# 2nd Conference of International Consortium on Terahertz Photonics and Optoelectronics

## PROGRAM AND PROCEEDINGS

FIR-LAB

International Research Network
"Bright Far-Infrared Optoelectronic
Sources to Field-Matter Interaction
Studies, Life Sciences and Enviromental
Monitoring"
2nd Workshop

July 6–7, 2019

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N. Novgorod

8th **R**ussia-**J**apan-**US**A-**E**urope
Symposium
on Fundamental & Applied Problems
of **Tera**hertz Devices
& **Tech**nologies

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International Research Network **“Bright Far-Infrared Optoelectronic Sources to Field-Matter Interaction Studies, Life Sciences and Enviromental Monitoring”** (**IRN FIR-LAB**) was created in 2017 by Agreement between French (CNRS, UPD, UPMC, ENS) and Russian (MSU, RFBR) institutions for 2018–2021 year to coordinate scientific activities between laboratories making up this network falling into the scope:

- propagation of FIR/THz beams in atmosphere;
- high power FIR/THz sources;
- FIR/THz field-matter interaction studies;
- FIR/THz plasmonics, metamaterials, nanomaterials
- applications.

1st IRN FIR-LAB meeting was carried out in July 3-4, 2018 at École Normale Supérieure, Paris.

Based on the successful organizations of preceding Russia-Japan-USA-Europe (**RJUSE**) symposia in Japan, Russia, USA and Poland the 8th RJUSE is organized in Nizhny Novgorod, Russia, on July 08–11, 2019. The symposium aims to bring together researchers who tackle “Fundamental & Applied Problems in Terahertz Devices & Technologies”, so as to stimulate discussions on the state-of-the-art results and promote the collaborations in the following topics:.

**THz physics**

- Carrier transport & quantum effects in devices;
- Nonequilibrium carrier dynamics;
- 2D materials & their heterostructures;
- Terahertz properties of Dirac matter.

**THz devices & electronic/optical components**

- Sub-THz/THz transistors, mixers, etc.;
- Metamaterials, photonic crystals;
- Surface-plasmon-polaritons;
- Electronic/photonic/plasmonic devices;
- Nonlinear optics based devices;
- Superconductors, bolometers, etc.

**THz applications**

- Wireless communications;
- Imaging;
- Spectroscopy;
- Astronomy.

# Terahertz Photoluminescence from HgTe/$Hg_{1-x}Cd_xTe$ Quantum Well Heterostructures due to Valence Band – Acceptor Transitions

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**Abstract – THz photoluminescence (PL) spectra from QW HgTe/CdHgTe heterostructures are studied in the temperature range of 30–100 K under the excitation power varied from 3 mW to 300 mW. The long-wavelength lines in the PL spectra, whose position does not change with temperature, are associated with the capture of free holes on the states of neutral mercury vacancies. Non-monotonic dependence of the impurity PL signal on the power of the exciting source has been observed.**

***Keywords – HgTe/CdHgTe heterostructures, photoluminescence, mercury vacancies***

## I. INTRODUCTION

Terahertz (THz) radiation due to transitions involving impurities and defects in bulk semiconductors and semiconductor quantum well (QW) structures has been of interest for a long time [1, 2]. The related effects can be useful for developing terahertz sources employing optical transitions between impurity states. Until recently, studies of impurities and defects were carried out mainly in the most commonly used semiconductor heterostructures based on Ge, GaAs and Si [3]. This work continues a series of work aimed at studying the impurity/defect centers in HgTe/CdHgTe QW heterostructures, in which the most common acceptor is a mercury vacancy. Mercury vacancies manifest themselves in the photoconductivity (PC) [4, 5] and photoluminescence (PL) spectra [6]. In this work we investigate the PL spectra related to the mercury vacancies.

## II. EXPERIMENTAL TECHNIQUE

The structures under study were grown by molecular beam epitaxy on semi-insulating GaAs substrates in the (013) direction with ZnTe buffer layers (500 A thick) and CdTe (5 μm thick). On a CdTe buffer a 49 A thick HgTe QW was grown, surrounded by 300g thick $Hg_{0.24}Cd_{0.76}Te$ barrier layers. The bandgap of the structure is about 50 meV at T = 4.2 K, and the residual hole density is $7 \cdot 10^{10}$ $cm^{-2}$. The PL studies were performed using a Bruker Vertex 80v Fourier spectrometer operating in the step-scan mode. The measurements were carried out in a closed-cycle optical cryostat with temperature range of 20–150 K. A silicon bolometer cooled to 4.2 K was used as a detector. Optical excitation was carried out by a continuous laser with a wavelength of 808 nm. The maximum laser power was 300 mW.

## III. EXPERIMENT RESULTS

Figure 1 shows the PL spectra of under study, measured at 30 K at different pump powers in the range from 3 to 300 mW. The quanta energy for interband transitions in such a structure at a temperature of 30 K is about 450 $cm^{-1}$. It can be seen that in all spectra there is a PL band from 50 to 400 $cm^{-1}$, separated by narrow dips in three lines: 50–160 $cm^{-1}$ (line 1), 160–250 $cm^{-1}$ (line 2) and 250–400 $cm^{-1}$ (line 3). Fig. 1 shows that at high excitation intensity (100 and 300 mW), the fourth PL line appears at 450–600 $cm^{-1}$ (line 4).

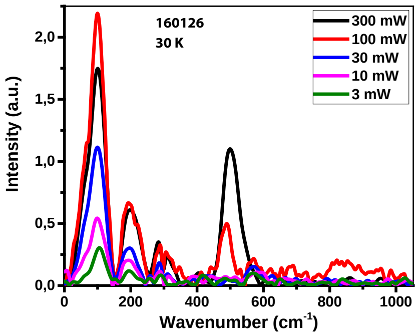

**Fig. 1.** The PL spectra of sample under study ($HgTe/Hg_{0.24}Cd_{0.76}Te$ 49 A thick QW) measured at 30 K and a source power from 3 to 300 mW.

As the power of the exciting radiation increases, the position of the 1–3 PL bands does not change, and the signal intensity changes non-monotonically. Fig. 1 shows that the amplitude of lines 1–3 grows as the pump power increases from 3 to 100 mW, but when the source intensity increases to 300 mW, the amplitude of the line 1 starts to decrease. The intensity of the short-wavelength band 4 increases with the source power, while the position of the long-wave front of this band remains unchanged.

Figure 2 shows the PL spectra of the studied sample, measured at a fixed source power (300 mW), but at different temperatures. As the temperature rises, the intensity of the PL bands decreases, while the position of the bands 1–3 does not change. Band 4 shifts towards high energy quanta suggesting that band 4 should be associated with interband transitions. Indeed, it is well known [4] that the band gap in the structure under study should increase with temperature. The 1–3 PL bands, however, do not shift with temperature, and, on the contrary, are associated with carrier transitions between states bound to a certain band. Previously, such long wavelength PL bands were associated with transitions involving mercury vacancies [4].

## IV. INTERPRETATION OF THE MEASURED PL SPECTRA

The mercury vacancy is a double acceptor and can be found in three charge states: a neutral $A^0$ center with two holes, an $A^{-1}$ center with one hole and an $A^{-2}$ center without any holes. The PL occurs due to the radiative transitions of holes from the valence band to the acceptor states. One can think of such transitions as the capture of holes to the acceptor centers: either the capture of a hole to a $A^{-2}$ center with the emission of a photon forming an $A^{-1}$ center or the capture of a hole to an $A^{-1}$ center with the emission of a photon forming an $A^0$ center. $A^0$ center, cannot capture the holes; therefore, such centers do not participate in PL. The calculation shows that the long-wavelength PL lines 1-3 can be associated with the capture of free holes on the states of neutral mercury vacancies. Band 4, which is associated with interband transitions, appears when the power of the exciting source increases. At the same time, the signal in the long-wavelength bands falls. This may be due to the fact that, under weak excitation, electrons from the conduction band transfer to neutral states of mercury vacancies ($A^0$ centers) in a nonradiative manner. The resulting $A^{-1}$ centers are contribute to PL. However, at a certain source power, most of the $A^0$ centers are filled with electrons, i.e. the number of final states for nonradiative transitions from the conduction band decreases. As a result, electrons begin to recombine with holes from the valence band radiatively. With an increase in the pump power, such electron transitions are getting more intense, while the number of holes in the valence band that can be captured to $A^{-1}$ centers decreases, and thus the signal of the impurity PL decreases.

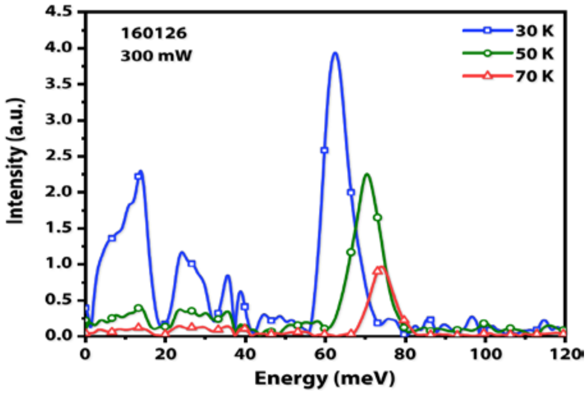

**Fig. 2.** The PL spectra of sample under study, measured under 300 mW excitation at different temperatures

## V. CONCLUSIONS

In this work, the THz PL spectra of HgTe / CdHgTe QW heterostructures. The long-wavelength lines in the PL spectra, whose position does not change with temperature, are associated with the capture of free holes on the states of neutral mercury vacancies. Non-monotonic dependence of the impurity PL signal on the power of the exciting source has been observed. It is shown that it is due to the saturation of the number of partially ionized mercury vacancies with increase in pumping intensity.

## ACKNOWLEDGMENTS

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