Polariton based THz sources and detectors

Scientific Reports for Short Visit Grants

Research visit of Dr. M. Kaliteevski to the Mediterranean Institute of Fundamental Physics (Rome).

Purpose of the visit

It was planned to develop a theoretical basis required for the creation of polaritonic devices for generation, detection and manipulation of THz radiation. In particular it was planned to develop the following subjects : ***i) Polaritonic system as active area for THz device and ii) Cavity for THz radiation***. According to original proposal, planned duration of the visit was 6 months, the grant was given for the period of three months.

Description of the work carried out during the visit

Technological feasibility of the fabrication of quantum well microcavity providing efficient THz radiative transition has been analysed the fundamental constrains on the design of the structure and operational frequency range have been analysed. Existing strong coupling microcavities include strained layers (for example InGaAs quantum well surrounded by GaAs cladding layers, as well as InGaAsN systems). Therefore there is a limited maximal thickness of quantum well below which quality of quantum well is maintained, and this critical value depends on composition of layer. On other hand separation of different exciton levels in quntum well and oscillator strength of exciton depends on composition of quantum well and its thickness. Since for efficient radiative THz transition matching of Rabi splitting and separation of exciton levels in quantum well is required, design of quantum well microcavity with predefined frequency of THz transition require development of special method, and such methods allowing the design of the cavity with predefined properties has been developed.

Microcavity polaritons exhibit pronounced non-linear properties at very low excitation intensities (of the order of 1 W/sm^2). Therefore, coupled systems of THz photos and exciton-polaritons are the candidate for realisation of non-linear THz devices such as THz switch. In order to investigate such possibility, the formalism based on generalized Linblad equation for the density matrix, which describe coherent interaction of THz radiation, polariton condensate, and reservoir of polaritons. Modelling of system demonstrated that coherent interaction of THz photons and polaritons lead to variety of new phenomena: oscillation of THz intensity (which could be used for generation of short THz pulse), THz bistability (which can be used for development of THz switching and detectors of THz radiations).

One of the problem, reducing quantum efficiency of polaritonic devices is small polariton lifetime due scattering on phonons. One of the possible way reduce the scattering rate of polariton is to modify mode spectrum of phonons by its spatial quantisation in pillar microcavities. Detailed analysis of polariton scattering on phonons has been conducted, and it was found that polariton scattering rate is reduced, but the value of this reduction is moderate, dozens of percent.

The work for development of the module for modelling for the THz microcavity simulator suitable for integration with software TiberCad has been carried out.

Description of the main results obtained

The formalism based on the formalism based on generalized Linblad equation for the density matrix for the description of coherent interaction of system of THz photons and microcavity polaritons has been developed. It was shown that the system demonstrate pronounced non-linear behaviour.

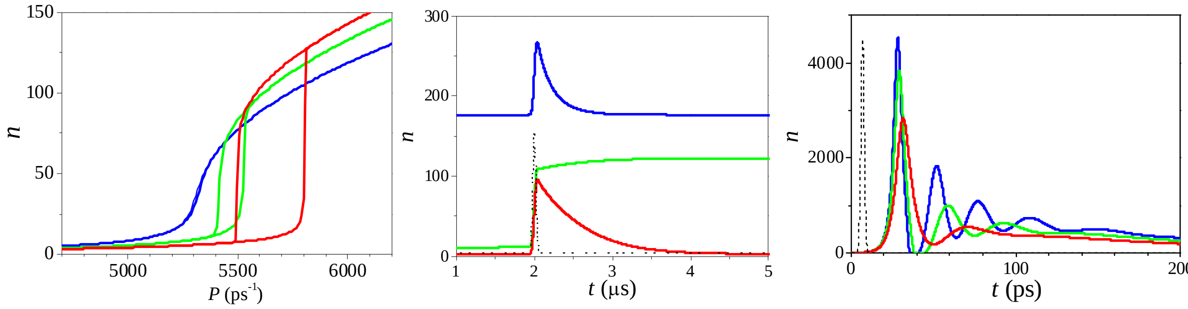

Figure 1. Occupancy of THz mode in equilibrium state as a function of pumping illustrating bistability (left); Response of the of the system to short incident THz pulse illustrating switching (centre); and temporal dependence of THz occupancy illustrating THz short pulse generation (right) From [1]

Equilibrium value of THz population *n* demonstrates threshold-like behaviour as a function of pumping *P*. For high enough temperatures, below the threshold the dependence of *n* on *P* is very weak. When pumping reaches the certain threshold value, polariton condensate is formed in the lower polariton state, radiative THz transition is amplied by bosonic stimulation, and occupancy of THz mode increases superlineary together with occupancy of lower polariton state *n* (fig.1, left, blue curve). This behavior is qualitatively the same as in the approach operating with semiclassical Boltzmann equations. However, lowering of the temperature leads to the onset of the bistability and hysteresis in the dependence *n*(*P*). The bistable jump appears when the intensity of the pump tunes into resonance with cavity mode (fig.1, left green and red curves). The parameters of the hysteresis loop strongly depends on temperature . For 1K, it is very pronounced and broad. The increase of the temperature shifts the loop into region of higher pumps and diminishes it width, until it disappears completely at T = 20K (Fig1, left,).

If the system of coupled THz photons and cavity polaritons is in the state corresponding to the lower branch of the S-shaped curve in the bistability region, illumination of the system by a short THz impulse can induce its switching to the upper branch, as it is demonstrated at Fig.1 (centre). It can be seen, that the response of the system is qualitatively different depending on the value of the pumping *P*. If *P* lies outside the bistablity area, illumination by THz pulse leads to a short increase of the n but subsequently system experiences relaxation and returns to its original state (Fig.1, centre, red and blue curves). However, when the system is in the bistability regime, application of the short THz impulse induces the switching.

Coherent nature of the interaction beween excitons and THz photons make possible the periodic exchange of the energy between polaritonic and photonic modes and oscillatory dependence of the THz signal in time. Fig.1, (right) shows temporal evolution of the occupancy of THz mode after excitation of the upper polariton state by a short pulse with duration of 2 ps. It is seen that the occupancy of THz modes reveals a sequence of the short pulses having duration of dozens of ps with amplitude decaying in time due to escape of THz photons from a cavity and radiative decay of polaritons. Note that if the lifetime of polaritons is less than the period of the oscillations, single pulse behaviour can be observed. Appropriate choice of the parameters can ultimately lead to a generation of THz wavelets composed of one or several THz cycles, which make polariton-THz system suitable for application in a sort pulse THz spectroscopy.

Future collaboration with host institution

It was planned to continue collaboration to continue to investigate the area of of polaritonic THz devices within MIFP. Two proposals have been prepared and submitted to EU Commission.

1) ICT FET Proposal “Polariton based TeraHertz sources”. This proposal is aimed at experimental realisation of prototype of polaritonic devices.

2) IRSES Proposal “ Polaritonic THz devices”. This proposal aimed at establishing of links between researchers working in different countries, and bring together “polaritonic” and “THz” scientific communities.

Projected publications/articles resulting or to result from the grant

[1] I. G. Savenko, I. A. Shelykh, and M. A. Kaliteevski, Nonlinear terahertz emission in semiconductor microcavities, *Phys. Rev. Lett.*, in press (2011)

[2] I. Iorsh, M.Kaliteevski, R. A. Abram, A. Di Carlo, I. Shelykh and A.V. Kavokin, Design and properties of continuous THz emitter based on polariton microcavity, to be submitted to *Phys. Rev. B*