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STUDY ON FOUR-DIMENSION NUMERICAL MODELING OF SRRS EFFECTS ON BEAM DISTRIBUTION IN NEAR FIELD AFTER ICF HIGH POWER ULTRAVIOLET LASER PROPAGATING THROUGH A LONG AIR PATH

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It is necessary for high power ultraviolet laser to propagate through a long air path during experiments of inertial confinement fusion (ICF), when beyond stimulated rotational Raman scattering (SRRS) threshold, the high power ultraviolet laser beam would be subject to loss of energy and a decrease in beam quality , results in the reduction of conversion efficiency of triple-harmonics, even causing the optical components to be destroyed. This paper studies the four-dimension numerical modeling of SRRS effects on ICF condition, emphasizing on beam intensity distribution in near field. We settled the simultaneous equations by finite element method of MATLAB without slowly varying amplitude approximation or process neglecting. Finally the rule of four-dimension numerical modeling of SRRS affecting on beam intensity distribution in near field after ICF high power ultraviolet laser propagating through a long air path was got and the first independence simulation of pump and Stokes laser 's transverse diffraction effects were got.

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Keyword: Ultraviolet laser, Stimulated rotational Raman scattering, Distribution in near field

1. Instruction

All energy comes from nucleus fusion of the sun .For people have grasped the technology of uncontrollable nucleus fusion, namely hydrogen bomb, then how to control nucleus fusion has become an important task. There are two methods to realize controllable nucleus fusion, one is magnetic confinement fusion, the other is inertial confinement fusion (ICF) which was first suggested by Lebedev and N.G.Basov from former Soviet Union in 1960s[1].

The strict requirements to ICF's high power laser drive [2] are(1) enough ensemble output capability to assure high temperature and high density conditions; (2)good beam quality to insure target practice experiment, to satisfy the basic requirements of high energy conversion efficiency of the triple- harmonic, running stability and safety; and (3)strengthen beam and pulse control to assure the black cavity radiation field can be strong enough in indirect driving of the physical experiment and to satisfy the drive running stability. These requirements suggest that the even quality of beams in the near field is important for running the laser drive. In the ICF laser drive, the power of the beam is far higher than the self focusing critical power and usually is 10 times that of the latter one. In this case the beam's uneven quality in near field leads to small size self focusing easily which divides the beam into silk, then makes partial of the beam destroy optics components. From above we know the beam's even quality in the near field determines the

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destruction threshold of optics components, and furthermore it restricts the working load (or light energy), running stability and safety[3] of the ICF drive.

However tens to hundreds of high power laser beams are required to propagate with equal optical distance, at the terminal of the high power ICF device and the beam quality must be even. Finally the space assignment of the high power laser is that tens of beams have to propagate though a long air path of tens to hundreds of meters. In this procession, high power pulse lasers interact with molecules in air (mainly nitrogen gas molecule) producing SRRS effects oriented in the direction of pump laser's propagation. Once reaching the SRRS threshold ,(1)the energy of laser is reduced;(2)the quality of laser beam is worse sometimes not reaching the fusion target;(3)the laser after propagation would be a fundamental frequency beam to be converted to triple- harmonic, so the quality of the laser significantly effects of the efficiency of triple-harmonic conversion;(4)it might destroy the optics components. So the systemic harmful effects of the SRRS process are necessary to study.

From the 1970s, the main trend of solid laser is the American's high power solid laser technology, represented by the NOVA laser drive made by LLNL laboratory in 1984, the Omega laser drive made by LLE in 1995 and the NIF laser drive now. The SRRS four dimension physical equations (Maxwell-Bloch-Langevin equations) were also be suggested by Y.Lin,T.J.Kessler and J.J.Armstrong from Rochester University in America. Their research was based on the SRRS effects through air on the Omega device. The simulation results fit the experiment results well. Yet owing to the limitation of computer function development, in the course of calculating they had to calculate with approximate values which might affect accuracy of the simulation model. In the recent two decades, scholars from different countries have made continuous research on SRRS modeling with different experiment parameters but most of the time they neglected diffraction effects or manipulated under slowly varying amplitude approximation which unfit the facts of ICF experiments.

We use the Maxwell-Bloch-Langevin equations to describe the ultraviolet laser's SRRS effects through long air path on the ICF high power laser drive[4~8].The modeling includes the laser pulse shape, medium excitation and relaxation, spontaneous and stimulated Raman scattering and the diffraction of the pump laser and the Stokes laser. The modeling synthetically describes three sub-influences transient coupling results. We compute the modeling with the finite element method of MATLAB without slowly varying amplitude approximation in manipulation or process neglecting. Finally the rule of four-dimension numerical modeling of SRRS effects on beam distribution in near field after ICF high power ultraviolet laser propagating through long air path is obtained and the first independence simulation of pump laser field and Stokes laser field 's transverse diffraction effects is got .

2. Physics of SRRS

When high power ultraviolet laser propagating through long air path, low energy level randomly polarize and produces spontaneous Raman scattering (The quantum-induced medium polarization is uncorrelated spatially, referred to as △-correlated spatially.) Such high power laser scattering of the △-correlated polarization region produces Stokes light which spreads to all directions, and only the Stokes light is primarily in forward direction receives appreciable stimulated amplification. So the Stokes light scatters backward or sideward are ignored[4]. A steady-state Raman gain was given instead of transient Raman gain, and it might be considered less than the former. As long as the conversion efficiency of Stokes beyond 1%, SRRS threshold is exceeded. These are based on common hot spots in near field of ICF experiments (hot spots arising from diffraction propagation of high-frequency aberration ,further Stokes light is enhanced by Raman conversion at the location of hot spots),the first independence simulation of pump laser field and Stokes laser field's transverse diffraction effects is got.

3. Four-dimension SRRS Mathematical Modeling

SRRS four dimension physical equations are described by Maxwell-Bloch-Langevin equations as following[4]-[9]:

$$[\nabla_{\perp}^2 + 2ik_L \frac{\partial}{\partial z}]E_L = 2\kappa_3 k_L Q E_S \qquad (1)$$

$$[\nabla_{\perp}^2 + 2ik_S \frac{\partial}{\partial z}]E_S = 2\kappa_2 k_S Q^* E_L \qquad (2)$$

$$\frac{\partial Q^*}{\partial t} = -\Gamma Q^* + i\kappa_1 E_L{}^* E_S + F^* \qquad (3)$$

where E_L and E_S are pump and Stokes laser's complex amplitudes；Q is medium polarization ；k_L and k_S are wave numbers of pump and stokes laser respectively；$\kappa_1, \kappa_2, \kappa_3$ are gain medium constants that $\kappa_1 = \sqrt{\frac{\Gamma c g}{8\pi^2 n\hbar\omega_s}}$ ；$\kappa_2 = \kappa_3 = (\frac{2\pi n\hbar\omega_s}{c}) \cdot k_1{}^*$; F is△-correlated random force represented random dephasing due to collisions；Γ is Raman bandwidth；g is steady state Raman gain；ω_S is the frequency of Stokes laser；n is density of activated atom number; h is Planck's constant.

Equation (1) and (2) are in a moving coordinate system at the speed of light.

Both of the initial Q distribution and the Langevin term F are generated as complex Gaussian random noise sources:

$$\Pr ob(Q_0(x,y,z,0)) = \frac{1}{\pi\sigma_Q{}^2}\exp(-\frac{|Q_0(x,y,z,0)|^2}{\sigma_Q{}^2})$$

$$\Pr ob(F(x,y,z,\tau)) = \frac{1}{\pi\sigma_F{}^2}\exp(-\frac{|F(x,y,z,\tau)|^2}{\sigma_F{}^2})$$

where

$$\sigma_Q^2 = \frac{1}{nA\delta_x\delta_y\delta_z} \;;\; \sigma_F{}^2 = \frac{2\Gamma}{nA\delta_x\delta_y\delta_z\delta_\tau};$$

A—region of interaction；δ_x—finite difference step in X direction；δ_y—finite difference step in Y direction；δ_z—finite difference step in Z direction；δ_τ—finite difference step in t direction.

4. Distribution Character of High Power Ultraviolet Laser Beams after SRRS Effects through air path in near Field

The parameters we used in this paper are as follows; the pump pulse distribution in space is 18-step super-Gaussian, the density of Raman activated atoms n is $2.234\times10^{19}cm^{-3}$, the Raman bandwidth $\Gamma = 7.52\times10^9 s^{-1}$, steady –state Raman gain $g = 6.76\times10^{-12}cm/W$, peak power of pump laser is $2.2GW/cm^2$,the wavelength of pump laser is $3.511\times10^{-5}cm$,the wavelength of Stokes is $3.5204\times10^{-5}cm$, FWHM (Full Width at Half Maximum) of the pump pulse is

$2.5\times10^{-10}s$ and the beam diameter is 2cm (square shape) .Condition threshold of SRRS is gIL≈25 fits the result gIL=25 obtained by Rochester University of America based on the SRRS effects through air on the Omega device from the literature[4].Then we discussed SRRS effects on pump laser and Stokes laser's longitudinal and transverse distribution of intensity in near field of ICF with the variation of distance separately .

(1) ICF pump laser and Stokes laser's longitudinal distribution of intensity in near field with variation of distance

(i)High power ultraviolet laser propagates 15 meters in air, GIL product is 22.308 approaches to SRRS threshold. The conversion of Stokes is smaller than 1% (figure 1). Figure 2 shows intensity distribution of pump and Stokes laser after spontaneous Raman scattering in time field have a delay of Stokes comparing with pump laser.

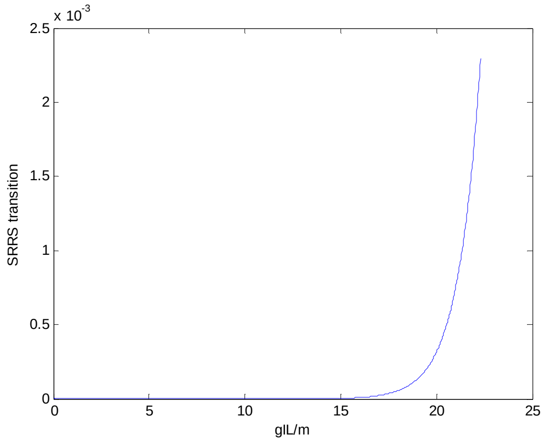

Fig. 1. SRRS conversion efficiency near threshold

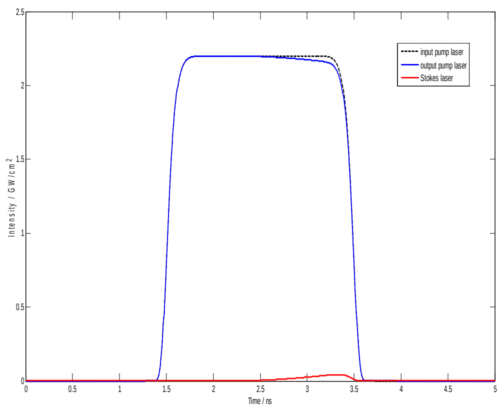

Fig. 2. Pump laser and Stokes laser's intensity distribution in time field near SRRS threshold.

(ii))High power ultraviolet laser propagates 25-meter in air. GIL product is 37 which beyond SRRS threshold. The conversion of Stokes has passed 1%(figure 3).Now we could see the growth of stokes intensity takes on semi–exponential in figure 3, this result fits well with the conclusion of related literature from American Rochester University . Figure 4 shows pump and Stokes light intensity distributions in time field beyond SRRS threshold with Stokes pulse producing a delay of pump laser. Then Stokes would be amplified continuously throughout the SRRS process. Finally pump laser would converse to Stokes laser entirely in theory. Noticing that not only Stokes laser intensity is amplified but also beam divergence angle is amplified in SRRS progress which might leads to such a serious consequence that output laser might miss the fusion target. Figure 5 shows comparison between relaxation of pump laser and amplification of Stokes laser.

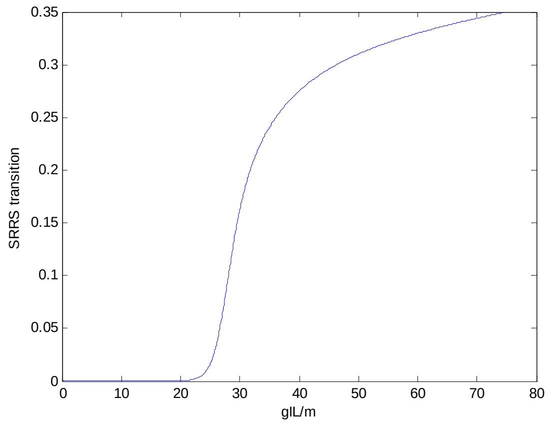

Fig. 3. SRRS conversion efficiency beyond threshold

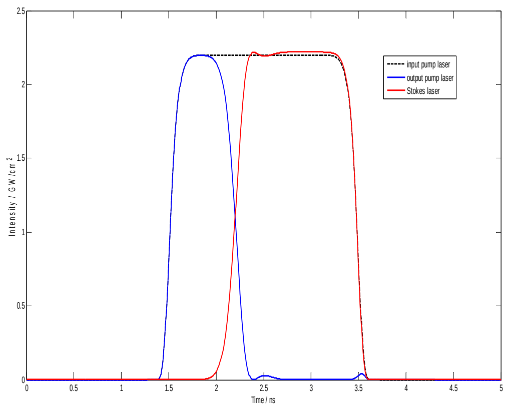

Fig. 4. Pump laser and Stokes laser intensity distribution in time field beyond SRRS threshold

(iii)High power ultraviolet laser propagates 50-meter in air. GIL product is 74.3 far beyond SRRS threshold. The conversion of Stokes is near 35% (figure 3) and pump laser relaxed seriously while the growth of stokes intensity taking on semi–exponential .

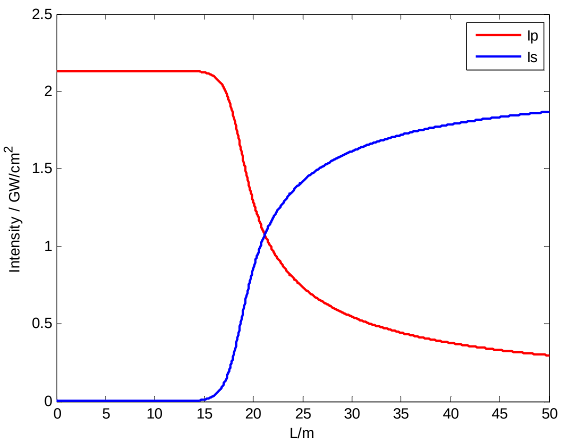

Fig. 5 .Pump laser relaxation and Stokes amplification with variation of propagation distance.

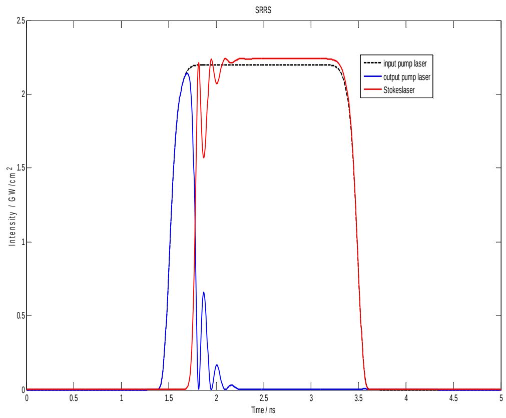

Fig. 6. Pump laser and Stokes laser intensity distributions in time field at triple threshold.

(2) The intensity distribution of high power ultraviolet laser beam in near field after SRRS (transverse surface which is perpendicular to the propagation direction of pump laser)

i) Under SRRS threshold, hot spots are not sharp (Figure 7),the quality of high power ultraviolet laser beam is even, diffraction modulation begins from borders and the fastest modulation points are all on the borders, the diffraction fringes symmetrical distribute at the center of diaphragm(Figure 8).

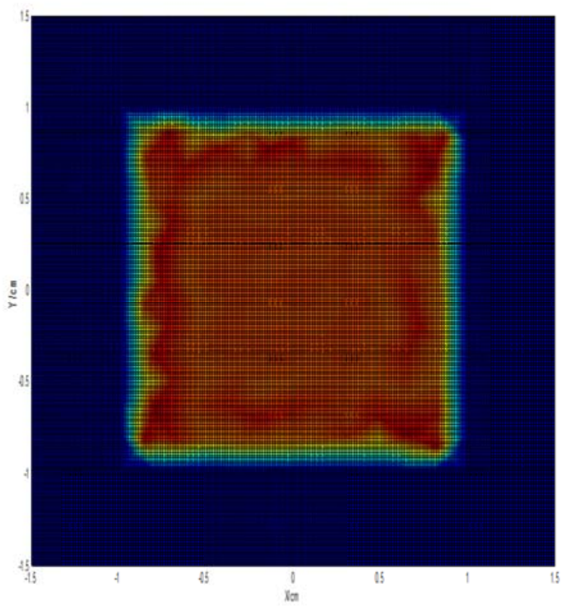

Fig. 7. Pump laser intensity transverse distribution after 15 meter propagation

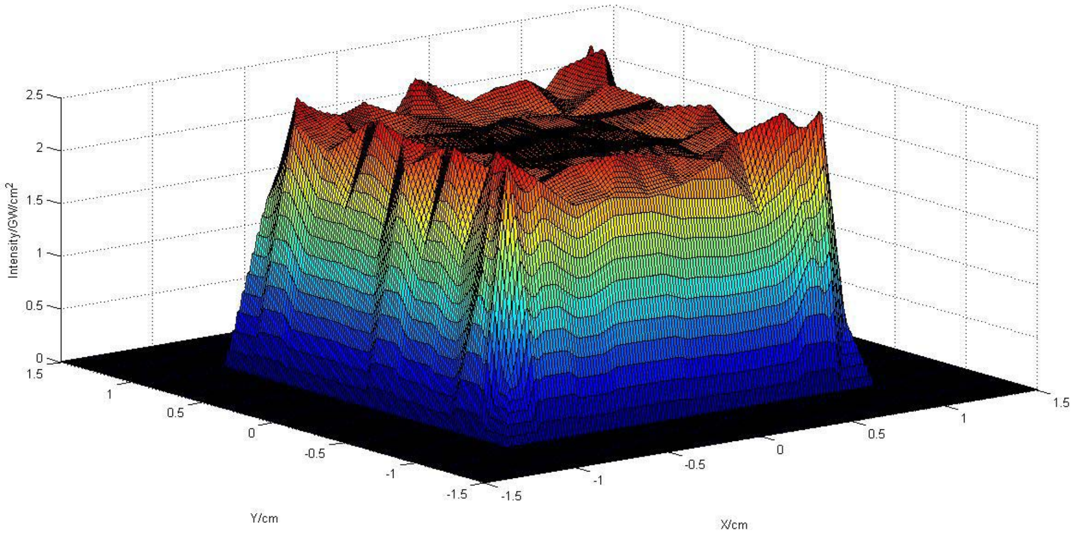

Fig. 8. Pump laser intensity distribution after 15 meter propagation

(ii) Hot spots became larger and began to expand to center when reached SRRS threshold(Figure 9), the quality of beam had been affected obviously, the distribution of intensity became uneven. The fastest modulation points are all on the borders (from this square transverse surface could we see that the fastest increasing point of modulation are four point angles) and all the diffraction fringes symmetrical distribute at the center of diaphragm (Fig. 10).

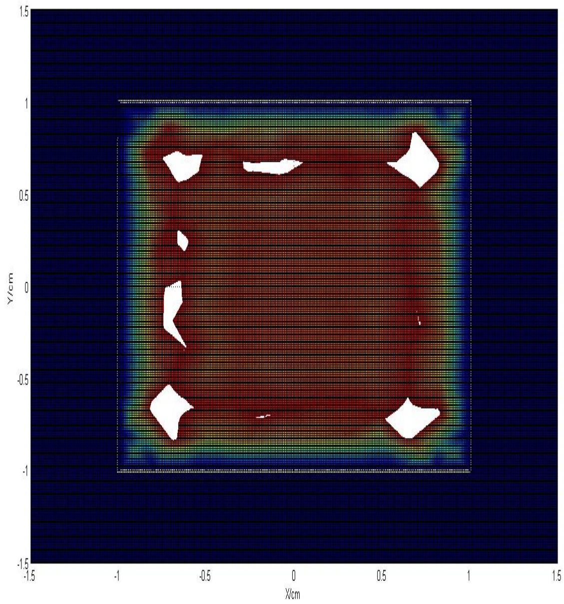

Fig. 9. Pump laser intensity transverse distribution after 25 meter propagation

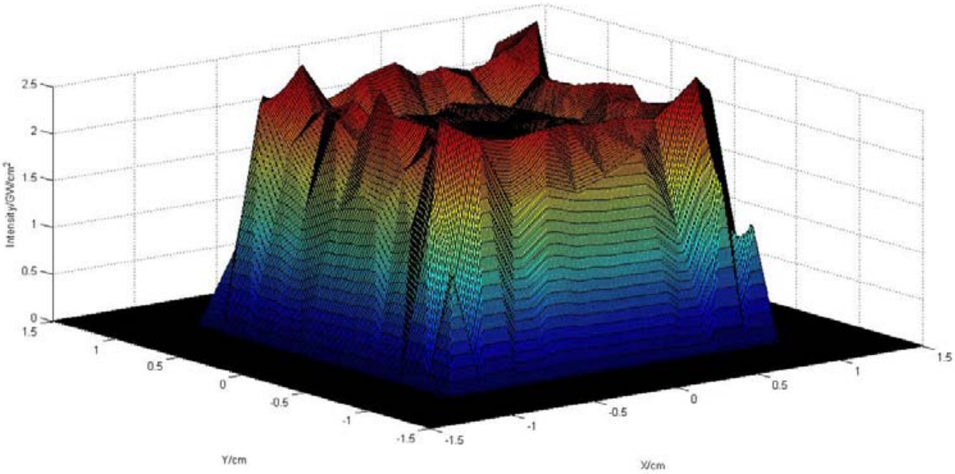

Fig. 10. Pump laser intensity distribution after 25 meter propagation.

(iii) After reaching triple SRRS threshold, the hot spot became more larger and began to expand to center field further(as Figure 11 showed), the quality of beam became worse seriously , the fastest modulation points are all on the borders and all the diffraction fringes symmetrical distribute at the center of diaphragm(Figure 12).

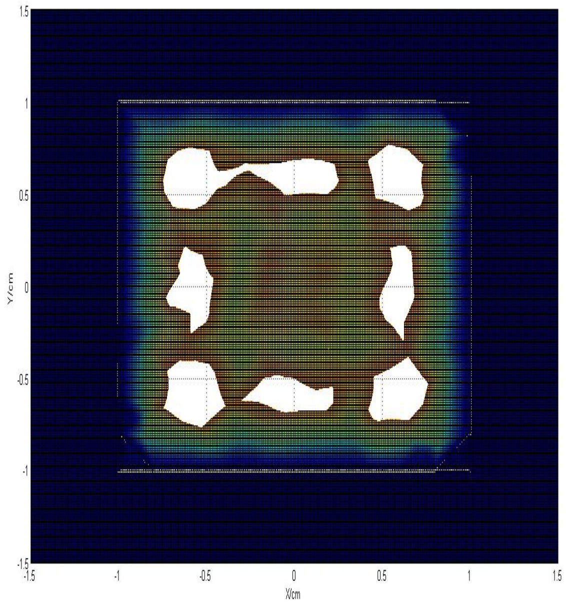

Fig.11.Pump laser intensity transverse distribution after 50 meter propagation

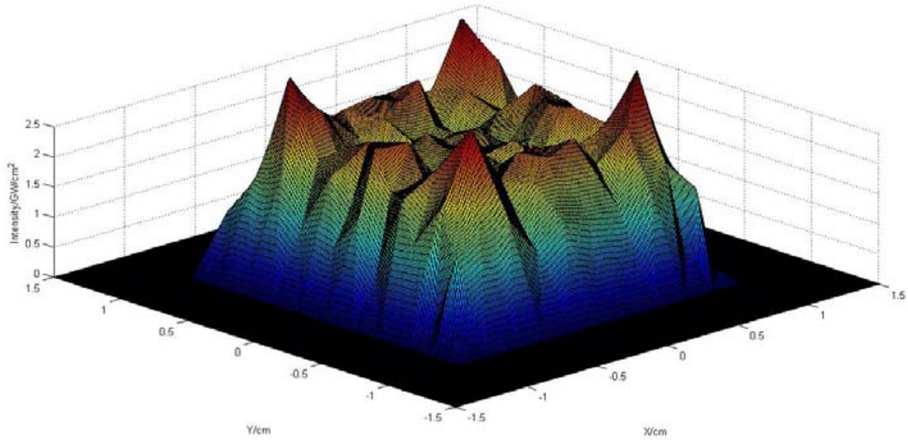

Fig. 12. Pump laser intensity distribution after 50 meter propagation.

5. Summary and Conclusion

The paper emphasized on study of four-dimension numerical modeling of SRRS effects on beam distribution in near field under ICF conditions.The rule of four-dimension numerical modeling of SRRS effects on beam distribution in near field after ICF high power ultraviolet laser propagating through long air path is got that SRRS effects are not sharp until beyond SRRS threshold, then the conversion of SRRS would be in shape of semi–exponential. Equally when parameter is below SRRS threshold, the diffraction of beam transversal surface is not intense. The quality of beam tends to be even. The hot spot phenomenon would be much sharper once exceeds SRRS threshold. The diffraction modulation expands from borders to center along with propagation length increasing and the fastest modulation points are all on the borders (the fastest modulation increasing locations of rectangle diaphragm are four point angles). All the diffraction fringes symmetrical distribute at the center of diaphragm.

Acknowledgments

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