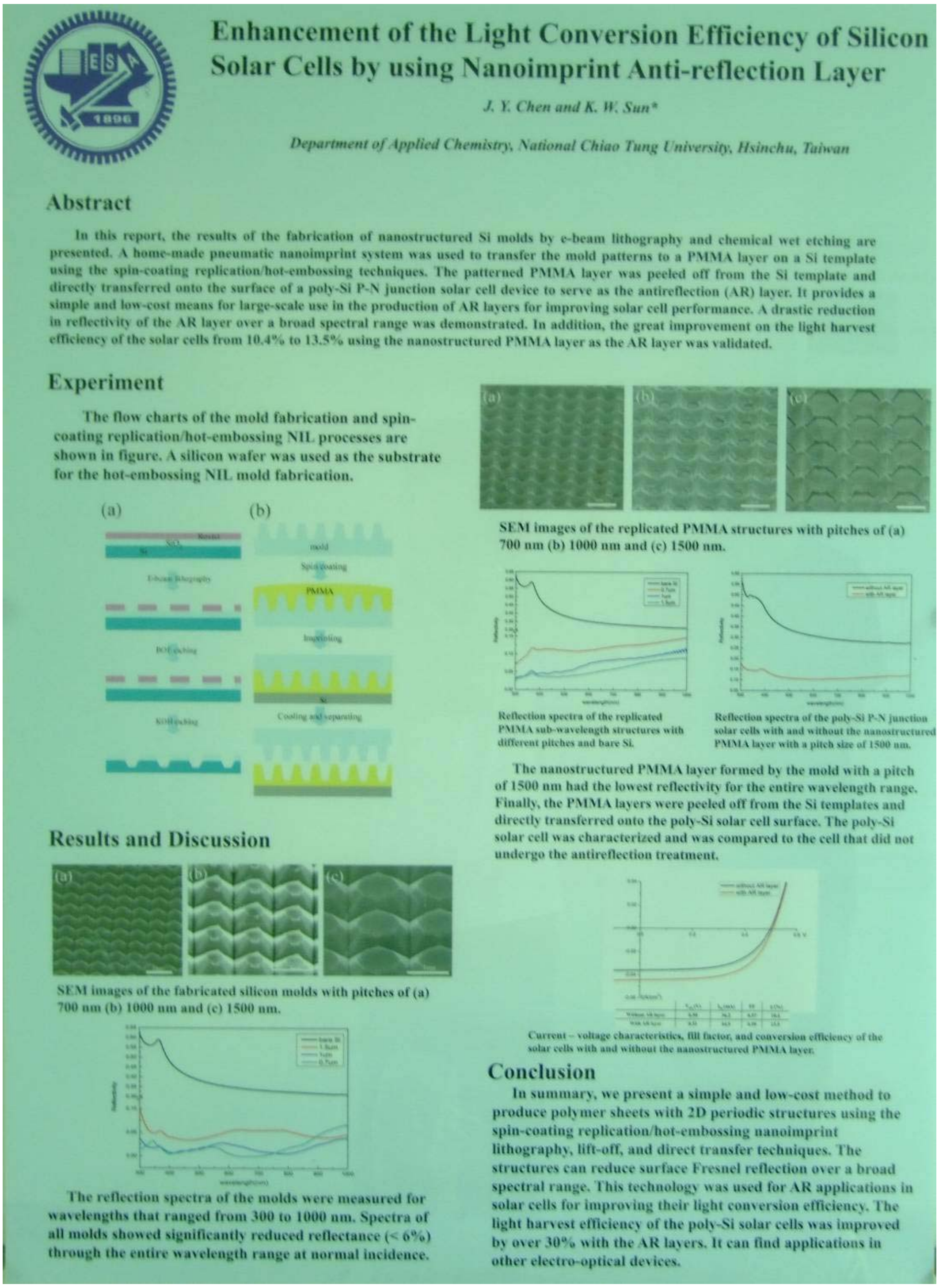
Wednesday, November 18

Room A (3F)	Room B (3F)	Room C (3F)
18A-4: 9:00-10:40 Page 7 Dr. Hiroshi Ito Tribute Symp. A. Computational Lithography I	18B-4: 9:00-10:30 Page 7 Nanomaterials I	18C-4: 9:00-10:40 Page 7 Microsystem Technology and MEMS I
Room D-1 and D-2 (2F)		
Coffee Break		
Room A (3F)	Room B (3F)	Room C (3F)
18A-5: 11:00-12:40 Page 7, 8 Symp. A. Computational Lithography II	18B-5: 11:00-12:50 Page 7, 8 Nanomaterials II	18C-5: 11:00-12:40 Page 7, 8 Microsystem Technology and MEMS II
		18C-4, 5: 12:40-12:55, Author's Interview
Lunch		
18A-6: 14:00-15:30 Page 8 Symp. A. Computational Lithography III	18B-6: 13:50-15:30 Page 8, 9 Nanomaterials III	18C-6: 13:35-15:45 Page 8, 9 NanoTool
18A-4, 5, 6: 15:30-15:45, Author's Interview	18B-4, 5, 6: 15:30-15:45, Author's Interview	18C-6: 15:45-16:00, Author's Interview
Room D-1 and D-2 (2F)		
18D-7: 16:00-18:00 Poster Session I Page 9-14 DUV, EUV Lithography and Metrology, Electron- and Ion-Beam Lithography, Resist Materials and Processing, Nanodevices, Nanofabrication, Nanomaterials, Nano-Tool, Nanoimprint, Nanoprint and Rising Lithography Bio MEMS, Lab on a Chip Microsystem Technology and MEMS		
Room A (3F)		
18:15-20:15 Banquet		

Thursday, November 19

Room A (3F)	Room B (3F)	Room C (3F)
19A-8: 9:00-10:50 Page 15 Nano-Carbon Devices	19B-8: 9:00-10:40 Page 15 Nanofabrication I	19C-8: 9:00-10:50 Page 15 Electron- and Ion-Beam Lithography
		19C-8: 10:50-11:05, Author's Interview
Room D-1 and D-2 (2F)		
Coffee Break		
Room A (3F)	Room B (3F)	Room C (3F)
19A-9: 11:10-12:50 Page 15, 16 Nanowire Devices	19B-9: 11:00-12:50 Page 15, 16 Nanofabrication II	19C-9: 11:10-13:00 Page 15, 16 Resist Materials and Processing I
19A-8, 9: 12:50-13:05, Author's Interview	19B-8, 9: 12:50-13:05, Author's Interview	
Lunch		
Room D-1 and D-2 (2F)		19C-10: 14:10-16:10 Page 16, 17 Resist Materials and Processing II
19D-10: 14:10-16:10 Page 16-21 Poster Session II Nanodevices, Nanofabrication, Nanomaterials, Nano-Tool Nanoimprint, Nanoprint and Rising Lithography, Bio MEMS, Lab on a Chip Microsystem Technology and MEMS		
		19C-9, 10: 16:10-16:25, Author's Interview

Poster


Enhancement of the Light Conversion Efficiency of Silicon Solar Cells by using Nanoimprint Anti-reflection Layer
J. Y. Chen and K. W. Sun*
Department of Applied Chemistry, National Chiao Tung University, Hsinchu, Taiwan
1896
Abstract
In this report, the results of the fabrication of nanostructured Si molds by e-beam lithography and chemical wet etching are presented. A home-made pneumatic nanoimprint system was used to transfer the mold patterns to a PMMA layer on a Si template using the spin-coating replication/hot-embossing techniques. The patterned PMMA layer was peeled off from the Si template and directly transferred onto the surface of a poly-Si P-N junction solar cell device to serve as the antireflection (AR) layer. It provides a simple and low-cost means for large-scale use in the production of AR layers for improving solar cell performance. A drastic reduction in reflectivity of the AR layer over a broad spectral range was demonstrated. In addition, the great improvement on the light harvest efficiency of the solar cells from 10.4% to 13.5% using the nanostructured PMMA layer as the AR layer was validated.
Experiment
The flow charts of the mold fabrication and spin-coating replication/hot-embossing NIL processes are shown in figure. A silicon wafer was used as the substrate for the hot-embossing NIL mold fabrication.
(a)
(b)
mold
Spin coating
PMMA
Imprinting
Cooling and separating
Results and Discussion
(a)
(b)
(c)
SEM images of the fabricated silicon molds with pitches of (a) 700 nm (b) 1000 nm and (c) 1500 nm.
The reflection spectra of the molds were measured for wavelengths that ranged from 300 to 1000 nm. Spectra of all molds showed significantly reduced reflectance (< 6%) through the entire wavelength range at normal incidence.
(a)
(b)
(c)
SEM images of the replicated PMMA structures with pitches of (a) 700 nm (b) 1000 nm and (c) 1500 nm.
Reflection spectra of the replicated PMMA sub-wavelength structures with different pitches and bare Si.
Reflection spectra of the poly-Si P-N junction solar cells with and without the nanostructured PMMA layer with a pitch size of 1500 nm.
The nanostructured PMMA layer formed by the mold with a pitch of 1500 nm had the lowest reflectivity for the entire wavelength range. Finally, the PMMA layers were peeled off from the Si templates and directly transferred onto the poly-Si solar cell surface. The poly-Si solar cell was characterized and was compared to the cell that did not undergo the antireflection treatment.
Current – voltage characteristics, fill factor, and conversion efficiency of the solar cells with and without the nanostructured PMMA layer.
Conclusion
In summary, we present a simple and low-cost method to produce polymer sheets with 2D periodic structures using the spin-coating replication/hot-embossing nanoimprint lithography, lift-off, and direct transfer techniques. The structures can reduce surface Fresnel reflection over a broad spectral range. This technology was used for AR applications in solar cells for improving their light conversion efficiency. The light harvest efficiency of the poly-Si solar cells was improved by over 30% with the AR layers. It can find applications in other electro-optical devices.

REPORT

on Dr. O. Voskoboynikov's attendance
in the 6th International Conference on Quantum Dots

The 6th International Conference on Quantum Dot (QD2010) was held in the University of Nottingham, the East Midlands Conference Centre, (Nottingham, UK) from the registration start in 25th of April to 30th April. QD2010 was the 6th conference in a series, which started in Munich (2000), before continuing in Tokyo (2002), Banff (2004), Chamonix (2006), and Gyeongju (2008). The aim of the conference was to provide a forum for scientists from different research branches including physics, chemistry, materials science and engineering to discuss fabrication techniques, optical and transport properties as well as applications of quantum dots. One of the main goals of the conference was to bring together different quantum dot communities involved in research on self-assembled dots, nano-crystals, and gated structures, in order to stimulate progress by combining the expertise developed in each community. The scope of QD2010 covered elaboration, basic physics and applied research on quantum dots. The focus of the conference was the optical and electronic properties of nanostructures grown both by epitaxial methods and chemical synthesis and leading to three- dimensional confinement of electrons. In the following, a non-exhaustive list of topics was given to illustrate the scope of the meeting: - Novel fabrication techniques of quantum dots (self-assembled nanostructures, nano-crystals, nano-wires, nano-rods, etc.); - Optical properties of quantum dots; - Transport properties of quantum dots, including single electron tunneling; - Theory of electronic and optical properties of quantum dots; - Device applications such as lasers, memories, photo-detectors, solar cells; - Exploratory applications of quantum dots: medicine, biophysics, spintronics, quantum computing and information processing.

The Conference program consisted of more than 350 presentations form scientists over the world. The conference was supported by IOP Institute of Physics, Andor Technology, Attocube Systems, Bruker, Hamamatsu, Horiba Scientific, IOP Publishing, IUPAP, Oxford Instruments NanoScience, Princeton Instruments UK, Veeco. All those organizations where presented at the conference like exhibitors.

In the Conference we presented two our works: L. M. Thu, W. T. Chiu and O. Voskoboynikov " Temperature stable positive magnetic susceptibility of semiconductor wobbled nano rings" and L. M. Thu and O. Voskoboynikov " Optical response of quantum dot multilayer structures". The presentations have called a considerable attention and produced fruitful discussions with Prof. G. Populan (National Polytechnic Institute of Mexico, Mexico), Dr. T. Shamirzaev (ISP, Russian Academy of Science, Russia), Prof. D. Yakovlev (Technische Universitat of Dortmund, Germany) and others.

Both our papers have been selected to be published in the proceedings of the QD2010 as a Special Issue of Open Access Journal of Physics: Conference Series (JPCS) which is published by Institute of Physics Publishing in the UK. Publication in this archival journal will promote wide dissemination and citation, particularly since all information will also be accessible on the Internet.

During this visit I discussed with local scientists joint research projects and possible future scientific collaboration in the field of semiconductor nano-structures and computational metamaterials.

Prof. O. Voskoboynikov

05/07/2010

國際會議出席報告

會議名稱	**Quantum Dot 2010 (QD2010)**
出國人員 日期	交大電子所 研究生 9711520 邱偉庭 2010　4 月 26 - 30 日
地點	英國諾丁漢, 諾丁漢大學, East Midlands Conference Centre
	本次會議在英國中部的古老城市—諾丁漢舉行，主辦單位邀請到來自美國、德國、日本...等世界各地與量子點相關領域的專家來發表演講，也有許多和我們一樣的投稿者以海報形式發表論文。我們海報及論文於 4 月 29 日以及 4 月 30 日在諾丁漢大學會議中心發表。本次會議議期為 2010 年 4 月 26 日-30 日，由於冰島火山爆發的原故，許多班機停飛，為保險起見訂了 4 月 26 日的飛機。 本次會議主要分為三大主題，主要都是與量子點的生長以及結構相關。其中我看到了一篇來自台灣大學的海報展示，題目為"The effect of wurtzite InGaN quantum well on electronic structures of shape-dependent wurtzite InGaN quantum dots"，以下做些簡述。他們使用了三種不同形狀的量子點，並在量子點的上方以及下方加入了兩個量子井來探討量子井對該量子點的影響並使用 8*8 kp Hamiltonian 來模擬這個系統。而他們的數據指出若只在量子點的下方加一量子井，則會大大的降低在量子點裡面的庫倫作用。另外聽了一個來自史丹佛大學的演講，題目為" Quantum and classical information processing with a single quantym dot in photonic crystal cavity"，他們測量到了一個強烈連結的量子點-腔室系統並展示了該量子點能夠調整該腔室的反射能力，他們也在上述的系統研究了光子的封鎖效應，並研究了這個效應要如何在量子點的光譜上顯示出來，是一個十分完整的研究。 諾丁漢是英國最古老的城市之一，諾丁漢城堡建立至今已超過一千年，當地也是羅賓漢傳說的發源地。諾丁漢距離倫敦只需搭兩小時的火車，當地的公車也十分發達，交通方便，而諾丁漢大學也是英國中部著名大學，校園內的 East Midlands Conference Centre 設備完善且十分現代化，非常適合舉辦國際會議。

國際會議出席報告

會議名稱	**The 37th International Symposium on Compound Semiconductors (iscs 2010)**
出國人員 日期	交大電子所 研究生 9711520 邱偉庭 2010 年 5 月 31 日~ 2010 年 6 月 4 日
地點	Takamatsu Symbol Tower,日本四國香川高松市(Takamatsu)
	本次會議在日本四國瀨戶內海旁的高松市舉行，主辦單位邀請到來自美國、德國、日本...等世界各地相關領域的專家來發表演講，也有許多和我們一樣的投稿者以海報形式發表論文。我們海報及論文於 6 月 4 日在 Takamatsu Symbol Tower 發表。 會議期間，我注意到一篇 poster，標題為"Development of a Novel Gated Electrolysis Cell and Its Application to Improved Electrolysis Efficiency in Neutral Solutions"，發表者為加州大學聖塔芭芭拉分校的學生。電解水時因為 H+以及 OH- 離子不多的原因，效率一般而言不高，他們為避開這個問題在電解的兩極之間加入一個 gate 電極 -- 就好像在 FET 裡面的閘極一樣的原理 -- 來控制電解的的效率。此外他們也有電路模擬來支持他們的實驗結果，是一篇相當有趣的發表。 高松為一古老的城市，古代的當地大名在賴戶內海旁建立了高松城，而城堡現址成為著名觀光景點 - 玉藻公園；紫雲山下的人工山水庭園為日本現存最大的文化財指定庭園；從高松港往外望去，映入眼簾的是女木島，又稱鬼島，為桃太郎打鬼傳說的地點。雖然古老又充滿傳說，不過高松也是一個進步、乾淨的城市且為四國的交通樞紐。在本次會議地點 Takamatsu Symbol Tower 旁即為 JR 高松站，高松機場也在附近。可惜台灣出發的飛機並沒有直達高松機場，但坐 JR 客運也能夠方便的到達當地。到關西國際機場後搭乘客運數小時內能到達高松市，如此方便的交通使 Takamatsu Symbol Tower 成為一舉辦國際會議的極佳場所。

出席國際會議報告

會議名稱	第三十五屆 國際電機電子工程協會 太陽能專家會議 35th IEEE Photovoltaic Specialists Conference
時間	2010 年 6 月 20 –25 日
地點	美國 夏威夷州 檀香山市 夏威夷國際會議中心
出席人員	張 資 岳
內容	國際電機電子工程學會的太陽能專家會議是全球太陽能重要會議之一，每一屆太陽能專家會議皆有相當多來自全球各地的太陽能專家、學者、工程師、學生和廠商等與會人士參與。 今年會議規模相當大，投稿量也比往年增加許多，即全球對太陽能的熱情不受經濟景氣的影響而依然高漲。我相當的榮幸能夠參加今年的會議，將實驗室最新的研究成果發表，並與全球頂尖研究機構和產業領先企業的高水準演講者、參展商和與會者交流與學習。 今年太陽能專家會議的 Cherry Award 是頒給對 III-V 半導體多接面太陽能電池貢獻相當多的 Richard R. King (Spectrlab, Inc.)。他帶領他的團隊製作出世界第一個超過 40% 的太陽能電池，在 2001 至 2007 年間，也受其他相當多的研發獎項肯定，他的努力與貢獻是相當值得我去學習效仿。 矽奈米晶體薄膜是邁向低成本與高效率第三代太陽能電池的主要角色之一。澳洲新南威爾斯大學(University of New South Wales, Australia)的 Martin Green 教授是矽奈米晶體薄膜太陽能電池的先驅，在這次會議中，他的研究團隊發表了他們利用矽奈米晶體薄膜於熱載子太陽能電池的理論運算結果與退火製程對矽奈米晶體薄膜應力的影響，實驗結果相當值得參考。此外，我把握會議的中場休息時間，向 Martin Green 教授請益有關矽奈米晶體薄膜的載子傳輸議題，並且，我多次向與他的團隊成員一同討論矽奈米晶體薄膜製程議題，獲益良多，對於我後續研究的研究課題幫助相當大。 當發表我的研究成果時，有相當多的專家、學者、、等與會者前來提問與提供相當多的寶貴意見，藉由多元的交流，間接提升了我的研究能力。太陽能專家會議提供了相當多的平台給來自全球各地的與會人士交流，然而，參加這次會議的台灣學生相較日本、韓國與大陸學生少很多，希望在後續的相關重要會議，有愈來愈多台灣學生參與，以儲備台灣在太陽能領域的競爭力。

無研發成果推廣資料

98年度專題研究計畫研究成果彙整表

計畫主持人：李建平			計畫編號：98-2120-M-009-002-				
計畫名稱：奈米結構超物質之新穎特性研究(3/3)							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	1	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	24	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	1	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	5	0	100%	人次	
		博士生	18	0	100%		
		博士後研究員	1	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	82	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	37	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	2	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	我們與下列單位進行了以下課題的合作研究 Exciton-Photon Polariton Condensation - 合作單位: USA, Michigan State University, Prof. Chi-Wei Lai Charge Sensitive Infrared Photodetector - 合作單位: Japan, Tokyo University, Prof. Susumu Komiyama Single Photon Emitters - 合作單位: UK, National Physics Laboratory, Dr. Alastair Sinclair

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：■已獲得 □申請中 □無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

在此計劃中,最重要的一項成果是我們完成了低溫強磁場下的橢圓儀設備。它是世界第一個可在如此環境下操作的橢圓儀。在發展這一套系統過程中,我們以特殊設計克服了長光程及低溫的環境限制,成功的量測到樣品的偏極光光學參數,並且正在對量子點及量子環等奈米結構組成的超物質光學性質進行分析量測。由於這是目前唯一可以在 4 K 低溫及 14T 高磁場環境下進行偏極光量測的系統,對於奈米光電研究的學者,這會是一個很理想的工作平台,為台灣的學術發展加入嶄新的活力。

針對量子環變溫下的光譜研究成果,我們進一步了解到其由量子點結構漸進演變至量子環過程中電子能態之變化及於不同結構中能量弛緩之不同過程。

在光子晶體元件上我們實現可作為電激發結構之光子晶體共振腔奈米柱,利用雙異質結構光子晶體波導設計並製作具有平面輻射特性之奈米雷射, 並且設計並製作具高靈敏度的光子晶體感測元件。

我們也進行了關於單一量子點的光激光研究,利用在磁場下的光激光量測,首次觀察到各種激子之間不同的反磁係數,並且用一個解析模型來定量地解釋此一差異的物理原因,此一工作深化了我們對量子點對磁場響應行為的理解,激發了此系統的應用可能性。