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Variable fiber optic attenuator using a bulk-micromachined deformable micromirror

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Abstract. A compact fiber variable optical attenuator (VOA) with <1-dB insertion loss and >25-dB dynamic range is proposed and demonstrated at the 1550-nm band using a fiber collimator lens and a bulk-micromachined deformable micromirror. Three versatile VOA designs are presented that exploit the principle of 3-D beam spoiling to achieve broadband polarization insensitive attenuation using simple single-drive controls. [DOI: 10.1117/1.1786940]

Subject terms: variable fiber optic attenuator; bulk machined; micromirror; fiber collimator lens.

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Fiber variable optical attenuators (VOAs) have been previously realized such as liquid crystal,[1] acousto-optic,[2] and MEMS[3] devices. A simple method to implement VOAs uses the concept of optical beam spoiling.[4] Although single tilt axis[5] and 3-D mirror control[6] can realize such a VOA, in this work,[7] 3-D beam spoiling is implemented via a simple micromachined deformable mirror lens device. The rest of the work describes the basics of the proposed deformable micromirror-based VOAs and their related experimental results, indicating the simplicity and versatility of the proposed designs for broadband light attenuation.

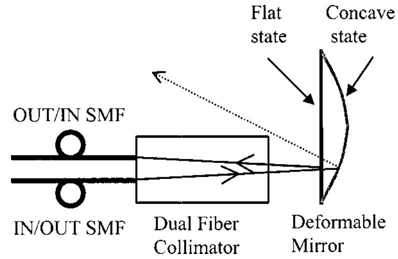

Fig. 2 Compact VOA design with dual fiber collimator and micromachined deformable mirror using the tilt effect.

The silicon micromachined mirror (from OKO Technology, Holland) used in the demonstrated VOAs is fabricated by using technology of silicon bulk machining.[8] The mirror consists of a silicon chip mounted over a printed circuit board (PCB) holder. The chip contains a silicon nitride membrane coated with aluminum to form the mirror. The control electrode structure is housed in the PCB. The shape of the reflective membrane is flat with no input voltage applied between the membrane and the control electrodes. When a dc voltage is applied across the electrodes, the membrane changes its shape and becomes concave. The deformable mirror is shown in Fig. 1. In the first VOA design, a dual fiber collimator is used as the input/output port for the VOA. The optical beam from the fiber lens is reflected by the deformable mirror and is coupled into the output port, as shown in Fig. 2. When a dc voltage is applied, the radius of curvature of the mirror membrane changes. This changes the direction of the reflected beam, as shown by the dotted line in Fig. 2, thus reducing the coupling and hence attenuating the input signal. Note that the center of the mirror is not used for reflection/deflection of the beam. This is because the center of the mirror has a focusing effect rather than the needed tilting effect. The focusing effect is used in the high-resolution VOA design presented later. The attenuation curve for the dual fiber collimator VOA is shown in Fig. 3. The static insertion loss of this dual fiber collimator VOA

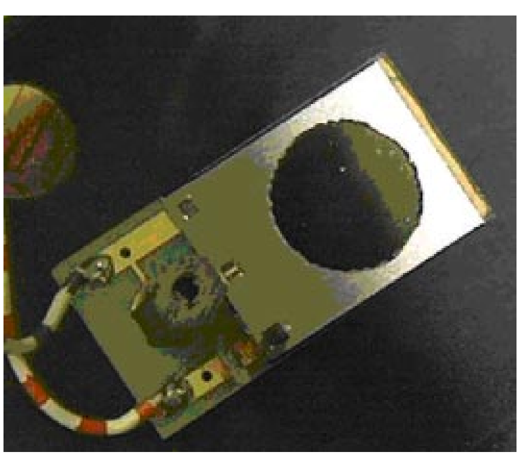

Fig. 1 The micromachined circular deformable mirror with a 10 mm diameter.

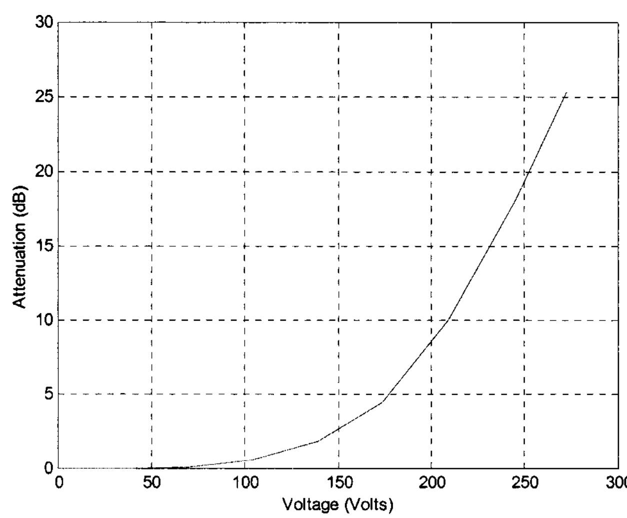

Fig. 3 Measured attenuation at 1550 nm versus the applied voltage for the dual fiber collimator VOA.

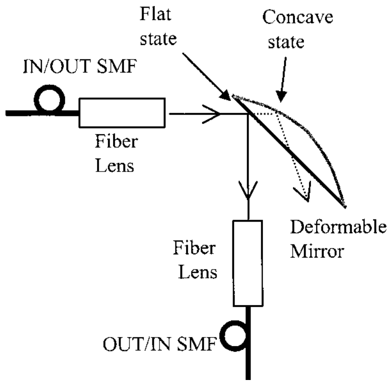

Fig. 4 VOA design using two single fiber lenses.

was measured to be <1 dB. The dynamic range is measured to be >25 dB, and the average resolution is calculated to be 0.09 dB/V. The power consumption of this VOA is low (e.g., in microwatts). Insertion loss measurements are taken with an optical power meter with both free-space and fiber optic adaptors.

Figure 4 shows an alternative design VOA, which uses two fiber collimators lenses. This VOA design is useful if input and output fiber ports must be separately located, as in most switching applications. The total distance between the fiber collimators is kept equal to the self imaging or working distance,[9] thus giving high coupling efficiency. The static insertion loss of this VOA is measured to be <1 dB. The dynamic range is measured as >20 dB, and the average resolution is calculated to be 0.07 dB/V. The related attenuation curve is shown in Fig. 5.

The two VOA designs presented so far use the tilting and translation effect of the deformable mirror to achieve dynamic attenuation control. In changing from a flat to concave shape, the focal length of the deformable mirror is changed. This focusing effect can be used to change the

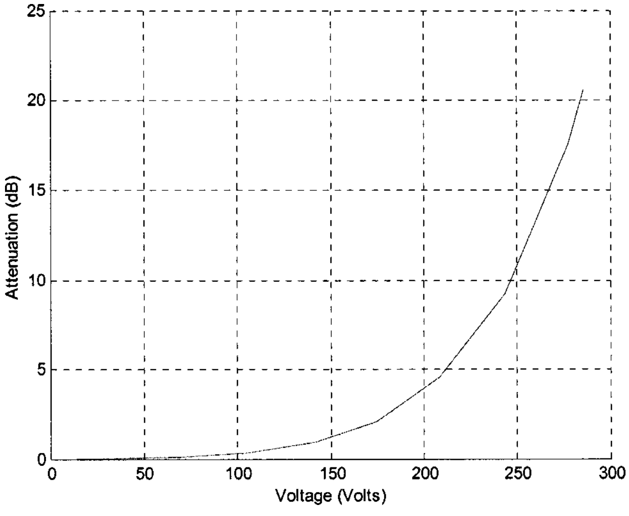

Fig. 5 Measured attenuation at 1550 nm versus the applied voltage for VOA using two fiber collimators.

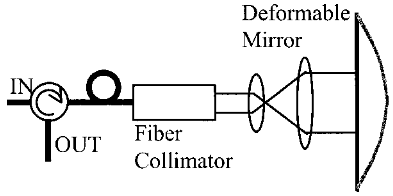

Fig. 6 High resolution VOA design using the focusing effect of the deformable mirror.

working distance of the self-imaging fiber collimator lenses. One application of the focusing effect is exploited in the proposed high-resolution VOA shown in Fig. 6. In this design, a single collimator lens is used as the input and output port of the VOA via an optical circulator. The expanded optical beam is reflected by the mirror and is coupled back into the collimator. The path length for the return signal is kept equal to the working distance of the lens. The focusing characteristic of the deformable mirror is used to change this working distance for the optical beam, hence introducing coupling loss and thereby providing high-resolution (<0.01 dB/V) attenuation control.

In conclusion, the change in the radius of curvature of a deformable mirror is intelligently used to implement 3-D beam spoiling to enable three different VOA designs. Two VOA designs have been successfully built and tested using a traditional telecommunication band 1550-nm center wavelength (i.e., λ). The VOAs demonstrate low polarization dependent loss (<0.1 dB) and low <1-dB optical insertion loss. Because these VOA designs are alignment and wavefront quality sensitive, the deformable mirror must have good flatness (e.g., λ/20) over the beam region for low VOA static loss. These VOAs also show good >20-dB dynamic range numbers, all within simple-to-assemble and control optics and electronics. These bulk-micromachined deformable micromirrors can also be designed to operate over broad visible and near-infrared wavelengths, thus enhancing the proposed VOA's versatility as an electronic adaptive feedback controlled fiber optic variable attenuator.

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