SAND 93-1847C
Conf-931197--1

LEOS-93
Invited talk

Spatial Patterns in Semiconductor Lasers

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SEP 07 1993

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Abstract.

Spatial solitons occur when an intense pulse propagates in a self-focusing semiconductor gain medium. Injecting light into a vertical-cavity surface-emitting laser causes dramatic modifications of the phase and transverse output intensity profiles, including the appearance of phase defects.

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This work performed at Sandia National Laboratories is supported by the U.S. Department of Energy under contract DE-AC04-76DP00789.

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A beam propagating in a planar waveguide exhibits the characteristics of both a fundamental soliton (little change in waist of a 5- μm beam; diffraction is compensated by self-focusing nonlinear refraction) and a second-order soliton (10- μm beam focuses to 3 μm with side peaks)¹. These one-dimensional spatial solitons are quite stable; bifurcations of transverse solitary wave are not seen, in sharp contrast to the case for two transverse dimensions². Plasma-theory planar-wave beam-propagation computations agree well with the data and resemble Kerr-medium solitons³ quite closely. Thus a semiconductor gain medium in a planar waveguide is almost ideal for the demonstration of fundamental and second-order spatial solitons; it is even a candidate medium for the formation of a light bullet⁴, i.e., a soliton in space and time.

Fig.1: Output spatial profile exhibiting a second-order spatial soliton. The input waist was $\approx 10\mu\text{m}$; $\approx 5\mu\text{m}$ per major division.

We have triggered transverse instabilities⁵ by injecting a CW monochromatic (10 MHz) beam into a vertical-cavity surface-emitting laser (VCSEL). With increased injection current, the TEM_{00} transverse mode changes to a combination of TEM_{00} , TEM^*_{01} (doughnut), and TEM_{11} . Various transverse modes patterns can then be produced by frequency tuning the injection. Interferometrically analyzing these patterns shows that some zero-field points are field vortices⁶⁻⁹; see Fig. 2. The position of the vortex depends on injection frequency, power, polarization, and input position. The circulation of the phase gradient on any loop that encloses the vortex core is equal to $2k\pi$, with k (equal to one in our experiment) representing the order of the vortex, or topological charge.

Fig.2: A phase singularity appears in the center of the interferogram of the near-field output of a VCSEL with injection (left). The corresponding intensity pattern shows a zero at the location of the phase singularity (right).

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