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All-Optical 2-D Serial-to-Parallel Pulse Converter Using an Organic Film with Femtosecond Optical Response

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1. Introduction

Time-to-space conversion of femtosecond optical pulses attracts much attention for all-optical signal processing [1-5] and is applicable to important optical signal processing functions, such as ultrafast serial-to-parallel pulse conversion. However, in most of previous works, space expansions were carried out in 1-D utilizing Fourier transform in frequency domain; namely, it was essential for the optical pulses to be transform-limited. A simple procedure for converting serial femtosecond pulse train into 2-D parallel outputs with loose limitation about pulse quality is desired for demultiplexing devices in future optical networks. We propose a new device concept for all-optical 2-D serial-to-parallel pulse conversion based on direct time-to-space conversion using the time-of-flight technique [6], not necessarily requesting fundamental pulses to be transform-limited. The core of this concept is the large-area organic all-optical shutter, which enables femtosecond operation.

2. Principle

The schematic diagram of serial-to-parallel pulse conversion is shown in Fig.1. Femtosecond optical pulse train having picosecond interval is fed onto a nonlinear optical (NLO) material with a finite diameter. The signal pulses are synchronized with a femtosecond gate pulse with the same finite diameter. The signal and gate pulses are aligned with a finite difference in the incident angle (θ). Because the signal and gate pulses are plane-wave pulses, each of the signal pulses meets the gate pulse at a different location on the NLO material due to θ. If the NLO phenomenon (for example, second harmonic generation (SHG) or breached absorption) recovers the initial state within the time scale of gate pulse interval, NLO signal stimulated by each of the signal pulses are detected at different locations of the NLO material. By monitoring the NLO signals, serial signal pulses are demultiplexed into 1-D parallel outputs. To expand output signals into 2-D, an optical delay can be introduced to the gate pulse in vertical direction. In Fig.1, the gate pulse is divided into two parts and each part is given a different arrival time by a grass plate [7]. The former gate pulse is synchronized with the fast half of signal pulse train, and the latter gate pulse with the latter half. Demultiplex operation mentioned before occurs by each part of the gate pulse. Consequently, 2-D 2 x 4 output signals are generated and detected on a screen by a single gate pulse.

3. Experiment and Results

Femtosecond pulse train having 1 ps interval , which corresponds to 1 THz repetition rate, was generated by retro-reflectors using amplified Ti:Sapphire laser pulses. θ was set to be 18 degrees and 1 ps pulse interval corresponded to 1 mm distance on the NLO material. Beam diameters of signal and gate pulses were about 10 mm ϕ.

For NLO materials, two types of materials were utilized. A type II crystal plate of BBO was used to confirm the principle of the device concept, and, for more practical device applications, an organic optical shutter using a spincoated film of squarylium (SQ) J-aggregates was examined.

A BBO crystal plate of 10mm ϕ was inserted at the position of a NLO material in Fig.1. SH signals were generated from each meeting location of the gate and signal pulses. Output signal images enlarged through a convex lens are shown in Fig.2. 1 x 4, 2 x 4, 3 x 4 and 4 x 4 output signals are clearly observed on a screen. Multi-stage optical delays were generated by piled glass plates like a stairway. Nonuniformity of the output image mainly comes from disorder of beam pattern due to edge diffraction. Results in Fig.2 prove the ability of system to demultiplex 1 THz femtosecond pulse train into 2-D parallel outputs by a single gate pulse.

A spincoated film of SQ J-aggregates, as we have already reported [8], exhibits the bleached absorption at 775nm and absorption change relaxes to half the maximum within 200-300 fs. Thus, a SQ J-aggregate film with a large area can be used as 2-D array of femtosecond optical shutters. Output signals were detected as the intensity change of signal pulses caused by the breached absorption and its relaxation, which accompanies the passing of gate pulse through a SQ film. A CCD camera in the differential image mode monitored the intensity change. An image of 1-D output signals and its intensity profile are shown in Fig.3. 1 x 4 clear output signals are observed. Each signal exhibits a very sharp rise and fairly rapid decay. This corresponds to the fact that an absorption reduction occurs within a few femtoseconds, while the relaxation to half the maximum requires about 300 fs. All-optical 2-D serial-to-parallel pulse conversion by a single gate pulse has been thus confirmed for the first time using ultrafast NLO materials. The SQ J-aggregate film has considerable advantages over crystals in cost, easiness of microprocessing and integration.

4.Conclusion

In summary, a new concept of 2-D serial-to-parallel pulse conversion has been proposed. Demonstrations were performed using a BBO crystal and an ultrafast optical shutter of SQ J-aggregate film. The converted signals of serial pulses having 1 ps interval into 1-D or 2-D parallel outputs has been clearly demonstrated.

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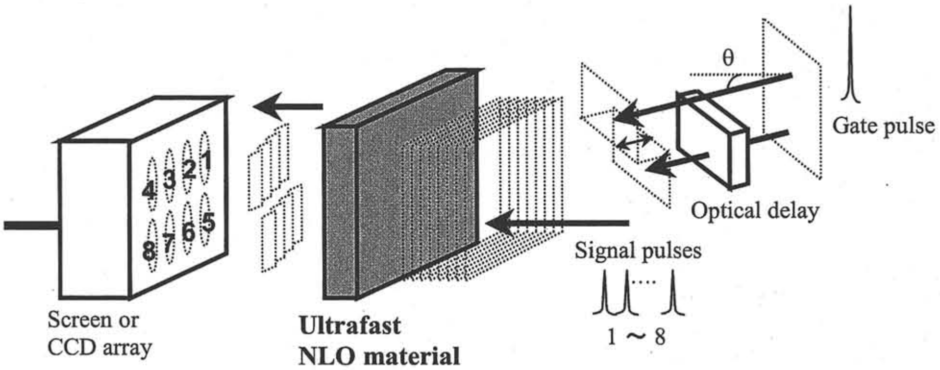

Fig.1. Schematic diagram of the serial-to-parallel pulse conversion system.

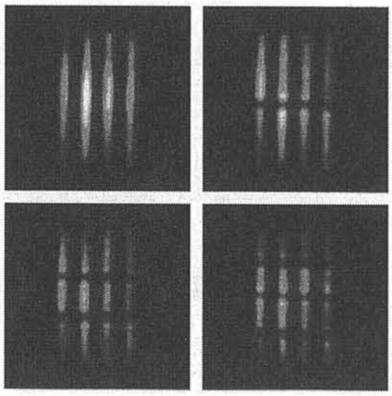

Fig.2. Output signal image on a screen using SHG of a BBO crystal

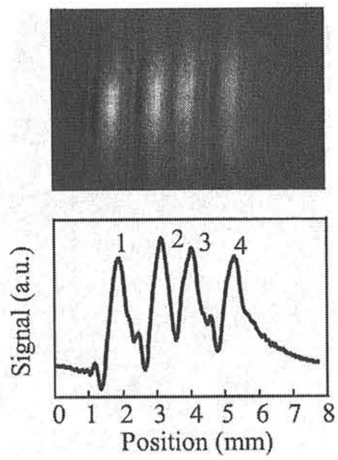

Fig.3. Output signals and intensity profile of the CCD differential image using a SQ J-aggregate film.