POST DOC

- Axe de GANEX : 2 - Laser et sources cohérentes
- Titre du sujet : ***Mid-IR intersubband polaritonics in the GaN/AlGaN system***
- Nature du post doc : **Academique**

  Laboratoire: Institut d'Electronique Fondamentale, 91405 Orsay – FRANCE
- Date souhaitée de démarrage : Juin 2015 - Durée : 12 Mois
- Lien avec un projet ANR ou H2020: Aucun
- Lien avec un autre partenaire de GANEX : INAC/E. Monroy / Open to other actors too

We are accustomed to optoelectronic devices operating in the weak coupling regime between light and matter. Conventional lasers, for instance, operate in this regime. Recently interest has arisen for quantum systems in the *strong coupling* regime instead, when the coupling for the light-matter interaction is so strong, that perturbation theory doesn't suit anymore the system description. The new eigenmodes - partially light, partially material excitation – are called cavity polaritons. In semiconductors, exciton-polaritons are most widely studied. Originally reported in 1992 [1], their extremely light mass and the bosonic character inherited from the excitonic component leads to Bose-Einstein condensates at relatively high temperatures.

Condensation is crucial for operating the system as a "bosonic" laser [2]. In a bosonic system, the transition probability to a final state is proportional to the population of that state. Polariton lasing happens when the scattering time towards the ground state – typically at $k=0$ – is shorter than the final state lifetime: population then builds up abruptly. High polariton densities are advantageous, but for exciton-polaritons it cannot be chosen at will: it must comply with the limit set by the Mott density (n_{Mott}). Above a fraction of n_{Mott}, bosonicity is lost. This explains the low threshold, and the low power, of exciton-polariton bosonic lasers.

Recently, polaritons have been explored in a different system, where the material excitation is an intersubband (ISB) transition (to be more rigorous, an ISB plasmon) in a semiconductor quantum well (QW). They are called *intersubband polaritons* [3], and their bosonic character is of crucial importance. They are composite bosons. Following Ref. [4], if $b^+_{\mathbf{q}}$ is the creation operator of the *bright* ISB excitation (wavevector **q**) the commutation operator on a state |ϕ> with N_{exc} ISB excitations is:

$$\langle \phi | b_{\mathbf{q}'}, b^+_{\mathbf{q}} | \phi \rangle = \delta_{\mathbf{q}',\mathbf{q}} + o\left(\frac{N_{exc}}{n_{QW} N_{el}}\right),$$

where n_{QW} is the QW number, and N_{el} is total the number of electrons in the QW. The formula states that bosonicity is preserved if $N_{exc} << n_{QW} \cdot N_{el}$. We have a new degree of freedom: in ISB polariton systems, the upper density limit for bosonic operation is not fixed by a Mott density, but it can be *engineered* (to a certain extent) with the electronic doping. The maximum temperature for an ISB polariton condensate to be sustained and the maximum output power of an ISB polariton laser can therefore be optimized / maximized. This is the rationale to develop mid-IR intersubband polaritons in the GaN/AlGaN system: for a given ISB energy, it is immediately possible to dope the system more than 3 times higher than - for instance – GaAs, given that the m^*_{GaN}=0.22 while m^*_{GaAs}=0.067. Also, the Rabi frequency is inversely proportional to $\varepsilon^{0.5}_{sc}$, (the semiconductor material dielectric constant): the GaN low dielectric constant is a further advantage since it enhances Ω_{Rabi}.

The goal of this research project is to jumpstart the field of ISB polaritonics in the GaN material system, in the mid-IR spectral range (3μm<λ<8μm). The mid-IR choice is motivated by the (i) the reasonably good quality samples currently available [5], and (ii) the possibility of using grating-based, dispersive metal-insulator-metal (MIM) cavities which we have recently demonstrated very effective for ISB polaritons [6]. These MIM cavities mimic the polaritonic dispersion of exciton-polariton systems based on Fabry-Perot cavities, which has been the enabling tool behind all the recent breakthrougths in that field. This project also has a strong *material-science* component (in collaboration with INAC/ E. Monroy), since the linewidth of mid-IR ISB transitions in the GaN material system are still larger than, for instance, in the InGaAs system.

The post-doc candidate will lead an experimental project, albeit with a strong modeling activity. She/he will first model the polaritonic system to determine the minimal requirements on the necessary GaN QW samples (IEF). She/he will then proceed, in collaboration with INAC/Grenoble, to the experimental development of the samples (INAC), which will then be inserted in the proper grating based, dispersive MIM cavities [6] to reach/observe the strong coupling regime (IEF). The candidate will also extend the recently developed concept of *step QWs* [7] to the mid-IR. This system allows one to cancel the internal field, adding design flexibility. The best samples will be then employed for optical-pumping experiments in order to at least observe the enhancement of spontaneous emission in strong-coupling, which has never been observed for ISB transitions. The topic is open to the participation of other GaNeX members.

References

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