Compensating laser wave-front aberration in atmosphere 1.27 km away with SBS

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It is reported that the wave-front aberration produced by atmosphere disturbance can be compensated with nonlinear optics phase conjugate technology. The distance of laser propagating in atmosphere is up to 1.27 km away. The result shows that SBS phase conjugating beam energy can be focus in a little area on target. And the biggest energy of phase conjugating beam on target is up to 142 mJ.

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Propagating in the atmosphere, the laser will spread, wander and scintilla, due to the wave-front aberration produced by the atmosphere disturbing. These phenomena will make laser power on target descend and influence laser applying[1]. This can be avoided by compensating laser wave-front aberration generated in atmosphere with optical phase conjugate technology[2]. There are two main methods to generate phase conjugate beam. One is coherent optical adaptive technology (COAT)[3], the other is based on nonlinear optical effects, such as stimulated Brillouin scattering (SBS) phase conjugate technology[4]. SBS phase conjugate technology is playing an important role due to taking advantages of simple structure, fast response, high sensitivity and full scene[5]. In 1999, B. N. Borisov *et al.* in Russia realized laser compensating propagation in atmosphere 2 km away[4]. Pulse energy is up to 20 J. It proved that the laser wave-front aberration caused by atmospheric disturbance is compensated with SBS phase conjugate technology. The power density compensated is up to $3-5$ J/cm^2. In our country, compensating laser wave-front aberration indoor was reported with SBS phase conjugate technology[6]. In this report, we demonstrate compensating laser wave-front aberration in atmosphere outdoor 1.27 km away with SBS phase conjugate technology.

The experimental setup is shown in Fig. 1. In this system, the YAG laser is used, which is composed of a YAG resonator, a dye Q-switching, a diaphragm, two-step amplifiers and a beam expanding system. The working wavelength is 1064 nm. The YAG laser generates

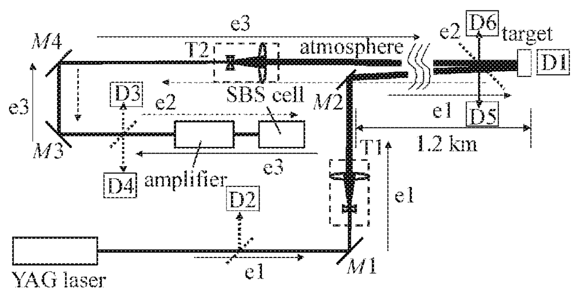

Fig. 1. Experiment of compensating laser propagation with SBS 1.27 km away. $M1-M4$: full reflectors; T1, T2: telescopes; D1 − D6: symbolize detecting places; e1: detection beam; e2: beacon beam; e3: SBS phase conjugate beam.

a detection beam e1, which is reflected by a mirror $M1$ into a telescope T1. Then e1 is expanded by a telescope T1 and reflected by a mirror $M2$ into the atmosphere to serve as a detection beam. Beam e1 arrives at a target 1.27 km away, which is simulated by two mirrors with reflectivity 99%, and the two mirrors are arranged vertically. The reflected beam from the target comes into being beacon e2, and back to experimental system through atmosphere 1.27 km away. The telescope T2 is used to receive beacon e2. Then beacon e2 is reflected into SBS system by $M3$, $M4$, which includes a YAG amplifier composed of two-step amplifier, a lens and a cell filled with CCl_4. Due to the characteristic of SBS phase conjugate beam, the back phase conjugate beam e3 of beacon beam e2 produced by SBS cell passes the YAG amplifier, $M3$, $M4$, telescope T2 orderly, and hits the target by original beam path of e2. And phase conjugate beam e3 of e2 has compensated the wave-front aberration caused by atmospheric disturbance. In this system, the available aperture of T1, T2 is 200 mm. We record the energy distributions of SBS conjugate beam and beacon beam by CCD, the energy by a detector (Newport J25) and an oscilloscope (TDS320).

In this experiment, all data is obtained in night of summer because of recording and weather condition in Harbin. Experiment of compensating laser propagation has been finished under different temperature and humidity of atmosphere according to case of weather. Atmosphere distance is 1.27 km away. Figures 2 and 3 are part of many spots obtained in case of 26 °C temperature and $3-4$ grade atmospheric wind's velocity. Figure 2 presents the beam spot (left) and energy distribution (right) of beacon e1 captured by CCD, which is detected in D1 when the beam e1 hits the target. It is shown that the energy distribution of spot is not regular. The distribution is elliptical. In our experiment, we detect repeatedly the spot. Due to atmosphere disturbance, different energy distributions are detected. Besides there are some speckles, the spots float too. We have measured the size of spot in Fig. 2, it is about 6 cm around the brightness center. Figure 3 is the spot and energy distribution of SBS phase conjugate beam e3 on target detected in place D1. In this case, the size of spot brightness center is 2 cm, and the spot's shape is circle regularly. The laser divergence angle is expressed about

3 times. But there are some obvious interference patterns in Figs. 2 and 3. This may be caused by telescopes T1 and T2, of which lenses are not coated for transmission, and laser forms equivalent thickness interference on target. On the other hand, in Fig. 1, if the SBS cell is replaced by a full-reflector mirror in wavelength 1064 nm. We cannot detect any spot in target. Only a spark in CCD can be found. It shows that the phase conjugate beam generated by a SBS cell can compensate the wavefront aberration caused by atmosphere disturbance.

We also investigated the influence on energy of SBS phase conjugate beam in case of different detection beam energy and SBS amplifier gains. Figure 4 shows energy of beacon beam versus detection beam. Detection beam energy is detected in place D2, and YAG laser generates beam e1. When detection beam e1 passes telescope T1 and atmosphere 1.27 km away, then arrives at simulated target, the beacon beam energy arriving target is detected in place D1. Beacon energy back to SBS is detected in place D4. When detection beam e1 arrives the target and is reflected, it becomes beacon beam e2, passes through atmosphere to telescope T2. Reflected by $M3$ and $M4$, at last it arrives at SBS cell. From Fig. 5, we can find there is a linear curve approximately. The atmosphere attenuation index one way is about 25%. The atmosphere attenuation index round trip is about 85%. This includes attenuation of optical system in setup. If the aperture of T2 is enough small to not accept beacon beam e2 completely, the atmosphere attenuation index round trip would rise.

Figure 5 shows the energy of SBS phase conjugate beam e3 arriving target detected in place D5 versus detection beam detected in place D2. SBS beam energy arriving target means SBS phase conjugate beam is generated and amplified by SBS system, and passes through atmosphere 1.27 km away, then arrives at target again. Figure 5 also shows the relation of SBS beam energy versus detection beam energy when SBS amplifier gains are 12.0 and 11.0 dB. In this figure, keeping the SBS amplifier gain, rising detection beam energy, SBS beam energy goes to saturation. This is the reason of saturation effects of SBS and amplifier. In this experiment,

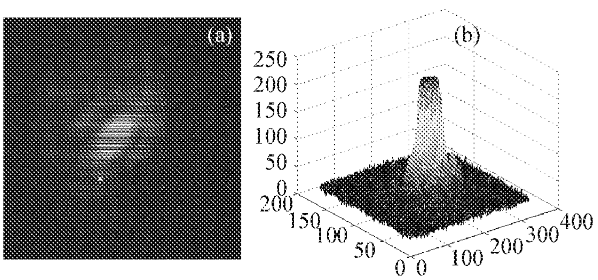

Fig. 2. Beacon beam spot and energy distribution.

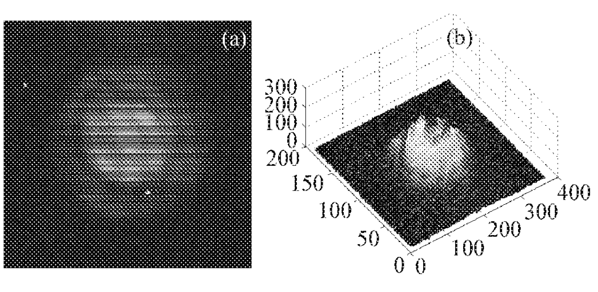

Fig. 3. Phase conjugate beam spot and energy distribution.

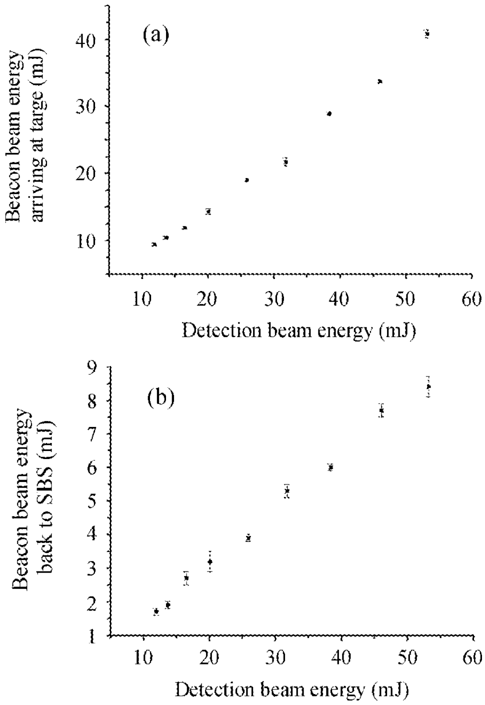

Fig. 4. Beacon energy via detecting light. (a) At target; (b) before SBS system.

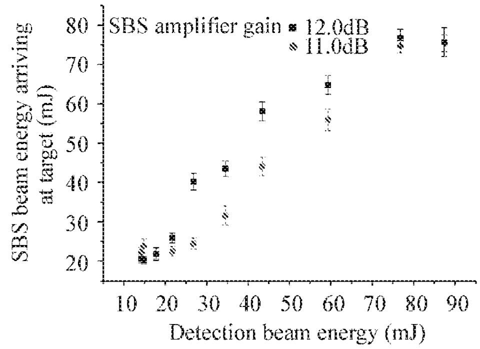

Fig. 5. Energy of phase conjugated beam arriving target versus detection beam.

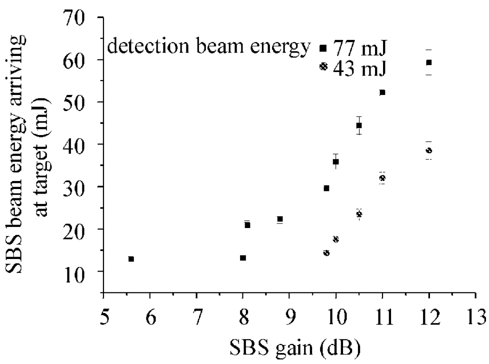

Fig. 6. Energy of phase conjugated beam arriving target versus SBS amplifier gain.

the biggest SBS phase conjugate beam energy arriving at target is up to 142.0 mJ.

Figure 6 shows the energy of SBS phase conjugate beam e3 arriving at target detected in place D5 versus SBS amplifier gain. In this figure, detection beam energies are 77 and 43 mJ, respectively. When SBS amplifier gain is too small, SBS phase conjugate beam energy becomes unstable. Even it cannot be detected on target. The SBS phase conjugate beam e3 from beacon beam e2 not only compensates the wave-front aberration of beacon beam e2, but also has been amplified due to SBS amplifier. The bigger of the SBS amplifier gain is, the higher the SBS beam energy arriving at target is. And the tendency of energy rising is more steep.

The phase conjugate beam generated by a SBS cell is used to compensate for the aberration caused by atmosphere disturbance. The energy distribution of detection beam and SBS phase conjugate beam is obtained. It is found that SBS phase conjugate technology can compensate wave-front distortion of laser propagating in atmosphere, concentrate energy distribution, and can focus laser beam in a little area on target in air 1.27 km away.

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