Abstract. We present important aspects of photoluminescence (PL) of \( \text{Cd}_{x}\text{Hg}_{1-x}\text{Te} \) in the infrared part of the spectrum where background thermal radiation significantly affects the PL spectrum. We show how the background spectrum can be removed from the data. We also show how the wavelength of the excitation laser affects the relative intensity of the PL peaks from a multi-layer structure. Finally, we present temperature dependent PL of a \( \text{Cd}_{0.36}\text{Hg}_{0.64}\text{Te}/\text{Cd}_{0.61}\text{Hg}_{0.39}\text{Te} \) multiple quantum well structure grown on a 4 \( \mu \text{m} \) thick \( \text{Cd}_{0.36}\text{Hg}_{0.64}\text{Te} \) buffer layer. We attribute the low temperature peak from the buffer layer to impurities. The impurity levels are depopulated as the temperature increases, resulting in a decreased PL peak intensity. Above ~200 K a band-to-band peak from the buffer layer is observed. The quantum well peak persists up to ~200 K.

1. Introduction

\( \text{Cd}_{x}\text{Hg}_{1-x}\text{Te} \) is an important material for infrared detectors [1,2] as the band gap can be compositionally tuned from -0.26 to 1.61 eV at 77 K [3]. Photoluminescence (PL) is a useful technique as it yields information about the optical quality of the material. We will in this paper focus on PL measurement techniques which are important to take into account when analyzing the PL spectra.

The infrared PL spectrum can be significantly distorted by the internal background radiation from inside the FTIR instrument because these spectra lie in the same wavelength range. We have solved this problem by subtracting the measured interferogram of the background radiation from the combined PL + background interferogram prior to Fourier transformation.

Two lasers with different wavelengths (\( \lambda = 678 \text{ nm} \) and 2.01 \( \mu \text{m} \)) were used. The higher absorption coefficient of photons from the red laser results in creation of electron-hole pairs close to the sample surface whereas the infrared laser has a longer penetration depth and will excite carriers much deeper into the sample. (The carriers excited by the red laser will thus be much more prone to non-radiative surface recombination than the carriers excited by the infrared laser. The red laser can thus be used to probe close to surfaces whereas the infrared laser will probe deeper into a structure.)

We will also show PL of a \( \text{Cd}_{x}\text{Hg}_{1-x}\text{Te} \) multiple quantum well (MQW) structure in the temperature range 10 – 300 K.
2. Experimental

A Cd$_{0.36}$Hg$_{0.64}$Te MQW structure was grown by molecular beam epitaxy in a 32P Riber machine on a (211)B oriented lattice-matched CdZnTe substrate. The structure consisted of a 4 μm Cd$_{0.36}$Hg$_{0.64}$Te buffer layer and four 92 Å thick Cd$_{0.36}$Hg$_{0.64}$Te quantum well layers between five 297 Å thick Cd$_{0.61}$Hg$_{0.39}$Te barrier layers, as shown in figure 1. The individual thicknesses of the wells and barriers were found from x-ray diffraction simulations [4]. A 16 Å CdTe cap was deposited on top of the structure. The composition of the thick buffer layer was measured using transmission spectroscopy.

The PL spectra were recorded with a Bruker IFS 66 spectrometer (FTIR). Both the infrared and the red lasers were used as excitation sources. Either laser was directed at normal incidence, through a hole in a large parabolic mirror, onto the sample which was mounted in a cryostat. The PL radiation was collected by the mirror, focused and directed into the FTIR. After passing through the interferometer, the radiation was detected with a CdHgTe detector. The red laser has a penetration depth in Cd$_{0.35}$Hg$_{0.65}$Te of approximately 100 nm [5,6] whereas the infrared laser has a penetration depth of approximately 1 μm [7]. The entire beam path was flushed with nitrogen to remove atmospheric absorption.

3. Results and discussion

3.1. PL spectrum extraction procedure

Since we are working in the infrared wavelength region there will be, in addition to the PL signal from the sample, thermal background radiation from both the sample (external background) and the detector side of the interferometer (internal background). The internal background will give rise to an interferogram which is out of phase with the interferogram due to radiation from the sample (external background + PL), as they come from opposite sides of the interferometer. If simply Fourier transforming the combined interferogram from all these contributions, the amplitudes of the resulting frequency spectrum become absolute values of the difference between the internal background and the (external background + PL spectrum) (figure 2 (ii)). This results in amplitudes of zero whenever the internal background and the (external background + PL) spectrum are of equal intensity.

In order to extract the correct PL spectrum, we must subtract the measured interferogram of the (internal + external background) from the interferogram of the (internal background + external background + PL) before Fourier transformation. Then, the resulting interferogram can be Fourier transformed to yield the PL spectrum only (figure 2 (iii)). The (internal + external background) is simply a measurement of the sample, at a given temperature, but with the laser off. At low sample temperatures, the internal background will be dominating. A comparison of figures 2 (ii) and (iii) shows how important it is to correctly subtract the background spectrum.

Figure 1. Schematic drawing of the MQW structure.

Figure 2. (i) Fourier transformation of (internal + external background) interferogram, (ii) the incorrect PL spectrum obtained when the (internal + external) background interferogram is not subtracted prior to Fourier transformation, and (iii) the correct PL spectrum obtained when the background interferogram is removed prior to Fourier transformation.
3.2. Effect of excitation wavelength

Since the penetration depth of the lasers differs by a factor on the order of 10, the lasers have different uses. PL obtained using the red laser can be used to characterize the volume close to the surface. PL using the infrared laser can be used to probe deeper into the layer.

We have used both the infrared and red lasers to characterize the Cd_{x}Hg_{1-x}Te MQW structure shown in figure 1. The PL spectra obtained using the red and infrared lasers are shown in figure 3. The spectra have been normalized to correct for different laser photon fluxes and laser spot sizes on the sample.

The PL spectrum obtained using the red laser shows a high-intensity peak from the quantum wells whereas the intensity of the PL peak from the buffer layer is very low. Using the IR laser the luminescence from the buffer layer increases significantly. The red laser is mostly absorbed in the MQW structure and has a low intensity when reaching the buffer layer, resulting in a small PL peak from this layer. The infrared laser (hν_{IR laser} < E_{g barrier}) is not absorbed in the barriers and hence gives a PL peak with a higher intensity from the buffer layer.

![Figure 3. PL spectra of the MQW structure using red and infrared lasers. Measurement performed with the sample at 30 K.](image)

3.3. Photoluminescence as a function of temperature

In order to get a PL signal from both the buffer layer and the MQWs, we performed temperature dependent measurements using the infrared laser. PL spectra recorded at different temperatures are shown in figure 4.

Three overlapping PL peaks from the buffer layer can be observed at approximately 325 meV at 10 K, in addition to the peak from the quantum wells (397 meV). Measurements of the PL intensity vs. excitation laser intensity in similar layers grown under equal conditions have shown that the intensity of the peaks from the buffer layer at low temperatures saturates. This is in agreement with Lusson et al. [8] and indicates that they are impurity related. Hg vacancies, as well as n-type background doping, are common in MBE-grown Cd_{x}Hg_{1-x}Te [1,2] and are most likely the origin of the PL peaks.

As the temperature is increased, the impurity levels become depopulated, which also results in a decreased PL peak intensity. From the data we see that in an intermediate range from approximately 60 - 150 K, the recombination in the buffer layer is mainly non-radiative. Presumably Auger recombination is dominant in this transition region. Above ~ 200 K a peak originating in the buffer layer starts to appear. We attribute this peak to band-to-band transitions.

The FWHM of the PL peak arising from the quantum wells measured at 10 K is 9.8 meV. This is an improvement over the earlier reported 18 meV FWHM for MQWs in this material system at 2 K [9]. More details of the PL arising from the quantum wells will be presented in another paper in this issue [4].
4. Conclusions
We have shown that a correct PL spectrum can be obtained by subtracting the measured (internal + external background) interferogram from the measured PL interferogram prior to Fourier transformation.

A temperature dependent PL measurement of an MQW structure has been performed. We believe that the PL spectrum from the thick buffer layer below approximately 60 K is due to impurities, whereas above approximately 200 K the band-to-band peak can be observed. The PL peak from the MQWs persists up to approximately 200 K.

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