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Nanocomposite Materials for Photonics

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Approaches to the development of new materials for use in nonlinear optics and laser science based on the concept of nano-structuring are described. Past successes and ideas for future work are summarized.

In this contribution we present some ideas for the development of novel materials for use in nonlinear optics and in laser systems based on the formation of composite materials out of a variety of constituent materials. This approach holds promise in allowing one to tailor the properties of the material for an intended application. It also allows one to develop materials that present the best attributes of each of the constituent materials or in the best situations with properties superior to those of the constituents.

One example of this approach is the fabrication of materials for use in nonlinear optics with a large third-order nonlinear response [1]. We have found that it is possible to construct a nonlinear material in such a manner that the nonlinear response exceeds those of its constituent materials [2]. The nature of the enhanced response can be understood in terms of local field effects. In particular, in a composite material, the electric field becomes nonuniformly distributed, which leads to localized regions of extremely large nonlinear response. Enhancement of the nonlinear response by a factor of three has been observed in a composite material fabricated of lossless materials [3].

Even larger nonlinear response can be obtained if one of the constituents of the composite is metallic. There are several reasons for this sort of behavior. One is that metals typically possess third-order susceptibilities that are many orders of magnitude larger than those of dielectric materials. Another is that metal-dielectric materials possess plasma resonances, and these can lead to extremely large localized values of the magnetic field within the structure. Moreover, through proper design it is possible to form composite materials in which the attenuation usually associated with propagation through a metal is dramatically reduced; this effect can also lead to an improved nonlinear optical response [4,5].

Some of our recent work is aimed at developing new laser materials based on composite structures. The goal of this work is to develop new laser gain media in which we can control the three basic material properties that govern laser action, that is, (1) the upper level lifetime, (2) gain coefficient, and (3) saturation intensity. Our approach is based on the observation that these three parameters depend differently on the refractive index of the laser host material, and that the background refractive index can be modified by controlling the composite structure.

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