Mode synchronization in GaN ridge polariton lasers

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Abstract: We experimentally demonstrate polariton laser in a GaN ridge waveguide. The strong-coupling regime is assessed through a comparison of the measured and modeled cavity free spectral range (FSR). The findings reveal that the laser exhibits a transition from monomode to multimode operation as the temperature is increased from 70K to 150K. The transition to multimode lasing is characterized by a flattening of the FSR just above the threshold, which constitutes the signature of mode synchronization induced by polaritonic nonlinearities.

Long-studied, polaritons have been most often studied in vertical microcavities with an active layer sandwiched between two distributed Bragg reflectors (DBR). More recently, polaritonic waveguides in which the photon confinement is achieved by total internal reflection have been introduced and begun to be studied. Polaritons in waveguides offer new possibilities for their use in optoelectronics, built upon the concept of the polariton laser. Unlike a conventional semiconductor laser, a polariton laser does not need a population inversion to stimulate the light emission, potentially enabling the development of laser components that operate with much greater gain and short injection sections. We experimentally evidenced the distinction between a ridge polariton laser and a conventional edge-emitting ridge laser in a Fabry-Perot cavity [1]. The laser effect is accomplished with an exciton reservoir length that constitutes only 15% of the cavity length, a feat that would not be possible in a conventional ridge laser. Recently, polariton lasing in the ultraviolet (UV) spectral range has also been reported in microring resonators that use GaN/AlGaN slab waveguides [2]. Beyond this, a nonlinear effect resulting from polariton nonlinearity, such as ultrafast pulse modulation, has been reported in an AlInGaN polariton waveguide [3]; due to the negative group velocity dispersion, this self-focusing nonlinearity is predicted to lead to frequency combs in such polaritonic devices [4].

In this study, the horizontal laser cavities are GaN etched-ridge structures with vertical Bragg reflectors, measuring 20-60µm in length (inset fig.1(a)). The wide bandgap material GaN has robust excitons and large oscillator strength, making it a suitable choice to maintain the strong coupling regime up to room temperature [5]. The cavity is pumped with a pulsed laser that quasi-resonantly excites the exciton reservoir using a line-shaped spot profile. Figure 1(a,c) shows power-dependent emission spectra across the lasing threshold, for a cavity length Lcav=60µm, at T=70K and 150K. The spectra exhibit Fabry-Perot (FP) modes over a large energy range. Beyond the threshold, a "monomode" laser is demonstrated to operate continuously at 70K [1], whereas "multimode" lasing is observed beyond 150K, due to a spectral broadening of the polaritonic gain. To evaluate the strong coupling between photons and excitons in a waveguide geometry, our analysis will be based on the cavity free spectral range (FSR). The demonstration of the strong coupling regime is supported by the agreement between the FSRs obtained from the FP transmission below threshold, and the FSR calculated from lower polariton branch (LPB) dispersions (fig.1(b,d)), especially with a decrease of the FSR near the exciton resonance. Just above threshold, the FSR dispersion is unchanged at 70K, whereas it exhibits a flattening at 150K. This provides a first indication of mode synchronization, that would occur based on the polaritonic self-focusing nonlinearity [3,4]. This paves the way to the development of polariton lasers based on harmonic mode locking.

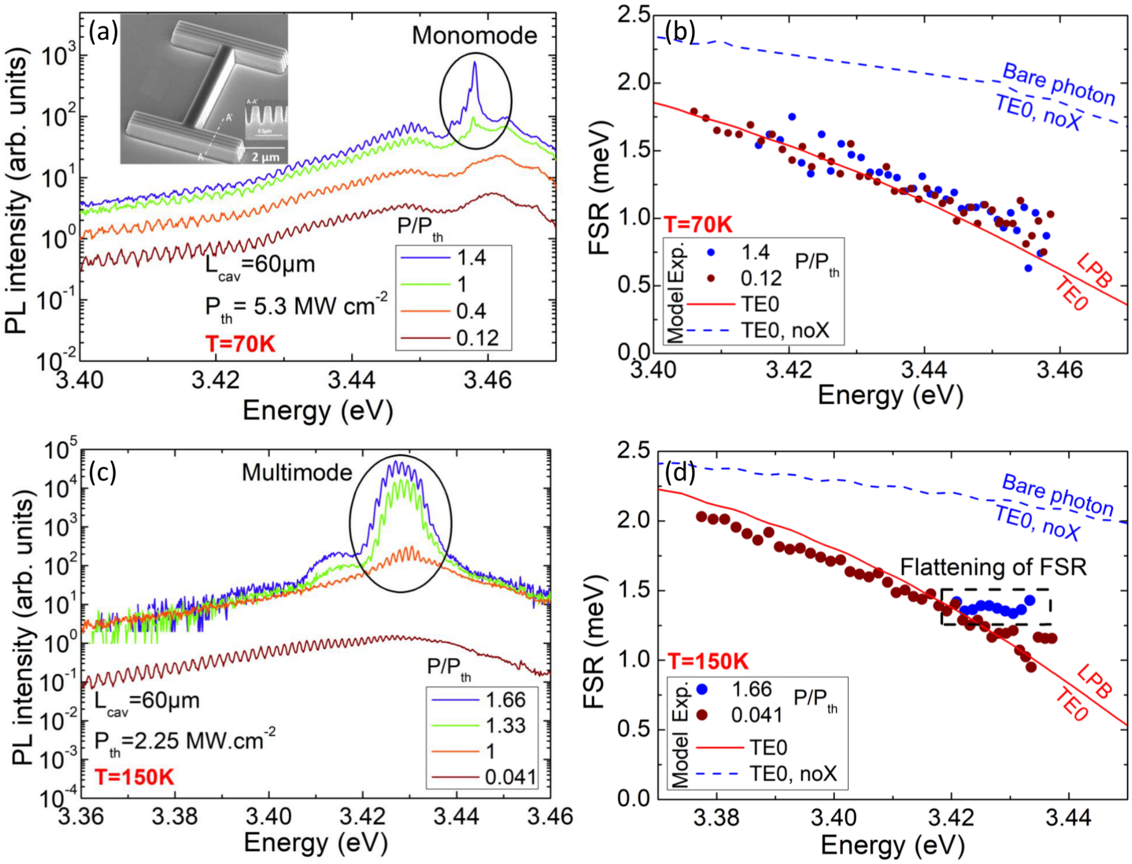

Figure 1: (a,c) Power-dependent PL spectra of the 60-µm-long cavity at 70K and 150K, respectively; Inset: SEM image of a 5-µm-long polariton ridge waveguide. (b,d) Experimental FSR versus excitation power (colored dots) and FSR calculated from LPB dispersions (plain line) at 70K and 150K ,respectively.

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