Mathematics Institute – University of Warwick

EPSRC Report

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New ideas to improve semiconductor laser efficiency and on the competition between nonlinearity and randomness

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Summary:

The main achievements of the work done on this proposal were:

a. The development of a theory which exploits the finite flux solutions of the quantum Boltzmann equation to improve semiconductor laser efficiency (Finite flux solutions of the quantum Boltzmann equation can enhance semiconductor lasing. (Y.V.Lvov

   and A.C.Newell Phys. Rev. Letts. 84 1894-1897 84 1894-1897 FREE (2000)).

   Before this work, the conventional picture assumed that the distributions of carriers (electrons and holes) were given by the zero flux Fermi-Dirac 'thermodynamic' spectra. However in the presence of sources (pumping) and sinks (the laser itself at low energies and phonon interactions at high energies), finite flux distributions are more relevant. They will be more and more important as semiconductor design shifts from a pn junction to a quantum well configuration. The ideas and results have also broad relevance to fermionic physics generally.

b. An understanding of how, in one space dimension, nonlinearity can overcome the attenuation signals experience in media with random material properties (IMA J. Appl. Math. **63,** 1-20 (1999)). The pioneering work of Anderson on localisation led to an understanding of how small amplitude (linear) dispersive waves are trapped in random media due to dephasing between the retransmission of reflected waves and the original signal. In light of that, the experimental observation of McCall and Hahn [Phys.Rev.Lett. **18,** 408 (1967)] on the self-induced transparency (SIT) of optical waves in inhomogoneously broadened (equivalent to random) media needed to be explained. In that context, trapping is due, not to reflection, but to absorption of the incoming photons by the active and excitable medium. The retransmitted photons are generally not in phase with the original signal. The reason for the partial transparency is nonlinearity. The finite amplitudes of some of the pulses created from the initial electrical field envelope phase lock the medium (a collection of oscillators with slightly different frequencies) so that each oscillator has the same frequency as that of the signal wave. As a result, all photons emitted by the medium remain in phase with the nonlinear part of the signal. We have used the exact integrability of the SIT model [Ablowitz, Kaup, Newell, J.Math.Phys. 15 1852 (1974)] to explain exactly how the randomness is thwarted. The ‘soliton’ and coherent part of the signal is phase locked and is left invariant (except that it travels more slowly) whereas the ‘continuous spectrum’ component is attenuated. This leads to a notion of Anderson localisation lengths which are amplitude dependent.

c. An improved understanding of the instability mechanism that leads to the development of sand waves formed on the seabed of tidally washed channels and the reasons for the apparent coexistence of sandbanks and sandwaves. The former are created by pondermotive forces induced by the gradients in spatial intensity of the latter.
d. A better understanding of the configuration of spiral wave pattern singularities in reaction-diffusion media with excitable dynamics.

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