Physics of Cavity Solitons in Semiconductors

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In the late eighties, the main focus shifted from temporal effects to spatial pattern formation in the structure of the e.m. field in the transverse sections of broad-area radiation beams, when they interact with nonlinear media. The investigations in this domain offer an approach to parallel optical information processing, by encoding information in the transverse structure of the field. The idea is of considering the transverse planes as a blackboard on which light spots can be written and erased in any desired location and in a controlled way. Optical patterns may display an array of light spots, but are unsuitable for this task because the intensity peaks are strongly correlated with one another, so that they cannot be manipulated as independent objects. This task becomes possible, instead, using cavity solitons (CSs), a peculiar type of spatial solitons which arise in a dissipative environment. They belong to the class of localised structures and arise under conditions of coexistence, in a nonlinear dynamical system, of a homogeneous stationary state and a patterned stationary state: for the same values of the parameters, according to the initial condition, the system may approach the homogeneous or the pattern state. Localised structures are intermediate between the two, in the sense that they coincide with the pattern state in a certain restricted region of the plane, and with the homogeneous state outside. By definition, localised structures must be independent of the boundary. A CS corresponds to a localised structure with a single peak [1]. A clear-cut demonstration of CSs in semiconductors, as objects that can be manipulated independently of each other and of the boundary, has been given recently, using broad-area, vertical cavity, driven semiconductor lasers above transparency but slightly below threshold [2]. In the present work we provide a complete and deep description of the characteristics of the CSs in semiconductor cavities. We demonstrate the generation of quite a number of CSs in the transverse section, and perform a careful analysis of the switching process of CSs. Furthermore, we present an extended comparison between the results of the numerical simulations and those of the experiment [3]. The laser where we are intended to generate the cavity solitons is an oxidized bottom-emitter VCSEL emitting around 970nm at threshold [2]. Its diameter is 150 m. The VCSEL is injected by a tunable laser system that emits a beam whose intensity is uniform across the whole section of the VCSEL and whose power is adjustable up to 33 mW. The tunable laser system provides also a second beam which is made10-15 μ m wide and is used as writing beam (WB). The emission profile of the VCSEL depends on injection current (J), on the HB intensity (Phb) and frequency detuning ( ) with respect to the VCSEL cavity resonance. For critical values of the parameters a modulational instability appears and the intensity profile exhibits a patterned state. Numerical simulations show that CSs can exist in the neighborhood of the modulational instability, where the lower intensity homogeneous solution is still stable. In these conditions, we inject the WB and we are able to write two CSs independently. CSs, once created, remain stable and they can be erased individually by applying again the WB. We have investigated the CS existence in the parameter space (J, Phb) and we have characterized the power requirement for the writing beam in order to switch on a CS. It is interesting to measure the rise-time of the CSs after application of the WB. The rise-time of the CS is 570 +/- 50 ps. This value is not significantly affected by parameters variations, provided that the CS can be switched on. CS cannot be generated in an arbitrary position of the VCSEL device. In fact, the broad-area VCSEL exhibits a strong gradient of the cavity length along the transverse section due to the non-parallel layers forming the cavity, owing to the standard epitaxial growth techniques. As a consequence, in our system, the cavity resonance varies along one direction of the transverse plane and there is a limited region in the transverse section of the device where the local value of the cavity resonance and field intensity meet the condition for the existence of the CSs. If we target with the WB an arbitrary point in the region where CSs exist, we can generate a CS but after removal of the writing beam it migrates towards a new position. Two elements determine this behaviour: first the presence of the above described gradient and second the presence of a roughness of the layer as well as random distributed impurities across the transverse plane of the device which trap the CS.

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