Ordered Vortex Lattice in Wide-Aperture Lasers

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Abstract — we report on the dynamics and stability of structures, which represents an ordered array of optical vortices in wide-aperture lasers. By means of the linear analysis and method of the bifurcation diagrams parametric areas of stability for the corresponding decision have been found. Using numerical simulation, the destruction scenario of vortex lattice is considered.

Keywords — vortex lattice, stability, wide-aperture lasers

I. INTRODUCTION

In the development paradigm of the area of optical manipulation of microscopic objects the solution to the problem of parallel control of optical vortices arrays seems promising. Along with the existing difficult and costly methods of artificial creation of such arrays, there are experimentally confirmed and potentially perspective for various applications possibility of spontaneous generation of so-called vortex lattices (VL) in various large-aperture lasers. Development of technologies based on the spontaneous formation of a stable vortex array is a serious and urgent task. It will be useful not only in the field of optical manipulation, but also, e.g. for wireless optical communication, interferometry and optical information processing. However, the formation processes of such structures in lasers are insufficiently studied for the further development of technology based on them.

In this regard, the aim of this work was to carry out a theoretical study of the conditions of formation of stationary and non-stationary VL in wide-aperture lasers using the complete system of laser equations in a wide range of operating parameters.

II. THEORETICAL MODEL AND LINEAR ANALYSIS

The semiclassical laser system of Maxwell-Bloch equations has been used as a mathematical model. It is known that the dynamics of the laser radiation significantly differs at different signs of the frequency detuning.

For positive detuning the model theoretically predicts off-axis radiation, for negative - paraxial. Therefore, in lasers VL forms only at positive detuning, because this structure is a superposition of four off-axis (tilted) waves formed in the process of self-organization with some phase ratio.

Using the methods of linear analysis we have obtained bifurcation diagrams illustrating the area of stability/instability of VL at different laser parameters.

III. NUMERICAL SIMULATION

Pseudo-spectral direct numerical simulations of the full system have been performed for checking the reliability of the diagrams. Besides, the mechanism of stability loss of VL was investigated at increasing the pump value.

Indeed, at the parameters in the stability region VL spontaneous formation of many random vortices had been observed. At sufficiently long time they occupies a stationary position and forms an ordered structure - lattice. In the center of vortices intensity tends to zero. Neighboring vortices have an opposite topological charges. The spatial spectrum consists of four main harmonics. The typical distributions of intensity are represented on fig. 1.

The increase of pump leads to the loss of stability of the VL in the result of bifurcation. Vortices begin to move on periodic orbits around the original position. Neighboring vortices move in opposite directions. In the spatial spectrum extra components appear, that indicate a complication of the optical field structure. Numerical simulation has showed that at the exceeding pumping above the critical value the VL are completely destroyed, and the optical turbulence will observe.

IV. CONCLUSION

The analytical predictions based on diagrams are qualitatively and quantitatively confirmed by numerical simulation. Also it should be note that the stability diagrams agree with earlier works for asymptotic cases of dynamic laser classes A and B [2]. This approach can help to define a stability area of VL, however the behavior in instability region is difficult to predict. The value of the pump, at which dynamics becomes irregular, is not established.

REFERENCES


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