Bipolar Optical Modulation and Demodulation Using Dual-Mode Fiber and a Fast Diffusion-Driven Photodetector

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Abstract—We demonstrate a bipolar fiber-optic signal processing and photodetection concept which combines a dual-mode optical fiber with a fast diffusion-driven photodetector.

INTRODUCTION

A DUAL-MODE fiber with an elliptical core of the proper dimensions can propagate a symmetric lowest order LP01 mode, or an antisymmetric LP11 mode, but not any higher order modes [1]. Suppose a coherent superposition of these two modes is excited in the fiber with comparable amplitudes but an adjustable phase difference between the two modes. The transverse intensity profile across the end of the fiber, measured along the major axis of the ellipse, will then have one or the other of the two forms shown in Fig. 1 if the two modes are excited either in phase or 180° out of phase with each other at the output end. Intermediate phase angles will produce intermediate intensity profiles. In physical terms, the intensity distribution can be skewed or shifted back and forth from one side of the fiber to the other by varying the relative optical phase difference between the two modes.

DISCUSSION

One of the authors (A.G.K.) has recently demonstrated a novel, very fast, diffusion-driven photodetector [2], [3] which will respond in a bipolar fashion to precisely the sort of spatially asymmetric optical intensity distributions shown in Fig. 1. That is, each of these intensity distributions can be viewed as being more or less a single period of an off-center intensity grating pattern, with a transverse shift in position of roughly one grating period between the two cases. The diffusion-driven photodetector, if properly aligned, will respond to these skewed intensity patterns with a positive photovoltaic output for a light pattern which is displaced to one side, and a negative photovoltaic output for a light pattern displaced to the other side. A symmetric or centered intensity pattern, such as is produced by either of the fiber modes alone, will produce no response from this photodetector. Note that the detector is purely photovoltaic in character, i.e., it requires no dc bias voltage. Detectors of this type have been found to exhibit pulse responses to properly skewed optical signals with response times from nanoseconds down to picoseconds [3], and subpicosecond responses have been observed in unpublished measurements.

Fig. 2 shows an elementary bipolar optical signal processing or photodetection system which can be implemented by combining these dual-mode fiber and diffusion-driven photodetector concepts. Coherently related LP01 and LP11 mode signals are assumed to be excited in the dual-mode fiber. The output light intensity pattern coming from the fiber is then imaged and properly centered, to more or less fill the gap of a diffusion-driven photodetector of the type described earlier [3]. The dual-mode fiber might be excited, for example, with one transverse mode already present in the fiber and the other mode injected through a suitable mode-selective fiber-optic coupler [4]. One or both of the light signals is assumed to be pulsed.

Neither input signal by itself will then produce an output from the photodetector, assuming the fiber and photodetector are properly centered. When both signals are present and overlapping in time, however, output pulses will be detected with one electrical polarity if the two signals are optically in phase at the fiber output end, or with opposite polarity if the two signals are 180° out of phase, or with any amplitude in between if the two signals have intermediate phases. A change in the optical phase of

Fig. 1. Transverse intensity profile in the x direction across the end of a two-mode fiber propagating the LP01 and LP11 modes when the two modes are (a) optically in phase, and (b) 180° out of phase.
either signal—such as might be produced either by an electro-optic modulator or through light-by-light modulation [5]—can thus be used to vary the amplitude and polarity of the pulse detection of the other signal. Only one of the two signals in fact needs to be a pulse train; the other could equally well be a coherently related CW signal. A variety of optical signal processing systems could be implemented using this general approach.

As an elementary demonstration of this concept we performed the simple experiment shown in Fig. 3. Optical pulses approximately 200 ps in duration from a mode-locked and frequency-doubled Nd:YAG laser were coupled into a 10-m length of dual-mode fiber with the input beam slightly offset so as to excite approximately equal amplitudes of the LP01 and LP11 modes in the fiber. The dual-mode fiber had a lowest order mode size of approximately 2 μm × 4 μm and was provided by the Polaroid Corporation. The output end of the fiber was imaged at between 5 and 10 times magnification onto the 25-μm gap in a silicon gap-type diffusion-driven photodetector as described by Kostenbauder [3]. The relative phase angle between the two modes at the output end of the fiber could then be scanned either by mechanically stretching the fiber [6] or, at higher modulation speeds, by wrapping the fiber tightly around a cylindrical piezoelectric element which was electrically driven at its lowest resonance frequency of 25 kHz. Mechanical stress in the wrapped fiber then led to a periodic relative phase modulation between the two modes. The output from the unbiased diffusion-driven photodetector was connected through a broad-band amplifier with an upper cutoff frequency of 300 MHz to the input of a fast oscilloscope, giving an overall response time of approximately 1 ns.

Examples of the resulting photodetector output are shown in Fig. 4. Fig. 4(a) and 4(b) show sections of the 80-MHz mode-locked pulse train detected with positive and negative polarity as a result of opposite values of the relative phase shift between the two modes. Fig. 4(c) shows the positive and negative modulation of the detection envelope for the 80-MHz optical pulse train over several cycles of the 25-kHz phase modulation frequency. The oscilloscope trace has been retouched to reduce baseline smearing and distortion caused by the low duty cycle of the laser pulses and by inadequate low-pass response of the amplifier following the photodetector. Careful positioning of the diffusion-driven photodetector was re-
quired to obtain a symmetrically balanced output as shown.

Conclusions

Various permutations of the ideas described in this paper can permit different kinds of coherent and incoherent optical signal processing and optical control of pulsed photodetection. If the end of a typical dual-mode fiber, with an intensity pattern width of approximately 4 μm is imaged onto a suitable photodetector gap with a 2 times demagnification, a photodetector response time of approximately 400 ps can be obtained. Various forms of integrated dual-mode fiber and photodetector combinations to obtain the bipolar photodetection without active alignment requirements can also be envisioned.

Acknowledgment

The authors thank C. C. Pohalski and K. A. Fesler for their assistance with the experiments.

References


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Paul Wysocki, photograph and biography not available at time of publication.