Coupled Electron-Phonon Modes in Optically Pumped Resonant Intersubband Lasers

Authors: H.C. Liu, C. Y. Song, Z. R. Wasilewski, et al.
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Recommended with a Commentary by Claire Gmachl, Princeton University

Mid-infrared intersubband (ISB) lasers, Quantum Cascade as well as optically pumped ISB lasers, are based on electronic transitions between quantized subbands in a semiconductor heterostructure of multiple coupled quantum wells (QWs). Population inversion, which allows for laser action, is generated by engineering the electron scattering times of a 3 level laser scheme. Electrons are pumped into level 3, the highest energy level of interest; the laser transition occurs from level 3 to level 2, and level 2 is rapidly depleted of electrons by resonant longitudinal optical (LO) phonon scattering into level 1. This simple picture has been very successful as evidenced by the rapid progress made in ISB lasers; nevertheless, the recent paper by H.C. Liu et al. reminds us that the picture should be far more complex, specifically it needs to include collective excitation phenomena. The latter are clearly noticeable, for a skilled and meticulous experimentalist, and need to be taken into account. In addition, the assumption that phonons are generated unrelated to the lasing process needs to be questioned as well.

H. C. Liu *et al.* present a careful study of optically pumped ISB lasers based on coupled asymmetric double QWs. The GaAs/AlGaAs QWs are chosen in thickness so that the energy separation of the two bottom most levels 2 and 1 covers the energy of the GaAs, and GaAs-like LO phonons around 36 meV. Furthermore, the QWs are designed such that the energy separation between levels 3 and 1 falls within the emission wavelength range of a high-power pulsed CO2 pump-laser. Electrons are supplied to level 1 through modulation doping of the wide barriers separating the double QWs.

Under optical pumping, laser action is observed in a Raman process instead of through the conventonal incoherent pumping process. This is the first surprise; in the simple (inaccurate) picture, electrons would rather lase from the point of largest dipole moment of the 3 to 2 level separation independent of the pumping energy. The second surprise is the energy of the Raman shift, which is different from the designed energy separation between levels 2 and 1, and different from the energy of the LO-phonon. Both values are well known or have been measured. The entire set of about 25 different samples with a wide range of designed levels 2 to 1 energy separations shows exactly this behavior. Even more, when recording the Raman Stokes shift of all the samples, Liu et al. show, that the pure LO-phonon energy is not accessible as a value; i.e. undressed phonons are not emitted. Rather, coupled ISB plasmon–phonon modes are the final product of the lasing process.

This is new and unexpected. The paper pleasantly surprises and educates. It remains to be seen if electrically pumped ISB lasers show a similar behavior. If so, the potential impact may be profound, e.g. as better lasers are designed as a result. Finally, as the final product of the laser process is not phonons, but coupled ISB plasmon phonon modes, this "could open up a new avenue for realizing a phonon or even a polaron "laser"…".