SAND2010-8466C

Temperature Insensitive Broadband All-fiber Power Selective Optical Filter

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Abstract: We developed a novel power selective all-fiber device, which utilizes polarization change due to self-/cross-phase modulation in PM fibers. It has a broad operating spectral range with environmentally robust performance. The experimental results agreed extremely well with the theoretical calculation.
OCIS codes: (060.4370) Nonlinear optics, fibers; (230.4320) Nonlinear optical devices

1. Introduction

An all-fiber power selective optical filter has an enormous significance for numerous applications. It can be used as an in-line dual-way optical isolator in high gain fiber amplifier chains, an optical limiter to protect the instrument from damage, and an all-optical switch when used with a gating signal [1]. Especially the all-fiber structure offers a practical solution for implementing such a versatile device in field-deployable optical systems. An ideal power selective optical filter would have a huge dynamic range for on-off performance, with a near lossless transmission at desired power levels as well as a near zero transmission at unwanted power levels. In addition, it should not be affected by temperature change and operate for a wide spectral range. So far the known power selective optical devices such as bulk saturable absorbers, SESAMs, and nonlinear fiber loops have been far short of such ideal performance, due to various reasons such as unsatisfactory blocking/transmitting capability, low damage threshold, and unacceptable environmental sensitivity.

Sandia has recently introduced an elegant concept for an all-fiber power selective filter device [1]. This revolutionary device is based on self- and cross-phase modulation of light in two orthogonal polarization states in a polarization maintaining (PM) optical fiber. Unlike the nonlinear loops, which utilize somewhat random residual birefringence in optical fibers, our device relies on well-defined polarization axes of PM fibers, ensuring the environmental robustness. The transmission curve of the invented device has excellent blocking characteristic as well as near lossless transmission. Additionally, it operates achromatically over a vast spectral range.

We fabricated the invented device and performed experiments to characterize the transmission curve. The experimental results had an excellent agreement with the theory in [1].

2. Working principle

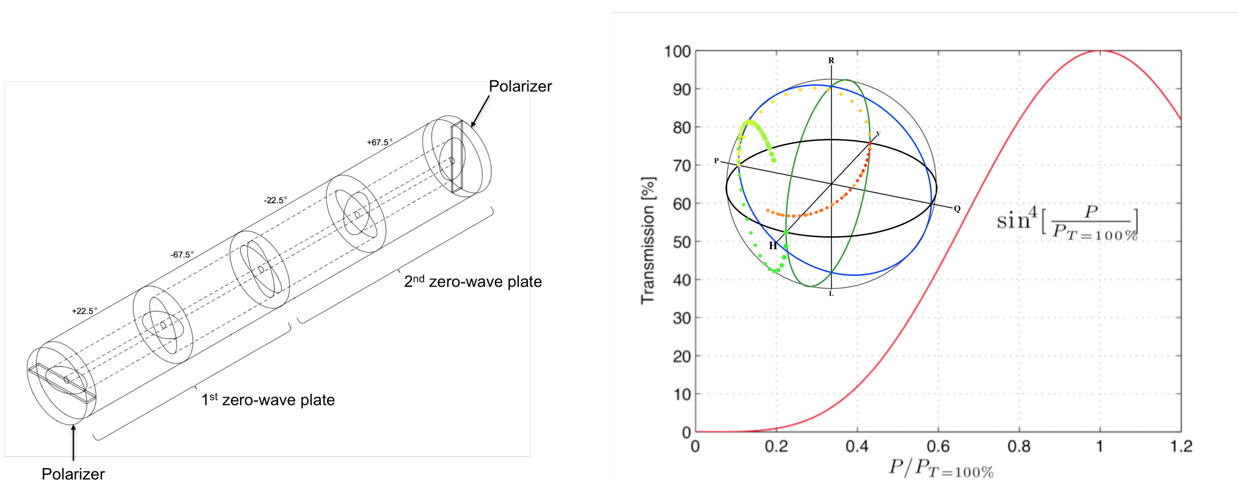

Figure 1. Structure of invented device (left) and theoretical transmission curve as a function of input instantaneous power (right). The inset is polarization trajectory on the Poincaré sphere for the case $P_{in} = P_{T=100\%}$.

The device structure, shown in figure 1, has two consecutive 'zero-order zero-wave plates', sandwiched by in-line fiber polarizers. The zero-order zero-wave plate consists of two PM fibers with identical length, which are spliced with 90° polarization angle. Therefore, the polarization state of the input light with low instantaneous power does not change after propagating through the device. However, an input light with large instantaneous power will undergo a well-defined polarization change. Combining the two zero-order zero-wave plates with 45° polarization angle and setting the input and the output polarizer angle against the input and the output pieces of PM fibers at 22.5°, we obtained a transmission function as $T\left(\triangleq P_{out}/P_{in}\right)=\sin^4\left(P_{in}/P_{T=100\%}\right)$, where $P_{T=100\%}=6\sqrt{2}\pi/\gamma L$, γ is the fiber nonlinear coefficient, and L is the combined length of the four fiber segments [1]. The transmission characteristic in equation (1) implies an excellent performance with near perfect blocking and near lossless transmission. In addition, since $P_{T=100\%}$ depends only on the fiber nonlinearity and the length, the device has a vast operating spectral range and a superb design flexibility.

3. Experimental proof

Since the differences of the fiber segment should be significantly smaller than the birefringence length of the Nufern PM780 fiber used (~ 3 mm), we adopted ribbon-cleaving technique to cut the identically long fiber segments. With this method, we could obtain 10 µm accuracy of relative fiber length difference, which is smaller than the device tolerance of 20 µm for sufficient blocking performance (- 35 dB). The combined length of the four segments was 70 cm. For proof of concept, we used free-space colorPol polarizers. However, one can directly splice commercially available fiber based in-line polarizers [2]. The calculated $P_{T=100\%}$ is 10.7 kW. Then, as a test optical source, we used a Q-switched microchip laser (Teem photonics), which produced near transform-limited 410 ps pulse train at 996 Hz at 1064 nm.

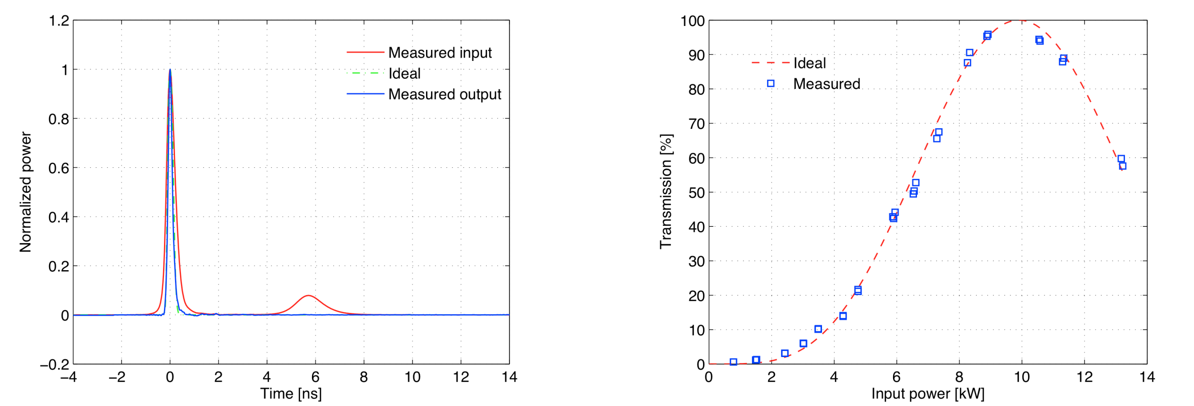

Figure 2. Input/output pulse traces (left) and measured/calculated transmission curve as a function of input power (right).

Figure 2 shows the measured input and output time trace. It is very clearly noticed that (1) the output pulse is compressed and (2) the after pulse disappeared, which clearly shows the device's performance. We conducted the experiment with different peak powers and obtained the transmission curve shown in figure 2. For this curve we have compensated for any loss mechanism such as slow response of the detector, fiber coupling loss, etc. The measured transmission curve follows the calculated one very closely with a measured $P_{T=100\%}\approx$ 10 kW. We also measured the spectrum and confirmed that the spectral broadening factor was 23.4, which agreed very well with the calculated theoretical nonlinear phase shift. The measured extinction ratio of the device using a low power cw laser (30 mW) at 1064 nm was 25 dB, which implies that the length difference among fiber segments were small.

4. Conclusions

We have successfully fabricated and experimentally demonstrated the invented all-fiber power selective optical filter. The experimental results agreed extremely well with the theoretical calculation. The developed device has a near ideal on-off performance, which opens up possibilities to use the device in various applications, such as an in-line saturable absorber for mode-locked or Q-switched lasers and/or an optical isolator between high gain amplifiers.

References

[1] J. P. Koplow, US Patent Application, "Wave-plate structures, power selective optical filter device, and optical systems using same," 2010.