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# COLLABORATIVE RESEARCH AND DEVELOPMENT (CR&D)

## Delivery Order 0069: Photoluminescence Investigations on Semiconducting Quantum Dots, Quantum Wells, and Thin Films


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**JULY 2007**
**Final Report**

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**14. ABSTRACT**
This research in support of the Air Force Research Laboratory Materials and Manufacturing Directorate was conducted at Wright-Patterson AFB, Ohio from 27 February 2007 through 22 July 2007. The task of the project focused on photoluminescence (PL) experiments on various semiconducting samples grown with Molecular Beam Epitaxy (MBE) at MLPS. Quantum structures and quantum dots composed of InAs, GaAs, and GaSb have been investigated. The structures are potential candidates for highly sensitive infrared (IR) detectors and the knowledge of their optical performance such as PL is of considerable importance for the AF and the community in general.

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## General Description of the Project

As in the past, the project's task focused on photoluminescence (PL) measurements on various semiconducting samples grown with Molecular Beam Epitaxy (MBE) at MLPS. Quantum structures, such as superlattices, and quantum dots composed of InAs, GaAs, and GaSb have been investigated. The structures are potential candidates for highly sensitive infrared (IR) detectors and the knowledge of their optical performance, specifically such as PL, is of considerable importance for the AF. The measurements have been carried out in the following time periods: 3/19-3/22, 4/9-4/12, 5/14-5/18, 5/29-6/1, 6/27-6/29, and 7/9-7/10. All in all, 370 measurements have been performed in the temperature range 5 K- 300 K. During the project, specific attention was paid to the correction of the PL spectra, which, with respect to the former projects, required additional measurements of the so-called baseline and made data treatment after the experiments necessary. The method is described in the report. A further key issue of the project was to achieve PL of the quantum structures at room temperature. The PL data provided are extremely useful as feedback for future developments of the low-dimensional semiconductor projects at MLPS.

## Description of Research

For the PL experiments a BOMEM Fourier Transform Infrared (FTIR) Spectrometer was employed and the sample emission was detected with an attached nitrogen cooled InSb detector. The PL of the samples has been excited with the 532 nm line of solid-state laser (2W Verdi from Coherent). The provided power to the samples was at most around 500 mW corresponding to an excitation intensity of about 60 W/cm$^2$. In order to measure at deep and stable temperatures, a helium cryostat with a temperature controller was used. Attached to the cryogenic equipment was a vacuum pump station consisting of a mechanical pump and an oil diffusion pump. The use of the oil diffusion pump lowered the isolation vacuum pressure down to $10^{-6}$–$10^{-7}$ Torr, while the employment of the mechanical pump does not lower the isolation vacuum below $10^{-3}$ Torr. During the current project, it became standard procedure to use the oil diffusion pump in addition to the mechanical pump.

## Results

Typical results of PL spectra of InAs/GaSb superlattices are shown in Figures 1-5. Figure 1 shows the uncorrected measurements and the baseline. The latter was measured by closing the laser shutter. The baseline represents basically the black body radiation and is represented by the dotted line. Figure 2 shows enlarged the baseline with respect to the PL signal of the sample. Subtracting the baseline from the PL signal resulted in the corrected PL, which is shown in Figure 3 (note the clearly achieved zero line left and right of the peak). Figures 4 and 5 show the corrected PL at 200 K and 300 K, respectively. The correction works well at cryogenic temperatures but is still not perfect at 300 K. Presumably, the feature on the lower energy side in Figure 5 is a result of the correction of the rather noisy signal rather than a real PL features. Clearly, this point requires further clarifications. The peak around 0.3 eV, however, is doubtless PL of the sample.

Summarizing, the experiments give new insights in the quantum nature of highly sophisticated superlattices and nano-structures and show that MBE is literally capable of the controlled atom-by-atom formation of materials. *Apparently, Figure 5 presents the first observation of room-temperature PL of an InAs/GaSb superlattice.* The project was based on previously published work [1-7]. Currently, the preparation of publications about the findings in this project is on its way.

## Works Cited


[1] H. J. Haugan, F. Szmulowicz, G. J. Brown, B. Ullrich, S. R. Munshi, J. C. Wickett, and D. W. Stokes, "Short-period InAs/GaSb superlattices for mid-infrared photodetectors", Phys. Stat. Sol. (c) **4**, 1702-1706 (2007).

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[5] G. J. Brown, H. J. Haugan, F. Szmulowicz, K. Mahalingam, S. R Munshi, B. Ullrich and S. Houston, "Short period superlattices: is thinner better"? Photonics West, San Jose 2006, Proceedings of SPIE Vol. **6127,** 381-392 (2006).

[6] H. J. Haugan, F. Szmulowicz, K. Mahalingam, G. J. Brown, S. R. Munshi, and B. Ullrich, "Short-period InAs/GaSb type II superlattices for mid-infrared detectors", Appl. Phys. Lett. **87**, 261106-1 - 261106-3 (2005).

[7] F. Szmulowicz, H. J. Haugan, G. J. Brown, K. Mahalingam, B. Ullrich, S. R. Munshi, L. Grazulis, "Interface as design tools for short-period InAs/GaSb type-II superlattices for mid-infrared detectors", Infrared Photoelectronics, Warsaw 2005, Proceedings of SPIE Vol. **5957**, 48-59 (2005).


## Related Activities

A new He-Cd laser (325nm, 200 mW) from Kimmon was delivered and installed in the BOMEM laboratory. The laser will be used for a future project in conjunction with the already present Jobin Yvon U 1000 monochromator. The laser was tested four two hours and operated flawless.

## Equipment failure

The Helium transfer, which is used to pump the helium from the dewar through the cryostat starts to leak severely at the controlling valve on the top of the transfer. The problem was reported and Dr. Brown decided to buy a new transfer from Janis Research and to keep the old one for spare purposes.

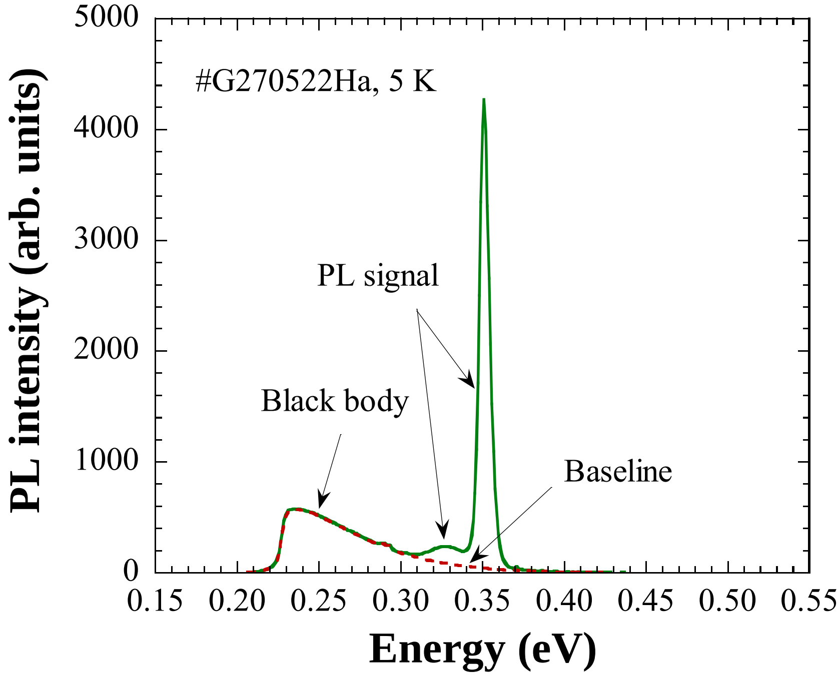


**Figure 1.** PL measurement at 5 K. Power output of the laser was 200 mW. The solid line represents the actual measurement and the broken one the baseline. In the black body region, the actual measurement and baseline are identical.

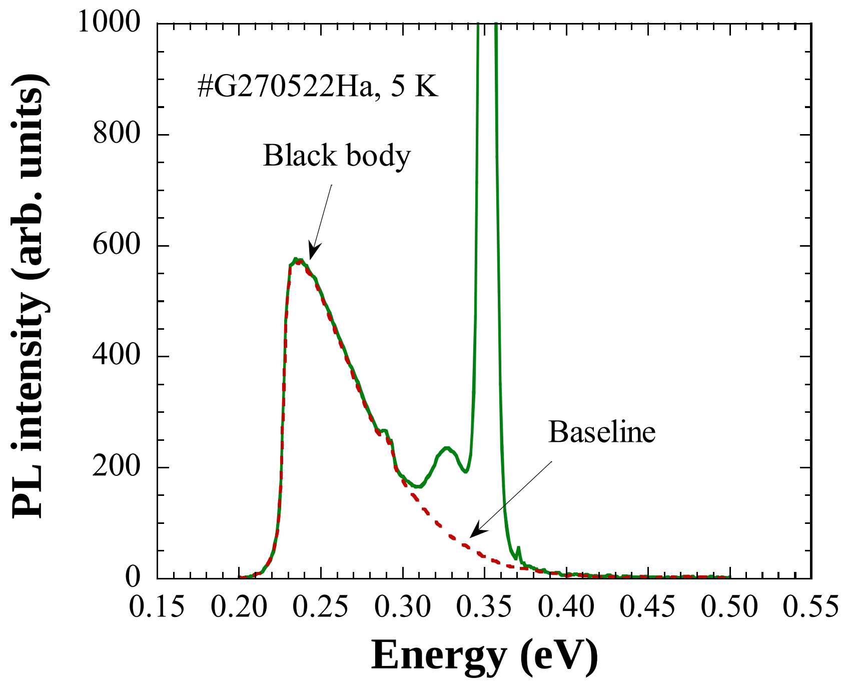


**Figure 2.** Same as Figure 1 with enhanced y-axis resolution in order to reveal more clearly the baseline.

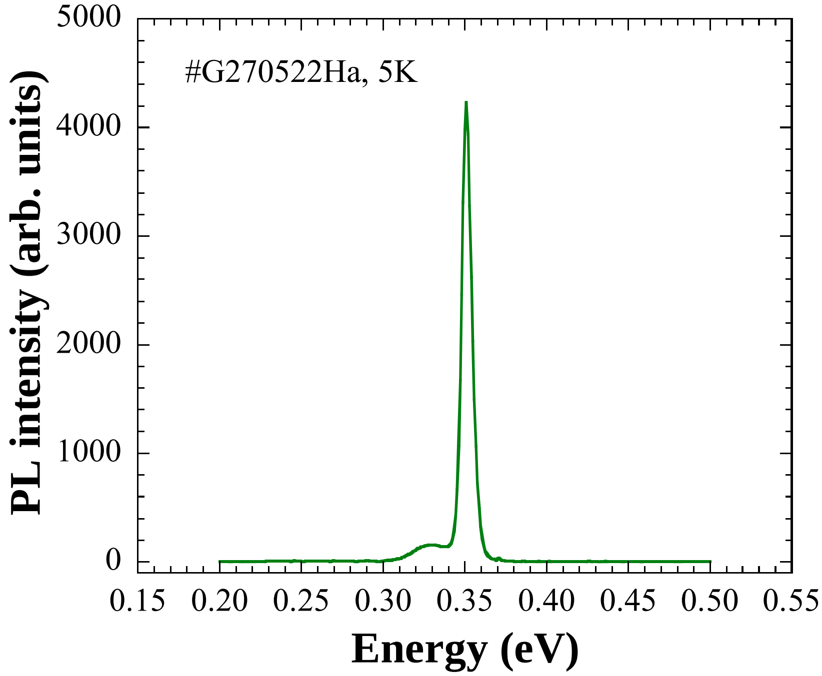


**Figure 3.** Corrected PL spectrum in Figure 1. The correction was done by subtracting the baseline (broken line) from the measurement (solid line) in Figure 1.

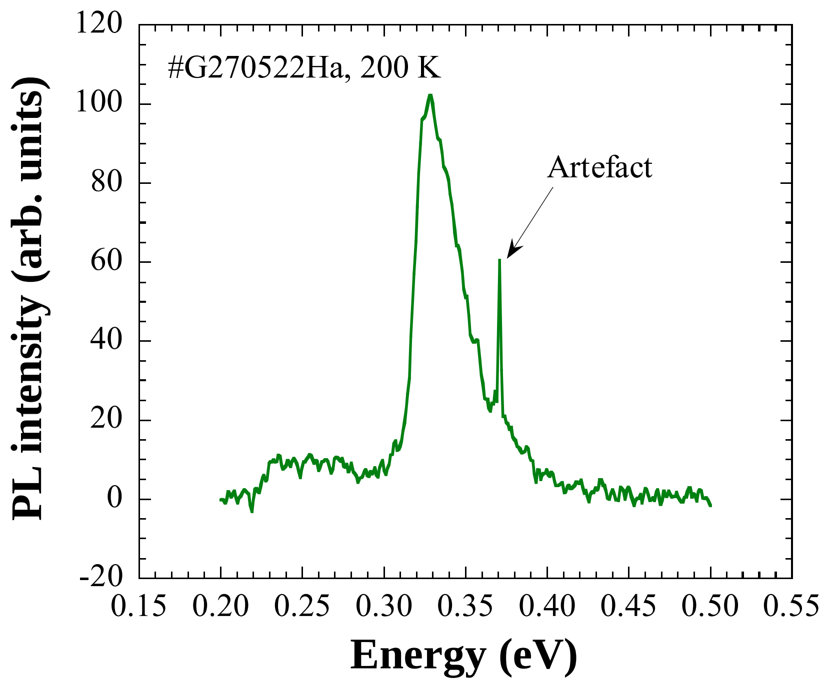


**Figure 4.** Corrected PL at 200 K. The narrow peak is not part of the signal but stems from the exciting laser.

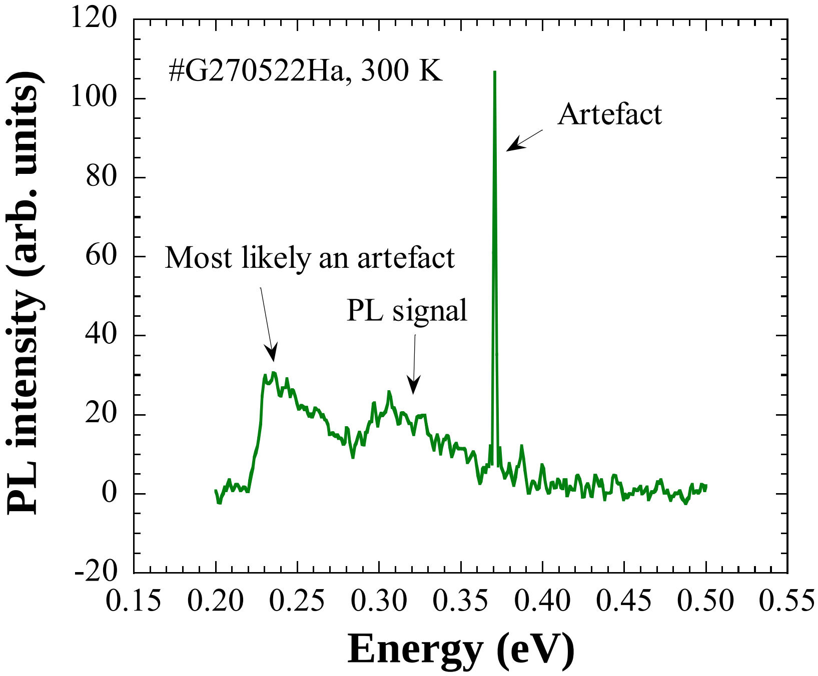


**Figure 5.** Corrected PL at 300 K.