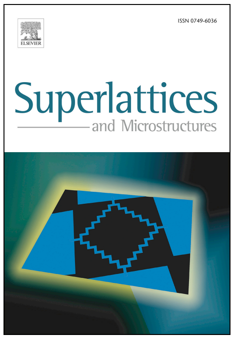

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FOUR WAVE MIXING AND COMPENSATING LOSSES IN METAMATERIALS

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Abstract. The conditions under which losses can be compensated in the case of propagation of an backward signal wave under parametric four-wave interaction are analyzed. It is shown that, in the presence of a parametric coupling between forward and backward waves, compensation of signal wave losses by losses of direct waves will allow the parametric amplification and generation of the backward wave to be realized at the threshold pump amplitude. An analytical expression is obtained for the threshold pumping amplitude under phase-matching conditions. It is shown that the threshold pump amplitude increases with increasing losses, the input intensity of the idler wave, and with increasing nonlinear coupling coefficients for pump waves. As a consequence, it is possible to control the threshold pump intensity. and it is possible to obtain significant amplification in the metamaterial, as well as parametric generation of the backward wave.

1. Introduction

The existence of significant losses in the compounds being constructed hindered the development of applied problems using metamaterials [1-3]. Intensive research is currently underway to compensate for losses in metamaterials. The next step was the use of the latest advances in nanoplasmonics, namely the results of an investigation of the electromagnetic field around localized plasmons, which accumulate large electric fields around themselves. It allows to reduce losses in such structures [4-5]. The introduction of plasmon metals, for example, silver [4] or gold [5], near the resonances of which the nonlinearity increases sharply, into the dielectric structure, leads to a significant concentration of the electromagnetic field around the plasmon nanoparticles. So in the case of a gold nanoparticle, silicon is used as a dielectric structure, because of the small work function of an electron from gold to silicon. This fact is successfully used to increase the sensitivity of photodetectors, solar photoconverters. The ability of plasmon nanoparticles to accumulate large electric fields around themselves allowed the authors of Refs. 4 and 5 to report on overcoming large losses in similar structures.

As is known, in the optical cavity a positive feedback is formed due to the reflection of the traveling waves from the mirrors of the laser resonator. As a result of repeated passage through the nonlinear medium of reflected traveling waves, the effective interaction length increases. In metamaterials, the possibility of propagating traveling waves in opposite directions is provided by frequency dispersion in the "left-handed" nonlinear medium for the backward wave. This allows us to realize a positive feedback between them through the parametric interaction in the medium. The metamaterial plays the role of distributed feedback. In this case, the energy for the backward wave is transmitted in the direction opposite to its wave vector. As is known, in the presence of losses in the medium, the amplitude of propagating waves decreases in the direction of energy transfer. For the backward wave, the attenuation occurs in the direction opposite to the direct waves. However, when taking into account the nonlinearity of the medium, loss compensation is possible and in this case the wave will propagate with a constant amplitude and possibly even amplification of the backward wave. In addition, with sufficient amplification, the parametric generation of the backward wave is possible in the metamaterial.

Third-order nonlinear processes, resolved both in centrosymmetric and noncentrosymmetric media, are more often encountered, they are easier to implement. For their observation, apparently, there is no restriction on the symmetry of the medium. Therefore, in spite of the fact