Optica Applicata, Vol. XI, No. 1, 1981

Beam deformations of high power laser radiation during passage through imaging optical elements

Sigurd Kusch, Reiner Güther, Klaus Junge, Horst Schönnagel

Zentralinstitut für Optik und Spektroskopie der Akademie der Wissenschaften der DDR, Berlin

The beam deformation of high power laser radiation during passage through optical elements is investigated theoretically with the aid of the cubic nonlinearity. We have shown that the perturbations are remarkable if the power of the laser beam is greater than $5\cdot 10^{9}$ W/cm^{2}.

We treat the imaging properties of optical systems in high-power-lasers by nonlinear effects in the media used for optical elements. We estimate the reflection of a high power laser beam by a prism and investigate the influence of nonlinear interaction between glass and laser radiation of the beam after having passed the prism (see fig. 1).

There exists a superposition of the arriving and the reflected electromagnetic waves caused by the nonlinear interaction between the electro-

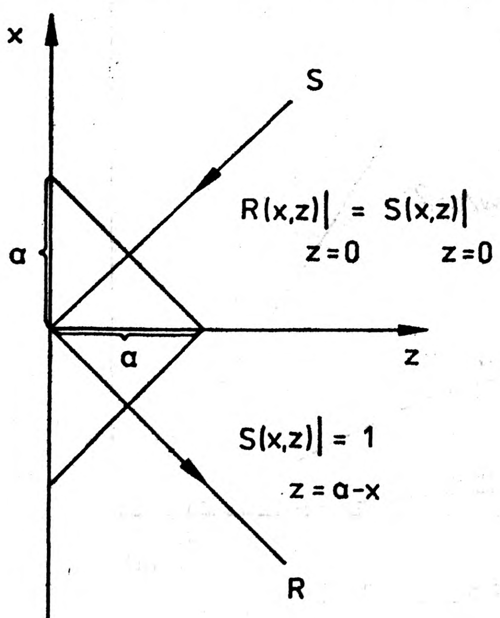

Fig. 1. Reflection of light by a prism

magnetic wave-field and the material of which the prism is produced. We obtain a spatial modulation of the dielectric constant.. This modulation corresponds to the formation of a thick hologram grating and the influences the reflected wavefront. Electromagnetic wave propagation in a medium with cubic nonlinearities can be described by [1, 2]

$$\Delta E - \frac{1}{c^2}\frac{\partial^2(\varepsilon E)}{\partial^2 t} - \frac{4\pi}{c^2}\frac{\partial^2}{\partial t^2}(\chi^{(3)}) \vdots EEE) = 0. \tag{1}$$

From this equation the following coupled wave equations is obtained

$$\begin{aligned} \frac{\partial S}{\partial z} + \frac{\partial S}{\partial x} &= -jA(3S^2S^* + 6R^*RS), \\ \frac{\partial R}{\partial z} - \frac{\partial R}{\partial x} &= -jA(3R^2R^* + 6RSS^*), \end{aligned} \tag{2}$$

where A is a constant, depending mainly on the wavelength λ and the cubic nonlinearity [3, 4]. S and R indicate the electric field of the arriving of the reflected laser radiation, respectively.

Taking into account the boundary conditions

$$R(x, z)|_{z=0} = S(x, z)|_{z=0}$$

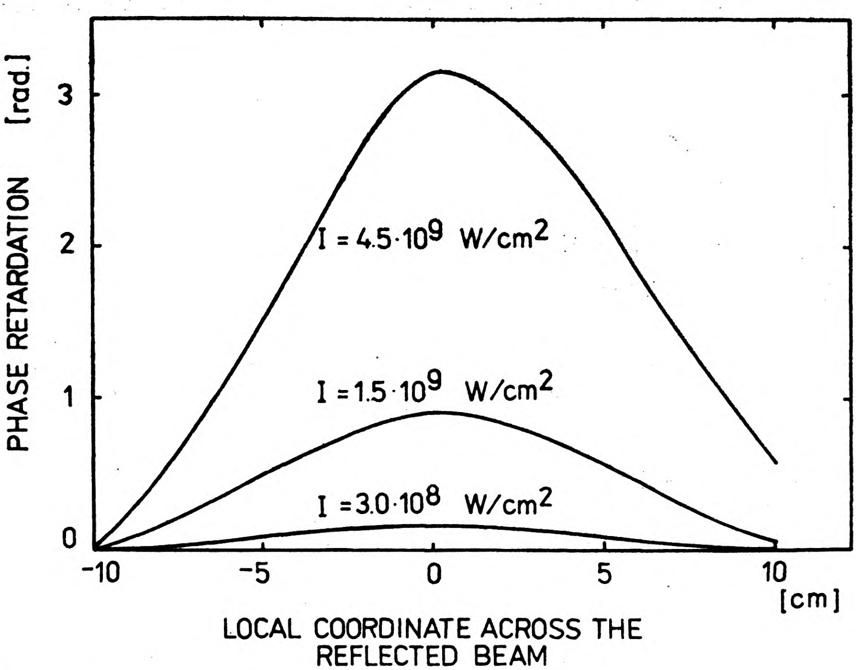

Fig. 2. Phase retardation across the reflected beam

and the facts that $S(x, z) = 1$ at the entrance plane of the prism (see fig. 1), and the phase is changed during reflection, we get a solution of equations (2) with changes of phase depending on the local coordinates.

A numerical evaluation of eq. (2) for Gaussian-beams is demonstrated in fig. 2. From fig. 2 it follows that the increase in laser intensity causes an increase of the phase difference between the central and the marginal parts of the reflected beam.

From the phase difference between the central and the marginal parts of reflected beam we can conclude that the focal point of an optical system arranged behind the prism must be shifted. Figure 3 shows the relative irradiation density as a function of the incoming laser intensity and as a function of the size of the irradiated plane. A decrease of the irradiated area increases the relative irradiation (see fig. 3).

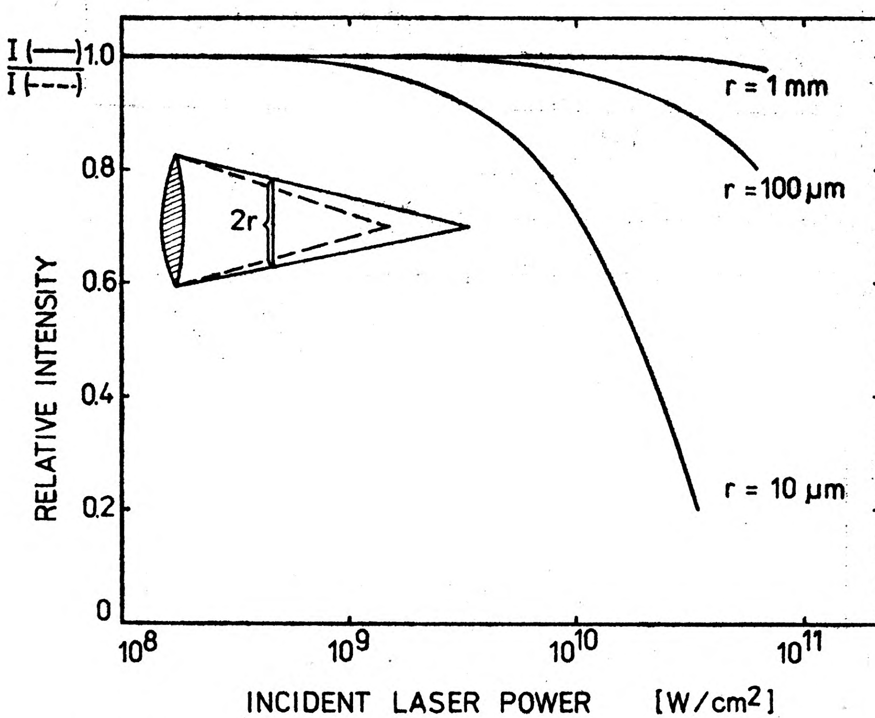

Fig. 3. Erroneous irradiation of small objects

The described changes are small if we use:

— ultrashort pulses,
— small prisms, and
— a uniform energy distribution across the beam.

Taking into consideration the reflection of a plane wave emerging from a high power laser, we get by this effect wavefronts, which are tilted,

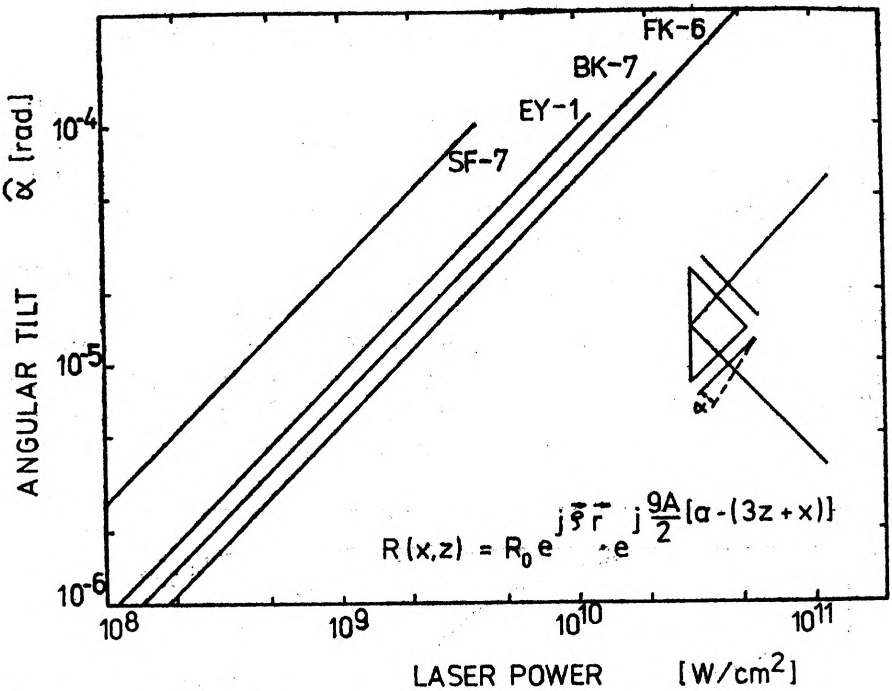

Fig. 4. Angular tilt of the wave front by a nonlinear prism

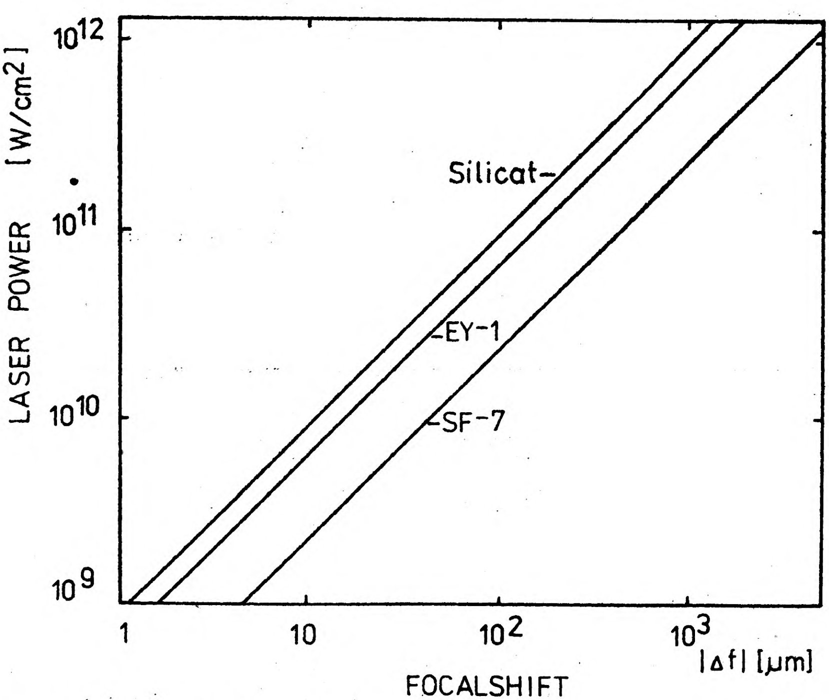

Fig. 5. Nonlinear focal shift after passing a lens

when compared with a normally reflected plane wave. The tilt of the wavefront reflected by the prism vs. the laser power is plotted in fig. 4.

This tilt results in a lateral translation of the focal point of the radiation after passing the optical system behind the prism, which is due to errors in the irradiation of small objects.

The described influences, being generally valid, must be taken into consideration while treating the reflection of high power laser radiation inside of an optical-cubic-nonlinear medium.

As a consequence of the cubic nonlinearity and due to the interaction between the electromagnetic field and the glass in a lens a change of the refractive index is connected with a lateral shift of the focal point with respect to the optical axis. This causes an error of the irradiation density at small objects. The shift of the focal point is demonstrated in fig. 5 as a function of laser power for different glass materials.

Our calculations have shown that the described effects cause perturbations in optical systems, if the power of the arriving laser beam is greater than $5\cdot 10^9$ W/cm^2.

References

[1] Bloembergen N., *Nonlinear Optics*, A Lecture Note Harvard University, W. A. Benjamin Inc., New York-Amsterdam 1965.

[2] Achmanov S. A., Chochlov R. V., *Problemy Nelineinoi Optiki*, AN SSSR, Moskva 1966.

[3] Maker P. D., Terhune R. W., Phys. Rev. **137** (1965), A 801.

[4] Weber M. J., Milam D., Smith W. L., Optical Engin. **17** (1978), 463.

Received December 11, 1979
in revised form May 7, 1980

Деформации пучка лазерного излучения во время перехода через элементы отображающей системы

Теоретически исследовалась деформация пучка лазерного излучения большой мощности во время перехода через оптические элементы при допущении нелинейности третьей степени. Показано, что искажения являются значительными, если мощность лазерного пучка является наибольшей $5\cdot 10^9$ Вт/см^2.