Proceedings of the 6th International Symposium
on
Advanced Nuclear Energy Research
—INNOVATIVE LASER TECHNOLOGIES IN NUCLEAR ENERGY—

Laser beam-forming by deformable mirror for laser isotope separation

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A rectangular laser beam of uniform intensity is very suitable for laser isotope separation. In this paper, we propose a beam-forming system which consists two deformable mirrors. One of the mirrors changes the beam intensity and the other compensates for phase distortion. We developed a deformable mirror for beam-forming. Its deformed surface is similar to the ideal mirror surface for beam-forming. We reshaped a Gaussian-like He-Ne laser beam into a beam with a more uniform intensity profile by a simple deformable mirror.

Keywords: Laser isotope separation, Beam-forming, Deformable mirror, Adaptive optics

1. INTRODUCTION

In some applications, it is necessary to reshape the laser beam intensity profile efficiently. For example, a rectangular laser beam with a uniform intensity is suitable for laser isotope separation as shown in Fig.1. There are two way to make rectangular uniform intensity laser beam. One is image relay system and the other is beam-forming. In order to reshape the laser beam intensity, several methods were studied. One method uses CGH (Computer Generated Holography)[1),2),3)] and other uses mirrors[4)]. Mirrors are more efficient than CGHs because the beam-forming efficiency of a CGH system depends on its diffraction efficiency. Furthermore, a mirror system can reshape high power laser beams. However, it is difficult to fabricate the mirror surface except mirrors which are symmetrical about their axis for long wavelength lasers. In this paper, we propose a beam forming system which consists of two deformable mirrors. This type of system can follow a beam with time varying intensity or wave front in the case of an adaptive system. The efficiency of this system depends on the precision of the mirror surface and the phase distribution of the input beam. We succeeded in reshaping a Gaussian-like He-Ne laser beam into a relatively uniform beam using a deformable mirror.

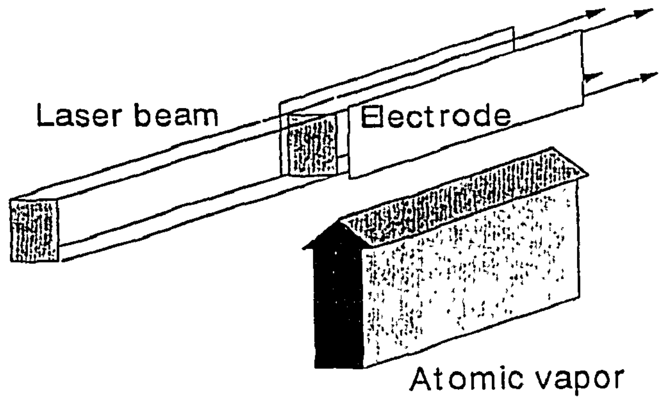


Fig.1 Configuration of laser isotope separation

2. CONCEPT OF BEAM-FORMING SYSTEM

The concept of the beam-forming system is shown in Fig.2 and consists of two deformable mirrors. The first mirror changes the laser beam intensity profiles and the second mirror compensates for the distorted phase distributions in order to improve propagation of the beam. If it is not necessary to propagate the beam over a long distance, the second mirror is not necessary.

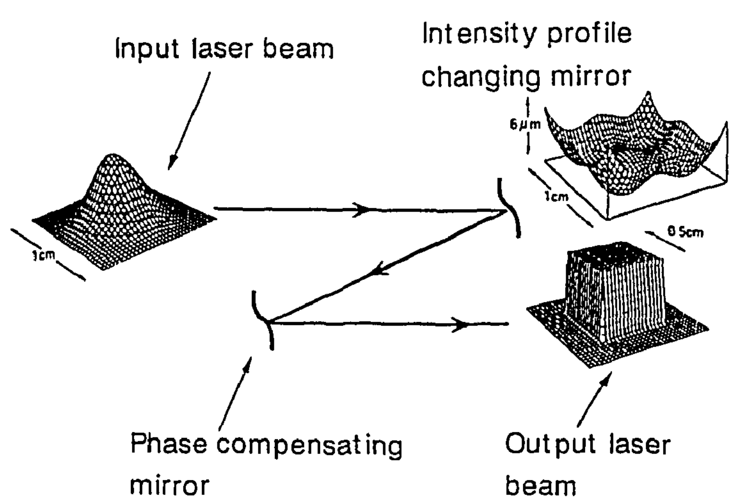


Fig.2 Beam-forming system using deformable mirror

The basic concept of laser beam-forming is based on the method of Olof Bryngdahl5). The complex amplitude of the laser beam at the second mirror before phase-compensation is described by the Fresnel equation and is as follows.

$$a'(u,v) = \frac{jk}{2\pi d}\exp(-jkd)\iint a(x,y)\exp[-j\psi(x,y)]\exp\left\{-(jk/2d)\cdot\left[(u-x)^2+(v-y)^2\right]\right\}dxdy \quad (1)$$

Where (x,y) and (u,v) are the coordinates at the first and second mirror, a(x,y) and a'(u,v) are the complex amplitudes of the beam at the first and second mirror, $\psi(x,y)$ is the phase distribution caused by the first mirror, k is the wave number vector of the laser and d is the distance between the two mirrors. From this equation, the following equations can be derived using the stationary phase method2) :

$$\partial \psi(x,y)/\partial x = k/z(u - x) \quad (2a)$$

$$\partial \psi(x,y)/\partial y = k/z(v - y) \quad (2b)$$

This equation shows that the direction of a ray which travels from (x,y) to (u,v) is the same direction as the vector which is perpendicular to the wave front. In order to design the first mirror, we must decide the relation between (x,y) and (u,v); we chose the relation using the same method as Chang1) and Nicholas2).

This system is a type of telescopes as shown in Fig.3. An ordinary telescope expands a beam with the same magnifying power all over the beam and an anamorphic telescope expands with two different magnifying powers depending on the direction. The magnifying power of this system depends on the intensity of the input beam profile and the desired output beam profile.

We can design the peak to valley of the mirror surface as a reasonable value because it depends on the distance between the two mirrors. We simulate the beam-forming property of the first mirror and solve the Fresnel equation using a Fourier transformation6). A circular Gaussian beam is transformed to a rectangular uniform beam or a circular uniform beam as shown in Fig.2 from these simulations7). Note that, the effect of the incident angle is ignored because it is assumed to be large.

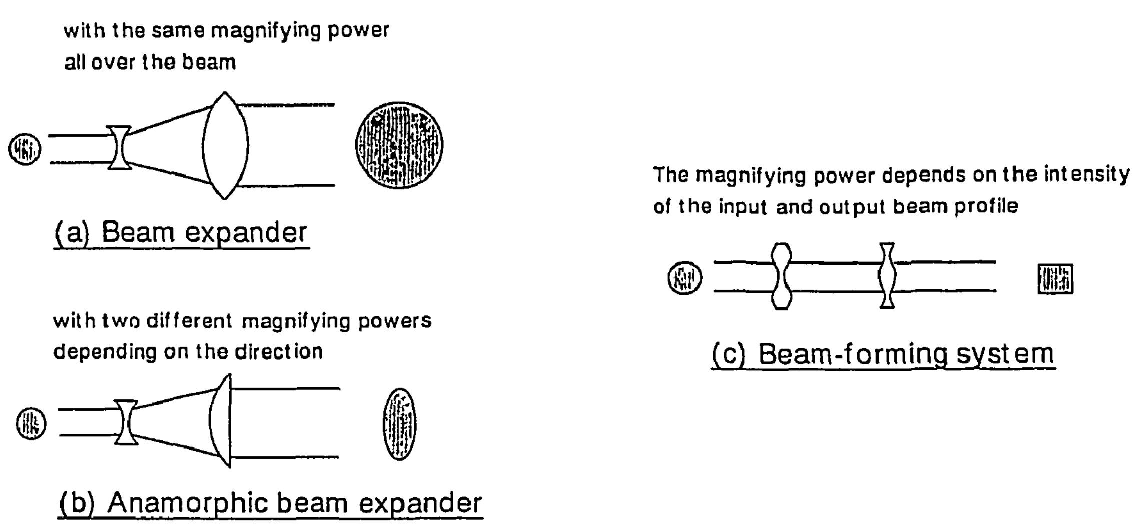


Fig.3 Beam-forming system and beam expander

3. BEAM-FORMING EXPERIMENT

3.1. Deformable mirror

The deformable mirror assembly for transforming a Gaussian-like beam profile to a circular uniform profile is shown in Fig.4. The assembly consists of a mirror and actuators; the mirror is made of BK7 and is coated with aluminum; the diameter is 30mm and the thickness is 1mm. The mirror is fixed on a ring of diameter 11mm and width 2mm, and is pushed on the center and periphery by micrometers and PMNs (Lead Magnesium Niobate). The stroke of the PMN is 15mm without stress. The mirror periphery is pushed by a pusher ring driven by four micrometers and two PMNs. Two of the four micrometers are located behind the two PMNs. The micrometers are used for positioning the PMNs and for roughly deforming the mirror surface. The PMNs are used for fine deforming. The applied voltages of the PMNs can be input from a computer key board while monitoring the beam profiles or mirror surface profiles. The deformable mirror surface is shown in Fig.5 and is similar to the ideal surface for beam-forming. The diameter of the measured region is 26 mm while the peak to valley of the deformed mirror is about 7 λ at the wavelength of the He-Ne laser. Although the surface profile of the mirror must be symmetrical about its axis as shown in Fig.3, the deformed surface is not axis-symmetric. The reason may be possibly due to inaccuracies in the pusher ring.

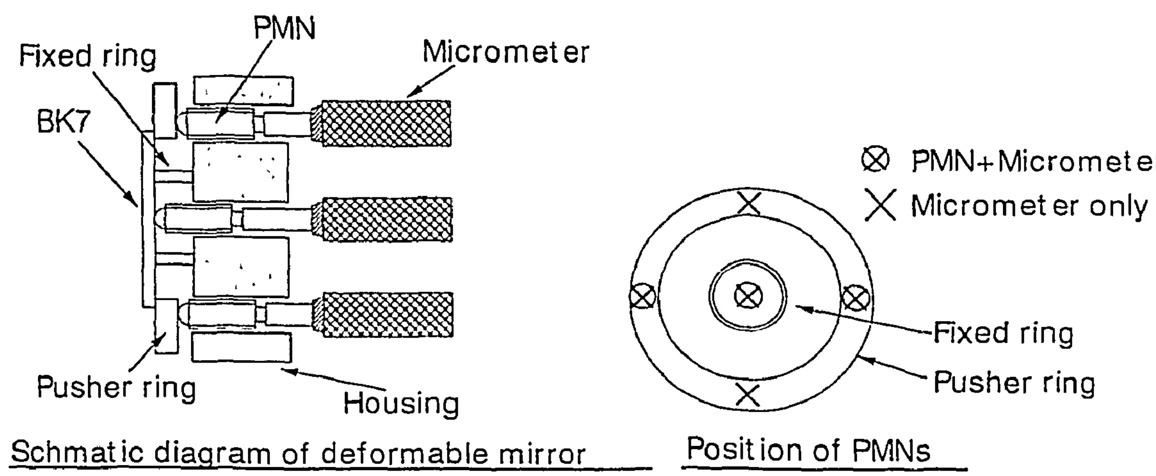


Fig.4 Deformable mirror

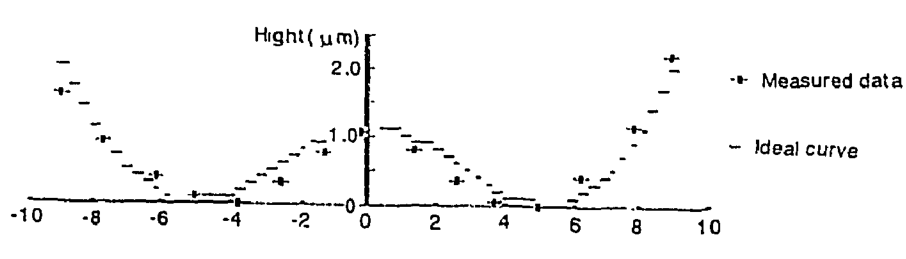


Fig.5 Surface profile of deformable mirror

3.2. Beam-forming property

The schematic diagram of the optical arrangement of the experiment is shown in Fig.6. A He-Ne laser beam is expanded by a spatial filter and a camera zoom lens. The pinhole diameter of the spatial filter is 25mm. The peak to valley of the wave front of the expanded He-Ne beam is 0.7 λ at the position of the CCD camera and looks like a spherical aberration. The wave front is measured from fringe patterns produced by a Mach Zender interferometer. The reference beam is magnified by 10 and is shielded when the intensity profiles are measured. Fringe patterns are analyzed by WYKO 400D. The intensity profile of the He-Ne laser is similar to a Gaussian profile but is not an exact Gaussian profile. The beam intensity profiles reflected by

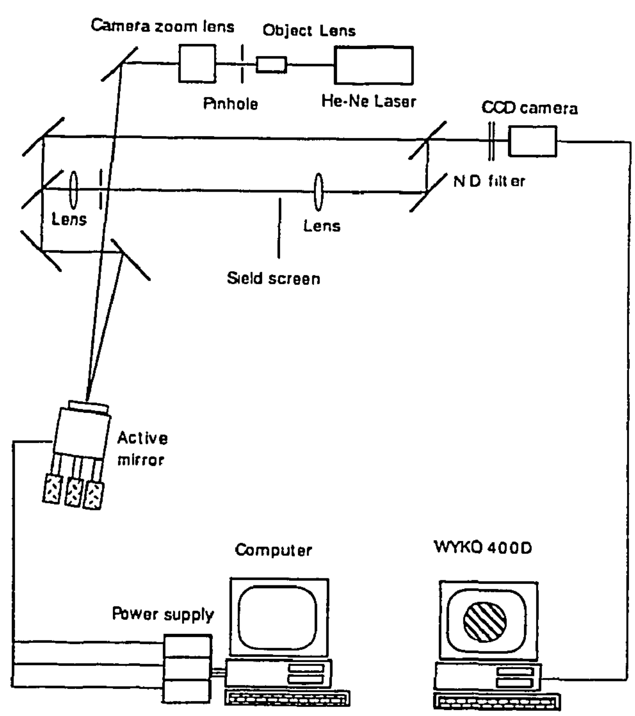
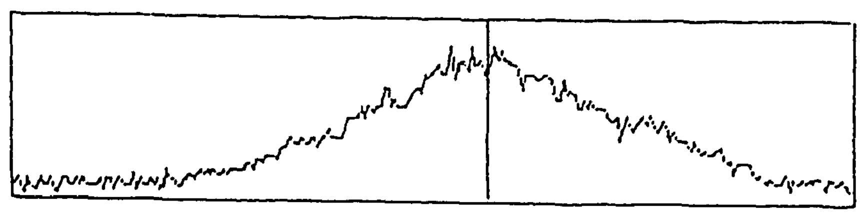
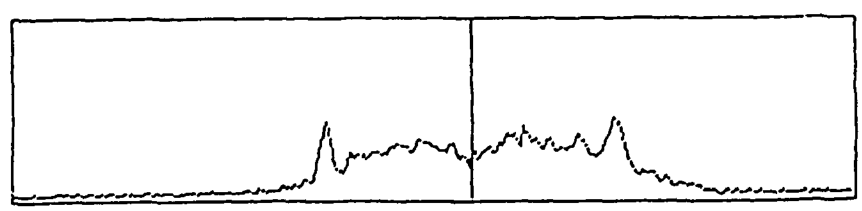


Fig.6 Schematic diagram of experimental setup

the deformable mirror are measured by a CCD camera and also analyzed by WYKO 400D. A Gaussian-like intensity profile changes into a more uniform circular profile as shown in Fig.7, however, the reshaped beam has a peak on its periphery. The reason for this peak is that the distance is too large compared with the optimum distance according to simulations as shown in Fig.8. In addition, the deformed surface is slightly different from the desired mirror surface and this difference causes a weak halo around the reshaped beam. This halo is a loss because the halo can not propagate over a long distance and diverges from the area in which photo reactions occur. The beam profile is also distorted far away from the CCD camera because no compensation is made for the phase distortion. Improving the accuracy of the mirror will make the beam intensity more uniform.



(a) Before reshaping



(b) After reshaping

Fig.7 Reshaped beam profile

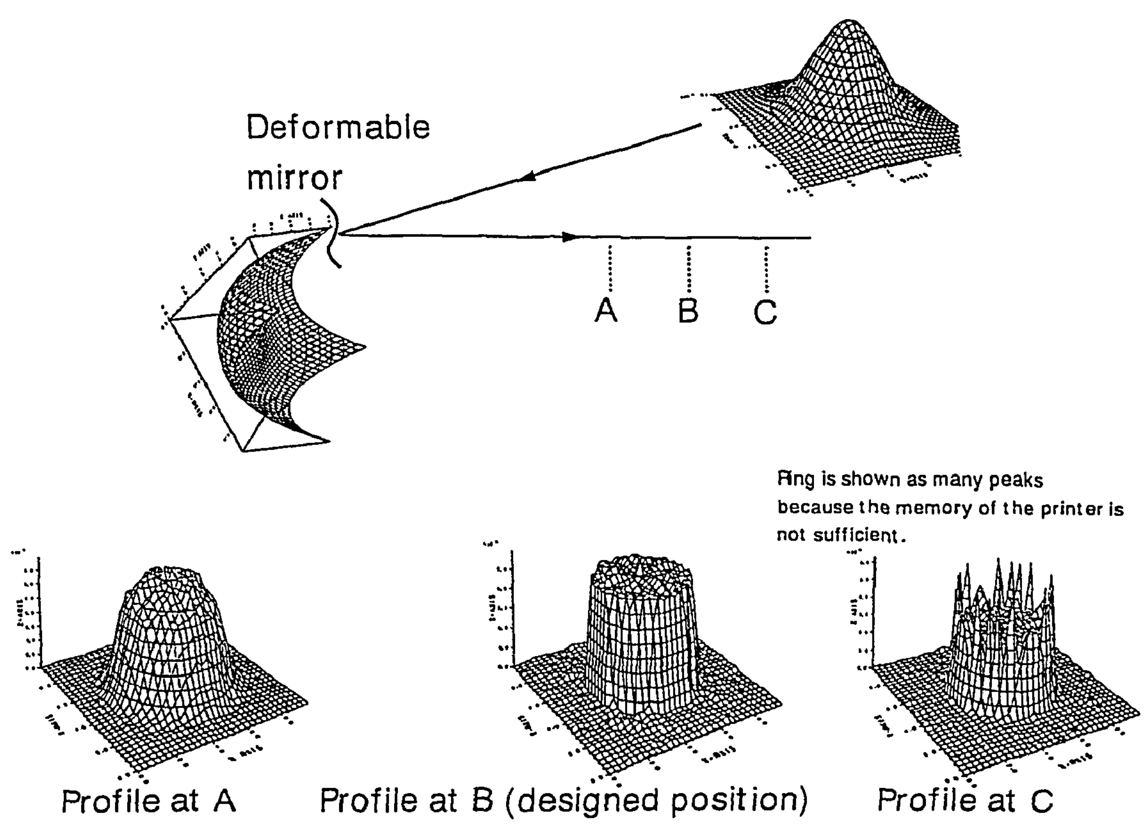


Fig.8 Simulation of beam-forming

4. SUMMARY

We propose a beam-forming system which consists of two deformable mirrors. The first mirror changes the intensity profile of the laser beam and the second mirror compensates for wave front distortions. This type of system can follow a beam with time varying intensity or wave front in the case of an adaptive system as shown in Fig.9. We simulated the reshaping property of the first mirror and reshaped a Gaussian-like He-Ne laser beam into a more uniform beam by a simple deformable mirror. The uniformity of the beam will be improved by using a deformable mirror with more actuators.

5. ACKNOWLEDGEMENT

The authors would like to thank Dr. Yokoyama, Mr. Kanai and Mr. Isoda for useful discussions and assistance.

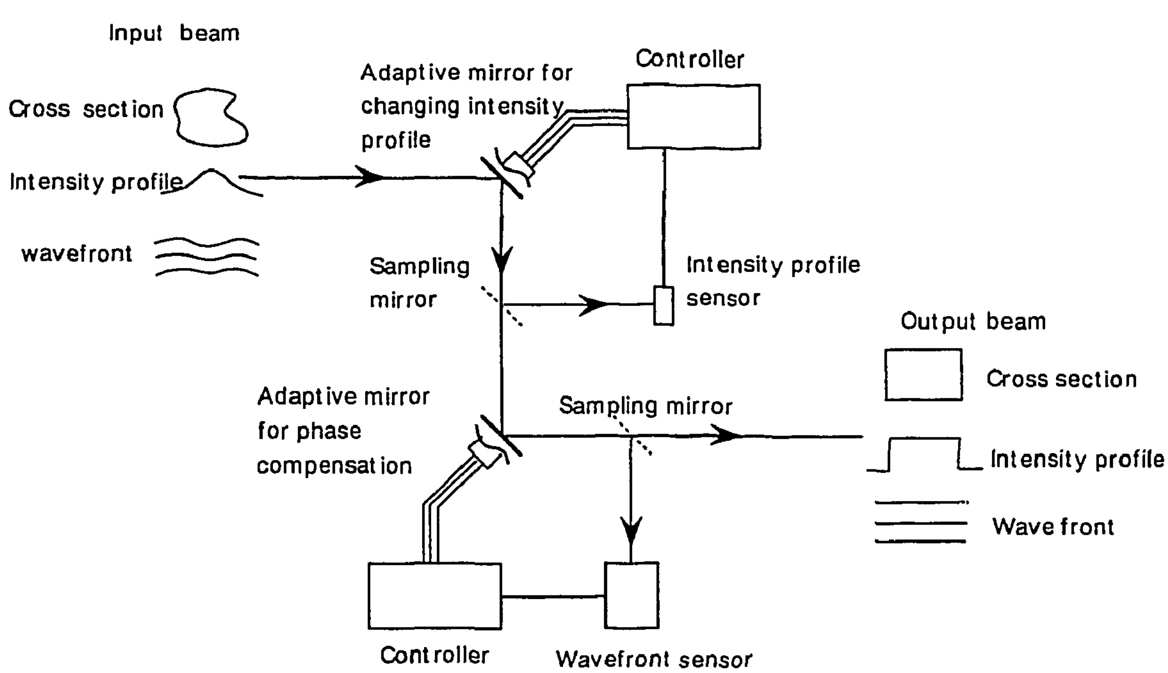


Fig.9 Beam-forming system by deformable mirror (Idea)

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