2nd Conference of International Consortium on Terahertz Photonics and Optoelectronics

PROGRAM AND PROCEEDINGS

FIR-LAB

TERA RJUSE 2019 TECH
N. Novgorod

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

July 6–7, 2019

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

July 8–11, 2019

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Ministry of Science and Higher Education of the Russian Federation
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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.

Dynamics of Terahertz Excitations in Group-IV Semiconductors Doped by Hydrogen-Like Impurity Centers

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Abstract – The hydrogen-like impurity centers are the major contributors to electrical and infrared properties of the group-IV semiconductors. Dynamics of nonequilibrium charge carriers bound to excited impurity states has been intensively studied over last decade by time-resolved THz spectroscopies. Typical characteristic times observed for excited impurity states, mechanisms of electron-phonon coupling will be reviewed for lightly, moderately and heavily doped diamond, silicon, germanium and silicon-germanium crystals.

Keywords – time-resolved spectroscopy, group-IV semiconductors, hydrogen-like impurity centers

Atomic-like energy spectrum of hydrogen-like substitutional impurities in bandgaps of semiconductors attracts specific interest due to its potential for infrared / THz photonics[1] and quantum technologies[2]. Among key characteristics of electronic states of such impurity centers for optical and optoelectronic applications are those related to dynamics of non-equlibrium electron distributions. Due to strong interaction of impurity states with characteristic lattice phonons typical nonradiative relaxation times of excited states often fall down to picosecond (ps) time scale.

Time-resolved spectroscopies utilizing ps-pulsed infrared free electron lasers are the most direct approach to assess ultrafast dynamics of excited states of such impurity centers.

In crystals with low/residual concentration of dopants induced populations in excited impurity states have, as a rule, the longest lifetimes, up to a few nanoseconds (ns) (Table 1) determined mainly by nonradiative decay due to interaction with single or multiple optical and acoustic phonons. Targeted (co-)doping and compensation of semiconductors allows to control intracenter electron dynamics, usually reducing intracenter relaxation times down to a few tens ps, and by this to enable design of fast / broad-band infrared photoconductive detectors[3] as well as to predict feasibility and performance of impurity-based THz emitting devices.

Table 1. The ranges of lifetimes of optically excited charge carriers measured by time-resolved spectroscopy in different group-IV semiconductors doped by hydrogen-like impurity centers

Semi-conductor	Range [THz]	Lifetimes in excited states	References
p-C [a]	73÷89	2.5 ps ÷ 330 ps	[4]
n-Si [b]	7.3÷20.0	25 ps ÷ 236 ps	[5], [6], [7], [8]
p-Si	7.3÷10.3	6 ps ÷ 130 ps	[9], [10]
n-Ge [c]	1.6÷2.9	70 ps ÷ 3.2 ns	[3], [11], [14]
p-Ge [c]	2.3÷15.8	30 ps ÷ 10.9 ns	[3], [12]
n-SiGe [c]	8.1÷10.8	90 ps ÷ 160 ps	[13]

[a] including isotopically enriched dopant.

[b] including isotopically enriched host lattice and co-doped crystals.

[c] including heavily doped highly compensated crystals, uniaxial stress.

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