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LASER PHYSICS AND LASER OPTICS

Acousto-Optic Power Summation for Mutually Noncoherent Pulsed Lasers

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Abstract—A method of the power summation for mutually noncoherent pulsed lasers of the same type using time interleaving is proposed and validated experimentally. The method uses an acoustic-optic deflector, which commutates radiation of different sources into one output channel simultaneously with radiation presenting in this channel. It is crucially important that the power of the final output radiation is equal to the power sum of the input sources, and the angular and coordinate parameters of an output beam are the same as that for the input sources. The experiments were carried out with single-mode diode lasers on a wavelength of 1.3 μm using a TeO_2-crystal-based deflector. The method is appropriate for the power summation for fiber-optic, diode, and solid-state lasers. We have estimated the main interrelated parameters.

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INTRODUCTION

The power summation for laser sources of the same type into one channel is an interesting and technically topical problem. The given conditions of such summation are as follows: the sources are mutually noncoherent, the power of the output beam is equal to the power sum of the input sources and the angular and coordinate parameters of the output beam should remain unchanged. The fulfillment of the mentioned requirements is possible only for coherent input sources [1]. At the same time, the wrong opinion exists that this summation can be realized for continuous noncoherent sources [2].

The pulsed lasers are widely used in the modern science and engineering including optical data communication, navigation, positioning of construction units, and material treatment. One of the main laser parameters is the integral (mean) power. For diode lasers, the power limitation is determined by heat effects. For fiber-optic lasers, it is determined both by heat limitations in pump diodes and by nonlinear effects in fiber-optic waveguides (FOWs).

The goal of the present work is to realize the power summation for several mutually noncoherent pulsed lasers of the same type into one output channel to increase the total power of the pulsed laser radiation. It is important that the optical parameters of the output channel such as the linear and angular aperture are the same as that for the input lasers, and there are no crucial losses of the optical power.

POWER SUMMATION PRINCIPLE FOR PULSED LASERS

The summation principle uses the time interleaving, when the "silence" of the first laser is superseded by others.

The summation is realized by an acousto-optic (AO) method, namely, using an AO deflector, which is used for deflecting (scanning) of a beam with a fixed direction within some angular range upon tuning of a control signal frequency [3–6].

In our work, we propose to use the AO deflector in a "reversed" mode, when the deflector does not switch the light beam of a fixed direction into several directions, but switches light from several multidirectional sources into a singular channel with a single direction. The validity of such use of the AO deflector is based on the fundamental physical principle of optical AO reciprocity. It is obvious that all theoretical calculations and engineering parameters of the deflector are similar and suitable also for the AO summation unit.

Keeping the general principle, for further specification let us assume that lasers are single-mode, which outputs match with single-mode FOWs.

The scheme of the AO summation is shown in Fig. 1.

The output butt ends of FOWs are placed in a row forming a linear matrix. The output beams are collimated into diameter D by lens $L1$ and are directed to the AOD. At the AOD output, lens $L2$ is placed, which focuses light into the butt end of the input FOW.

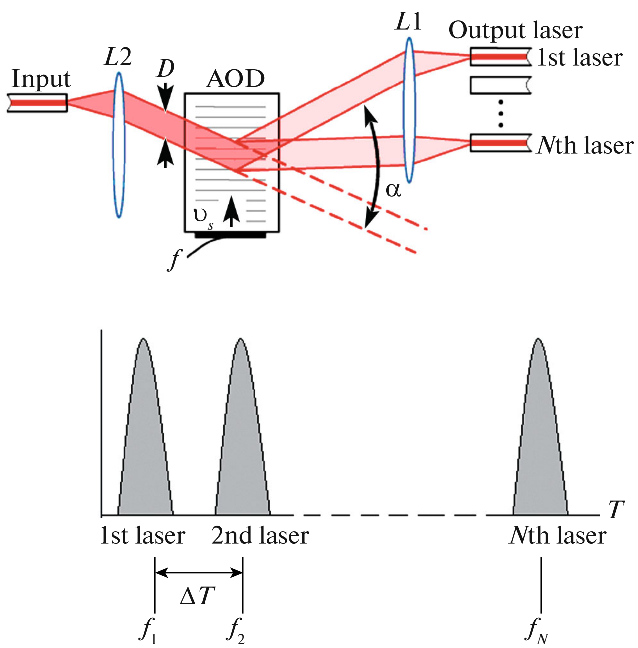

Fig. 1. (Color online) Principle of the AO laser power summation.

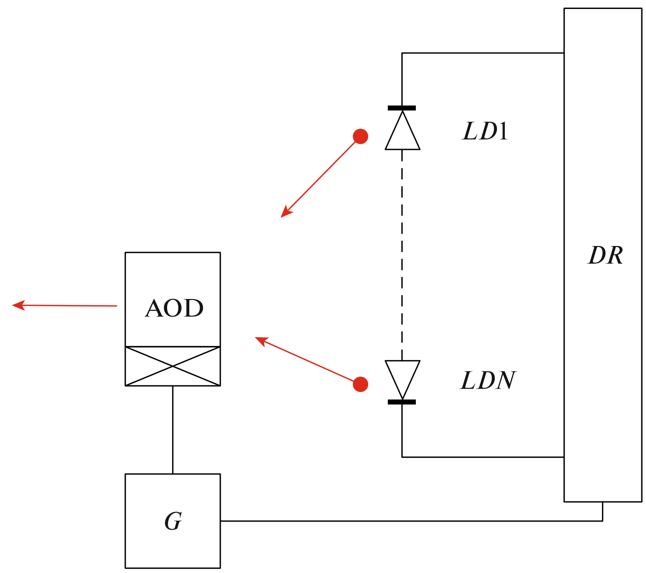

Fig. 2. (Color online) Principle diagram of the AO summation.

The operating principle is shown in Fig. 2.

Laser sources *LD*1–*LDN* are controlled by processor driver *DR* and are alternately switched on with some time shift ΔT, which yields the time division of pulses. The serial switch-on of lasers is synchronized with signal generator *G*, which controls the AOD operation. A particular acoustic frequency corresponds to each laser and is tuned in such a way that a diffracted beam is always directed toward the input FOW.

ESTIMATION OF THE MAIN PARAMETERS

Experiments were performed using TeO_2-crystal-based deflectors with diffraction on a slow acoustic wave propagating at an angle of 6° to the [110] crystal axis with the sound velocity of 0.65×10^6 mm/s. The calculations and experiments correspond to this situation.

The main interrelated parameters of the power summation unit are operation speed (switch time) τ and number of channels *N* that are in a compromised relation with each other: the increase of *N* decreases the operation speed. Let us estimate their numerical values.

Diffraction angle of deviation (scattering) α is

$$\alpha = f\lambda/v, \quad (1)$$

where *f* is the ultrasonic frequency in the AOD, λ is the light wavelength, and *v* is the sound velocity in TeO_2.

Aperture *D* is selected from a given operation speed determined by time τ, which an acoustic wave takes to pass through a given light aperture:

$$D\ [\text{mm}] = 0.65\tau\ [\mu\text{s}]. \quad (2)$$

As an example, aperture $D = 4$ mm is for the switch time of 6 μs. Maximum (ultimate) number of channels N_m is determined by the maximum operating frequency bandwidth of the AOD, Δf, and by the value of *D*:

$$N_m = \Delta f D/v. \quad (3)$$

The operating frequency bandwidth of the practically used deflectors is 15–30 MHz. Therefore, we obtain for $D = 4$ mm and $\Delta f = 20$ MHz that $N_m \sim 120$ if FOWs are located from each other at a distance matching the Rayleigh criterion similarly to a common deflector. Clearly, the packing density of FOWs in the matrix a practical limitation of the channel number.

Optical fibers of a FOW are spaced from each other by a certain distance for two reasons. The first reason is engineering and the second one is “parasitic” penetration of light into neighbor channels. The degree of this penetration is determined by the packing density of FOWs in the matrix, i.e., by the ratio of distance *R* between neighbor fibers to diameter *d* of the optical-fiber core (Fig. 3).

The selected operation speed, realized operating frequency bandwidth of the AOD, and the packing density of FOWs in the matrix determine the maximum number of channels:

$$N = (d/R)\Delta f\tau. \quad (4)$$

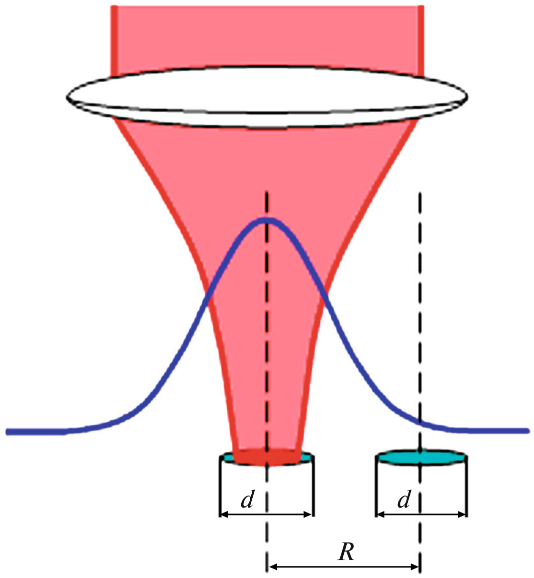

Fig. 3. (Color online) Parameters of the FOW packing.

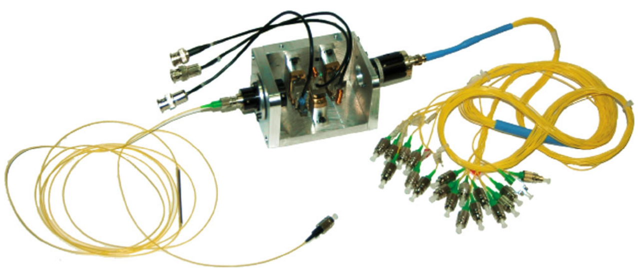

Fig. 5. (Color online) Experimental commutator with the following parameters: 19 channels, FC-PC fiber-optic waveguide connectors, diameter of the collimated beam in TeO_2 crystals 4 mm, FOWs are single-mode, wavelength range 1.3–1.5 μm, input–output losses 3 dB, control power 1 W at 1.3 μm and 2 W at 1.5 μm.

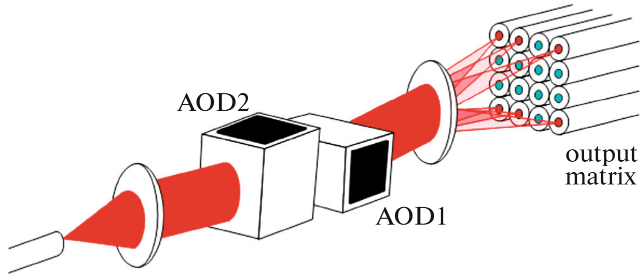

Fig. 4. (Color online) Scheme of the two-axis laser power summation unit.

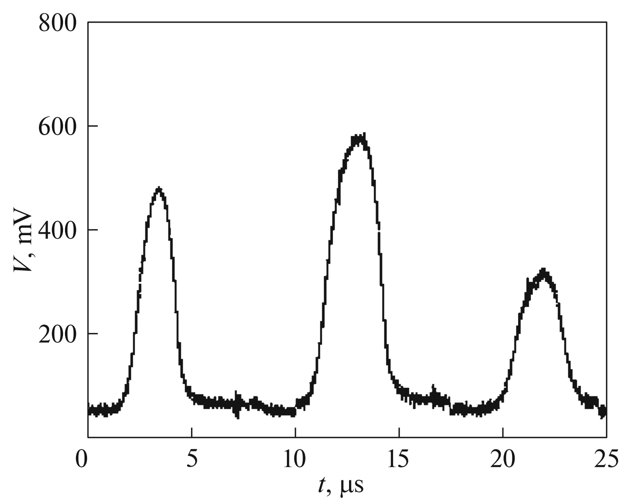

Fig. 6. (Color online) Electron oscilloscope image of the output signal.

For the experimentally used AOD [7], the packing density is 3 and the operation frequency bandwidth is 20 MHz, so the single-axis AOD has $N \sim 7$ channels.

The use of the two-axis scheme (Fig. 4) yields N^2 output channels.

In addition, one AOD follows the other and is oriented normally to it. The first and second AODs cause light to deviate into mutually normal directions. The deviation angles are controlled independently, which makes it possible to direct light from any FOW of the two-dimensional matrix.

EXPERIMENTAL RESULTS

The practical implementation of the AO power summation for pulsed lasers was realized using previously manufactured two-axis commutator of fiber-optic channels [7]. This commutator was intended for switching light from one output FOW into the matrix of input FOWs. As it was mentioned before, we operated in a “reversed” mode due to the reciprocity of the AO effect. Figure 5 shows a picture.

The basic peculiarity of the commutator is the polarization insensitivity [8].

We carried out experiments with two FPL-1310-8DL-2 single-mode laser diodes operating in a pulsed mode at a wavelength of 1.3 μm. The output power of each diode was 2 mW.

Figure 6 shows the oscilloscope image of the output signal of the summation unit, which is the result of the laser power summation.

For clearness, the amplitude and pulse duration of each laser were adjusted as different.

In our case, the delay between pulses of 10 μs was selected to provide switching of frequency by the AOD operation speed (6 μs).

CONCLUSIONS

A method of the power summation for mutually noncoherent pulsed lasers using time interleaving is proposed and practically validated. We have practically realized the power summation for three diode lasers at a wavelength of 1.3 μm using a TeO_2-crystal-based deflector. It is crucially important that upon such summation the angular and coordinate parameters of original sources do not change. The result of summation could be very high, since the AO devices control laser radiation of a considerable power. The method is appropriate for the power summation for fiber-optic, diode, and solid-state lasers.

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