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A mems variable optical attenuator based on a vertical comb drive with self-elevated stators

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ABSTRACT

Vertical comb drives are critical for electrostatic optical switches and variable optical attenuators (VOAs), but fabricating vertical comb drives requires the formation of two levels of comb fingers and thus suffers from the difficulty of dealing with the comb-finger alignment. This paper presents a vertical comb drive design and its micro-fabrication method that can realize self-aligned two-level comb fingers. The self-aligned vertical comb fingers are enabled by a novel vertically-elevated flat-end (VEFE) bimorph structure. Both the stator and rotor fingers of the vertical comb drive are formed by the same photomask and the same silicon etching step, which automatically ensures accurate alignment of the stator and rotor fingers. The vertical separation between the stator and rotor is created by the VEFE structure. A 1mm-aperture MEMS mirror with the proposed VEFE comb drive has been fabricated using SOI wafers with buried cavities. The mirror rotates 0.94° at 8 Vdc. The resonant frequency is 1.428 kHz. The MEMS mirror has been assembled into a VOA module. Measurements show that the VOA achieved a dynamic range of 55 dB and an insertion loss of less than 0.4 dB and met the telecommunications standards on shock, vibration and long-term stability.

1. Introduction

MEMS mirrors are the key components for all-optical switching [1,2]. Fig. 1 shows a typical fiber optic network, where the green blocks represent VOAs and each channel has at least one VOA, which is used to adjust the optical power [3]. Using MEMS mirrors for either channel switching or optical power balancing, out-of-plane actuation is required. Note that resonant actuation is not applicable to the intended applications. This out-of-plane actuation must be quasi-static, which can be achieved using vertical comb drives. However, microfabrication of vertical comb drives is very challenging because of the difficulty of aligning the stator fingers and rotor fingers that are at two different height levels vertically. Also MEMS mirrors for VOAs in telecommunications must meet some key specifications including mirror size greater than 0.8 mm, static rotation angle greater than 0.8°, and first resonance frequency greater than 1 kHz [4].

Lots of efforts have been made to fabricate vertical comb drives. Vertical comb drives on two layers of silicon were demonstrated by wafer bonding and two-side alignment [5,6], but a relatively large gap was needed to compromise the misalignment between the upper and lower comb fingers [7]. Krishnamoorthy et al. presented a self-aligned vertical comb drive with three steps of etching to define both the top and bottom comb fingers to ensure the alignment but again at the price of large gap [8]. Xie et al. demonstrated a self-aligned vertical comb drive using the curling of bimorph structures in CMOS to lift up the stator comb fingers, but the stator fingers were tilted, not parallel to the rotor fingers [9]. Aguirre et al. reported an angular vertical comb drive using a photoresist hinge [10]. Isamoto et al. developed a self-assembled vertical comb drive using surface stiction force to pull down one set of fingers and permanently fix them on the substrate [11]. Hailu et al. reported an auto-aligned vertical comb drive of which the upper comb is attached to a curved beam [12], but there still existed a large bending moment at the end of the curved beam.

In order to fabricate self-aligned vertical comb drives that have both stators and rotors straight and parallel, the authors proposed a novel auto-aligned vertical comb drive with the upper comb fingers attached to a vertically-elevated flat-end (VEFE) bimorph structure [13]. In this paper, a MEMS mirror based on the VEFE structure has

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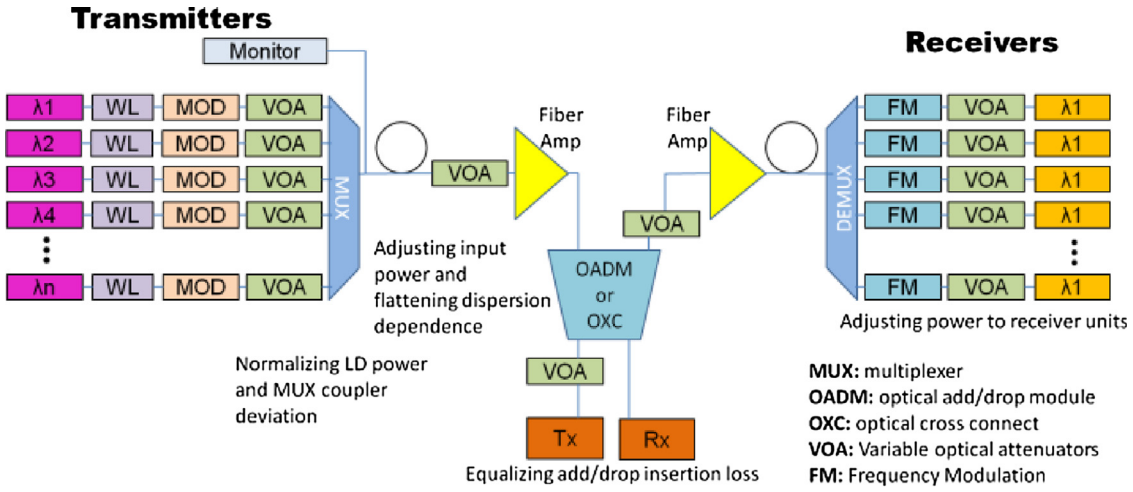

Fig. 1. Variable optical attenuators (VOAs) in a fiber optic network.

been demonstrated and successfully assembled into a VOA module. In the following, the design, modeling, fabrication and characterization of the VEFE based MEMS mirror is presented, followed by the assembly process and testing results of the VOA module.

2. Actuation concept and device design

2.1. VEFE bimorph structure concept and design

Vertical comb drives are critical for electrostatic optical MEMS switches and MEMS VOAs. Generally, vertical comb drives were divided into three categories: staggered vertical comb drives [14], angled vertical comb drives [15], and unequal height vertical comb drives [3]. We propose the vertically-elevated flat-end (VEFE) bimorph structure to realize a new vertical comb drive, which greatly simplifies the manufacturing process.

The concept of the VEFE bimorph structure is illustrated in Fig. 2. The VEFE bimorph structure consists of five segments: three bimorph segments and two rigid silicon arms, as shown in the cross-sectional view of the structure in Fig. 2(a). Note that there is a platform at the end of the VEFE bimorph structure, which will be the stator fingers in the vertical comb drive presented later. The bimorphs curl as they are made of two materials with different thermal expansion coefficients (TECs). The corresponding top view

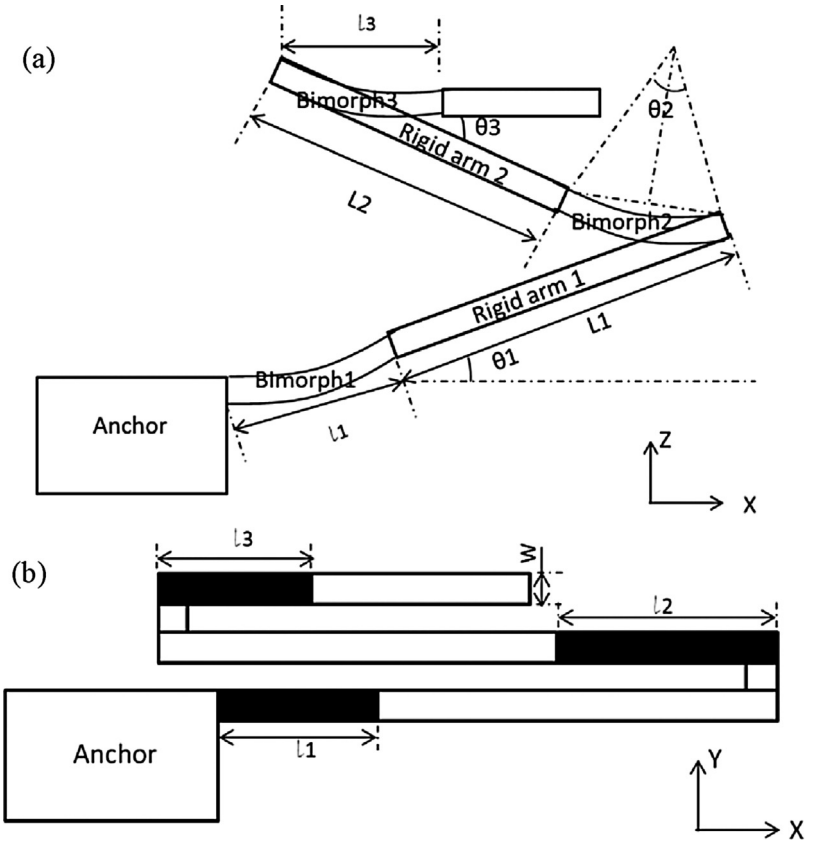

Fig. 2. Schematic of the vertically-elevated flat-end (VEFE) bimorph structure. (a) Side view. (b) Top view.

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