Statistical Theory of Random Lasers and of Coherent Enhancement of Absorption

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Steady-state ab initio laser theory (SALT) is a recently developed method for finding the steady-state solutions of the semiclassical laser equations directly without integrating them in time [1]. It is formulated for arbitrary laser cavities and treats the openness of the cavity exactly, while treating the non-linear modal interactions to infinite order; hence it is an excellent tool for developing a statistical theory of random lasers. It has been confirmed to give the same solutions (to high accuracy) as brute force integration of the lasing equations for one-dimensional random lasers. Here were present an approximation to the SALT equations, valid for random lasers, which allows analytic calculation of the statistical properties of the multimode non-linear lasing state, such as the average number of lasing modes above threshold and their average total output power [2]. Comparison of this theory with full SALT simulations shows good agreement.

The time-reverse of a random laser is a random coherent perfect absorber (CPA), which is a random system with loss that completely absorbs the time-reversed lasing mode of the corresponding system with gain, but scatters other input states of light. This raises the question of whether appropriate input states can be found more generally that strongly enhance total absorption in random scattering systems with weak absorption. In other terms, the S-matrix of a CPA has an eigenvector with eigenvalue zero; for a more general random system with absorption, are there extremal S-matrix eigenvalues with very small modulus (i.e. high absorption)? Study of a modified DMPK equation shows that indeed such extremal states exist generically in disordered waveguides, even when there is no perfectly absorbed state [3]. To measure such effects at optical frequencies it is necessary to consider open geometries with transverse diffusion, and to take into account incomplete control of the input wavefronts, which can been done theoretically [4]. Recent experiments are reviewed which demonstrate significantly enhanced absorption in random media and also significant enhancement of transmission through opaque media [5] (similar to the “open channel” concept developed in mesoscopic electron physics).

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