Investigation of Phase Effects in the Nonlinear Hollow Waveguides

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INTRODUCTION

Numerical calculations of the phase velocities of collective modes of a hollow waveguide at the Stokes frequency is carried out. The self- imaging of transverse structure of modes superposition (Talbot effect) is investigated.

It is shown that the sum of longitudinal wave numbers of collective modes is not changed with change of pump power. On raising the pump power the linear increase of Talbot length in stimulated Raman scattering (SRS)-active medium and periodical variation of Talbot length in the process of nonresonant SRS are predicted.

TECHNIQUE

An arbitrary hollow waveguide, which has gas in hollow region, is examined. The SRS is stimulated by laser radiation in this gas.

The Raman field strength as superposition of modes of some cylindrical region with radius *R* is presented.

$$E_s(\rho,z)=\sum_{m=1}^{M}A(q_m z)j_0(q_m\rho)\exp(ik_{zs}z)$$

$$\frac{\partial A(q_m,z)}{\partial z}=\frac{i}{2k_{zs}}(q_p^2-q_m^2)A(q_m,z)+\frac{g_s}{2}N_p\sum_{n=1}^{M}\chi_{mn}A(q_n,z)$$

where

$$\chi_{mn}=2\pi\int_0^\infty j_0^2(q_p\rho)j_0(q_m\rho)j_0(q_n\rho)\rho d\rho$$

is discontinuous, two-dimensional, non-local SRS response of active medium [1,2].

RESONANT SRS IN HOLLOW WAVEGUIDES

On the basis of the technique mentioned above I have taken the next result: “The existence of gain in optical waveguide and also the changing of its linear dissipative properties don not change the sum of longitudinal wave numbers of its collective modes” and consequently we would have next equation

$$\frac{\partial}{\partial ?}\sum_{m}^{M}k_{zm}=0$$

Where *X* is the gain or dissipative parameter of waveguide.

When there is no pump, discreet collection of partial modes of hollow guide is demonstrating effect of self-recovery of transverse field structure, as it’s shown on figure 1.

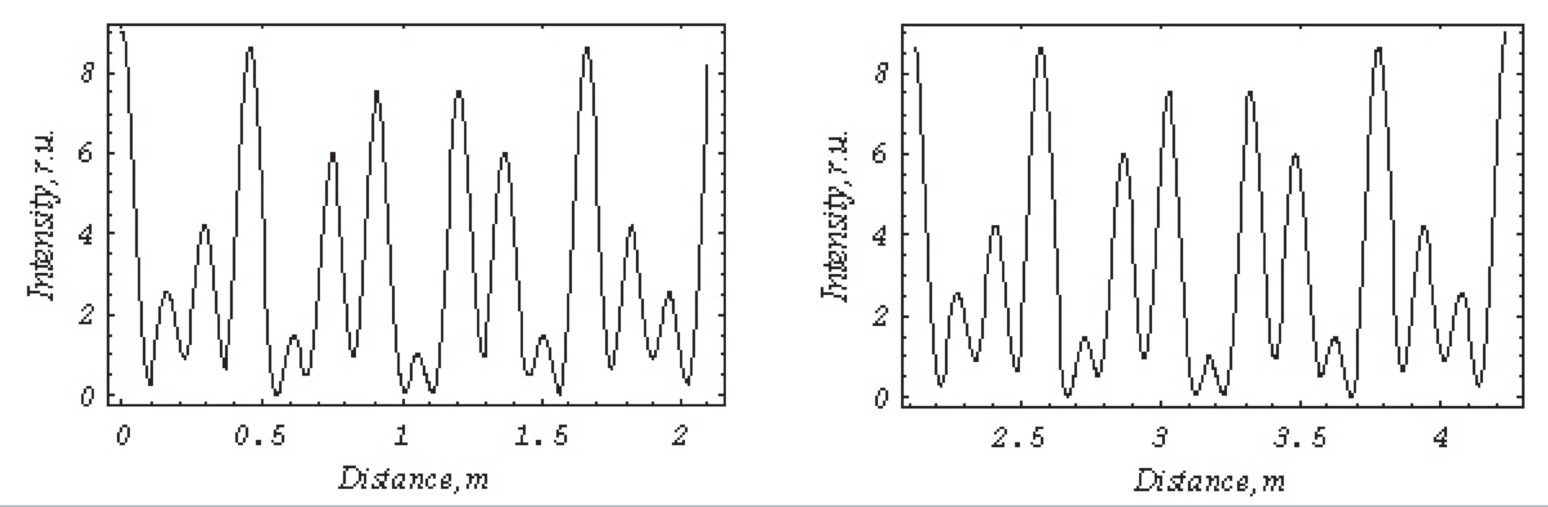

Figure 1: Longitudinal dependence of axial intensity of sum of three partial modes; λ = 0.68 mkm, R = 600 mkm

On figure 2 two examples of repeating of transverse structure of Stokes field when pump power 00.1 MW are shown.

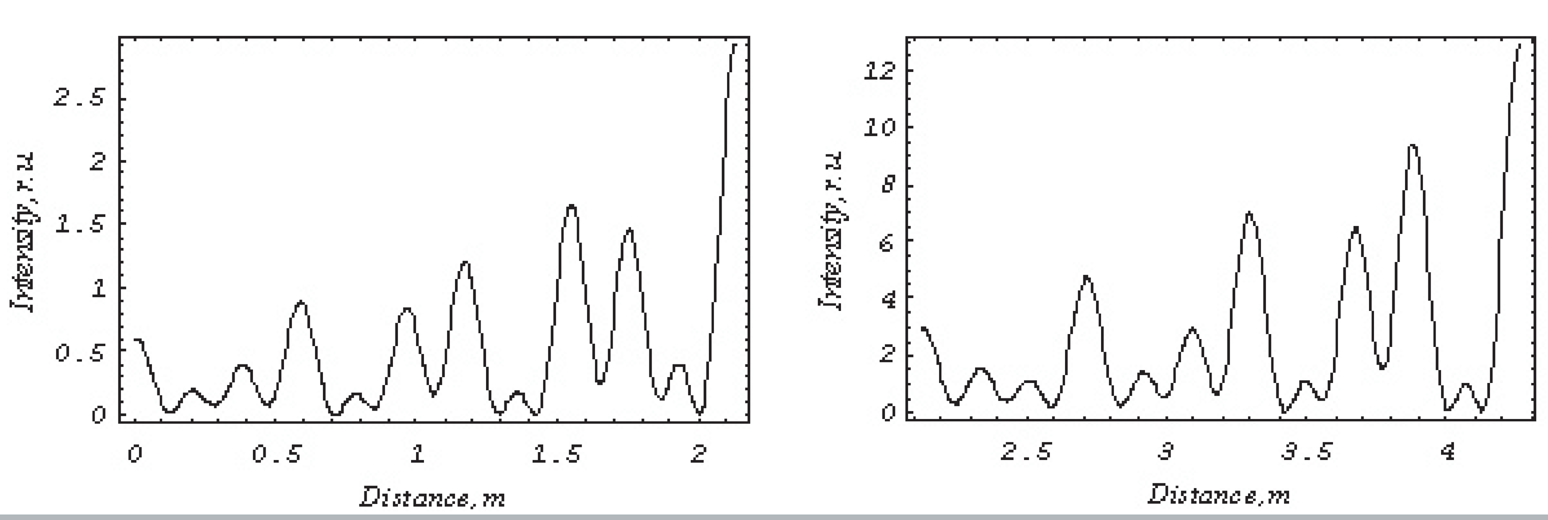

Figure 2: The manifestation of Talbot effect combined with magnification of Stokes field

On figure 2 longitudinal dispose of axes intensity of three collective modes is shown. As it is seen, in spite of change of energetic characteristics of Raman field, its transverse structure is approximately repeated.

Using technique mentioned above also I have calculated Talbot length for different value of waveguide radius

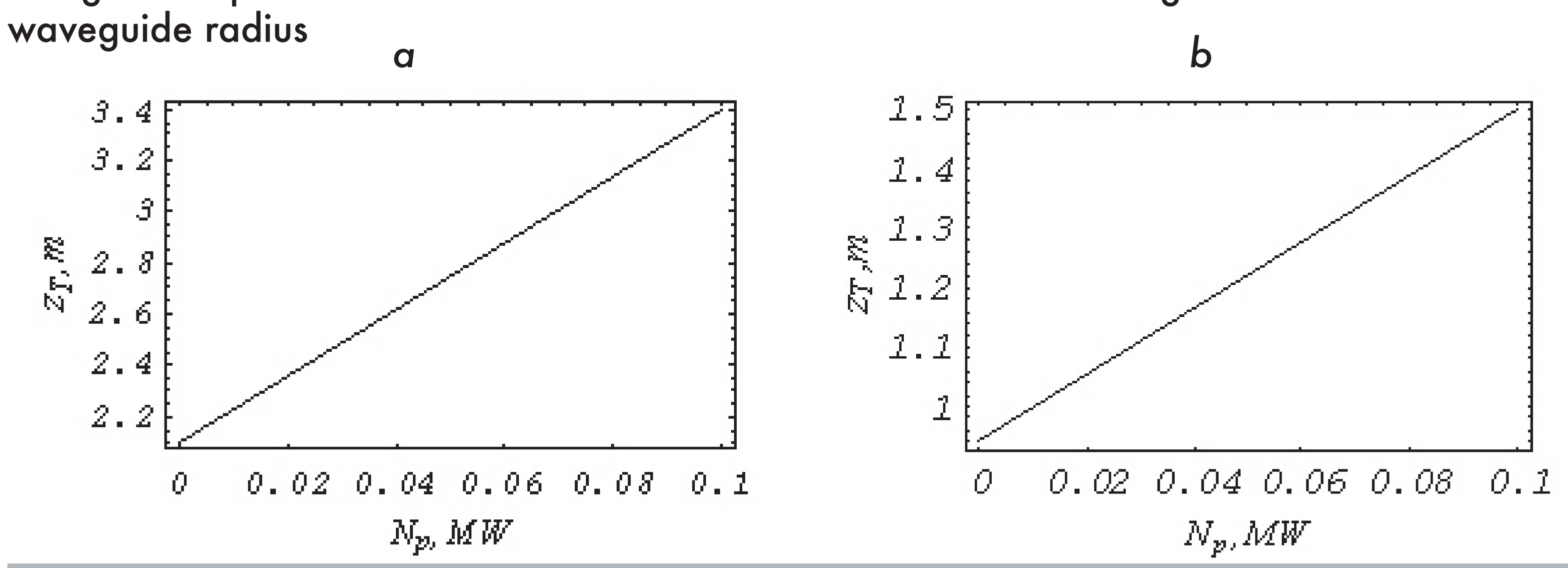

Figure 3: The dependence of Talbot length on pump power for different values of waveguide radius is shown; a)-R = 200mkm, b)-R = 300 mkm. When there is no pump z_T is close to Talbot length without SRS and equal to 2.1 m for 300 mkm

From last graph we can see that when there is no pump z_T is close to Talbot length of common waveguide without SRS and equal to 2.1 m, Talbot length is directly proportional to squared radius of this waveguide. So we can write

$$z_T=\frac{16R^2}{\lambda}+\alpha N_p$$

where α is constant value, independent of radius.

For description of phase effects caused by SRS it is possible to use effective radius R_{eff}. Then $z_T=16R_{eff}^2/\lambda$ and change of pump power will cause change of effective radius according to equation

$$\Delta R_{eff}\sim\frac{\Delta N_p}{R_{eff}}$$

When pump increases, effective radius is increases as well.

NONRESONANT SRS IN HOLLOW WAVEGUIDES

The investigations carried out in previous section are related to resonance band only. Nonlinear susceptibility and consequently coefficient g_s become in the general case complex numbers, i.e. $g_s=g_s'+ig_s''$, when resonance detuning takes place [3-5]. At the same time imaginary part of g_s will describe effects connected with dependence of phase velocity on pump power. In the case under consideration, when Raman radiation extends in hollow waveguide, availability of imaginary part will result in change of phase velocity of partial modes.

Further for description of SRS process, instead of (1) we will use the following equation:

$$\frac{\partial A(q_m,z)}{\partial z}=\frac{i}{2k_z}(q_p^2-q_m^2)A(q_m,z)+\frac{g_s'}{2}N_p\chi_0A(q_m,z)+\frac{ig_s''}{2}N_p\sum_{n=1}^{M}\chi_{mn}A(q_n,z)$$

The dependence of Talbot length z_T on pump power in the case of nonresonant SRS is presented on next figure:

The equation for dependence of sum all longitudinal wave numbers on pump power is:

$$\frac{\partial}{\partial N_p}\sum_{m}^{M}\beta_m(N_p)=Const$$

In the case of resonant SRS we had totally different behaviours of sum longitudinal wave numbers.

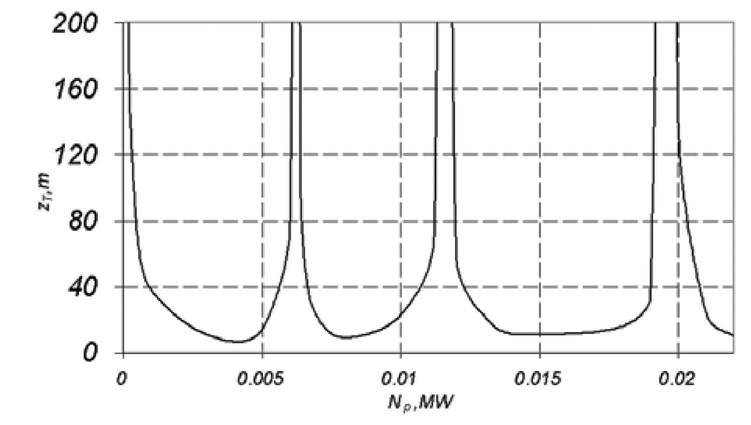

Figure 4: The dependence of Talbot length on pump power, in the case when we are far from resonance located, is shown. We can see oscillation behavior of Talbot length for nonresonance SRS

CONCLUSION

It is necessary to do strong analyses of mode structure of waveguide for theoretical and experimental investigation of SRS process in hollow waveguide. The phase effects investigated in this paper which become apparent in Raman radiation are independent interest, and also, they have to be taken into account for increasing of SRS efficiency and improvement of quality of Raman field.

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