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Optical Switch Based on Thermocapillarity

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1. Introduction

Space-division optical switches are essential for the protection switches, optical cross-connects (OXCs), and optical add/drop multiplexers (OADMs) needed in future fiber-optic communication networks. Optical switches fabricated with micro-electro-mechanical systems (MEMS) technology are strongly anticipated; their excellent optical characteristics are due to the use of micromirrors to redirect optical signals. MEMS optical switches are roughly divided into two types: free-space and waveguide. This paper describes the basic concept and the characteristics of a thermocapillarity optical switch, and its applications.

2. OLIVE concept

Fig. 1 shows the structure of a thermocapillarity optical switch, called the oil-latching interfacial-tension variation effect switch (OLIVE). It consists of a crossing waveguide substrate that has a groove at each crossing point and a pair of microheaters. The groove is partially filled with the refractive-index-matching liquid. The microheaters are positioned so that they produce a thermal gradient along the groove. Fig. 2 shows the concept of the optical switching. Turning on one microheater reduces the surface tension at the air-liquid interface in that area, which drives the liquid in the groove toward the cooler region (thermocapillarity). When the liquid is present at the waveguide crossing point, the optical signals pass straight through the groove; however, when the liquid moves away from the crossing point, the signals are switched into the crossing waveguide by total internal reflection on the groove sidewall, i.e., at the silica-air interface. This switch is self-latching and bi-stable because the variation in groove width interacts with the capillary pressure [1]. In addition, this switch has a lot of the essential characteristics for optical switching, such as low insertion loss, low crosstalk, polarization- and wavelength-insensitivity, and long-term reliability.

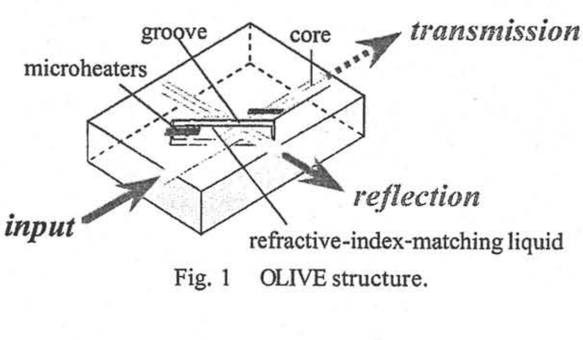

Fig. 1 OLIVE structure.

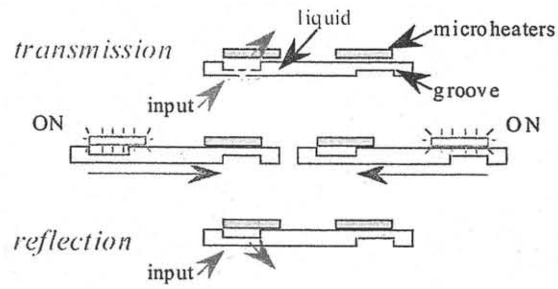

Fig. 2 Bi-stable self-latching switching.

3. Characteristics of OLIVE

Fig. 3 shows the view of an OLIVE and its typical characteristics are shown in Table I. For unpolarized input light with a wavelength of 1.55 μm, the transmission loss though a crossing point filled with liquid was 0.12 dB and the reflection loss from the groove sidewall was 1.5 dB. (Connection loss is not included.) The crosstalk was less than -50 dB and the extinction ratio was higher than 50 dB. The polarization dependent loss (PDL) was less than 0.2 dB. These results indicate the possibility of large-scale switches with low insertion loss.

In order to shorten the switching time of the OLIVE, we aimed at the point where its switching time is proportional to the viscosity of the refractive-index-matching liquid. We succeeded in developing a new liquid with the low viscosity of 9.59 cP by controlling the weight-average molecular weight. The switching time of an OLIVE injected with this liquid was 6 ms under the condition of a driving wattage of 0.15 W. Moreover, we have demonstrated that the device can perform over 10 million switching operations without any degradation in the optical characteristics, because the injected liquid is chemically stable over a long period in spite of being heated by the microheaters [2].

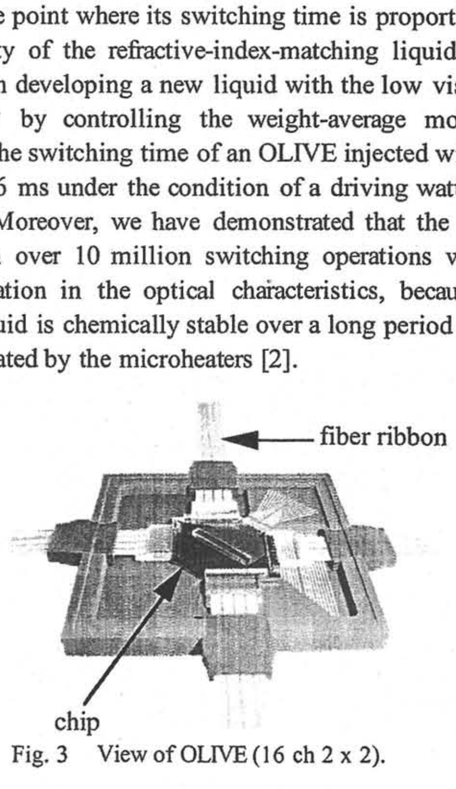

Fig. 3 View of OLIVE (16 ch 2 x 2).

Table I Typical characteristics of OLIVE.

Insertion loss (2 x 2)	< 2 dB
Crosstalk	< -50 dB
Extinction ratio	> 50 dB
PDL	< 0.2 dB
Wavelength sensitivity	< 1 dB (1.3 to 1.7 μm)
Switching time	6 ms
Consumed power	0.15 W (at switching)
Self-latching function	equipped

4. Applications

4.1 Optical selector switch

In the NTT's passive double star (PDS) optical access network system, thermocapillarity optical selector switch (OLIVE) could be used to share a reserved optical subscriber unit (OSU) in an optical line terminal (OLT) [3]. Sharing a reserved OSU reduces the cost of the back-up system without sacrificing system reliability. The OLIVE, whose biggest merit is that a continuous power supply is not required to maintain the switching state because of the equipped self-latching function, would also be able to contribute to the construction of different back-up systems.

4.2 OXCs

Aiming at the point where the OLIVE can be highly integrated, we developed a prototype 16 x 16 OLIVE [4]. The chip size was 23 mm x 23 mm and the waveguide core pitch was 500 μm. The insertion losses were 2.0 dB and 5.5 dB at the shortest and longest optical paths, respectively. The transmission and reflection losses were estimated to be approximately 0.12 and 1.5 dB, respectively. The insertion loss in the longest paths could be reduced to 2.1 dB in a 16 x 16 switch or 3.7 dB in a 32 x 32 switch by further improving the groove fabrication process.

4.3 OADMs

Focussing on the point where the OLIVE exhibits low crosstalk, we proposed an OADM with low crosstalk, which consists of a multiarrayed 2 x 2 OLIVE and 4 arrayed waveguide gratings (AWGs) whose channel spacing is 0.8 nm [5]. The chip size of the multiarrayed 2 x 2 OLIVE was 15 mm x 15 mm. The insertion loss was 2.0 dB. In a configuration where switch elements 1, 3, and 4, which correspond to λ_1, λ_3, and λ_4 are set to the reflection state and switch element 2, which corresponds to λ_2, is set to the transmission state, we observed drop signals in the drop port, as shown in Fig. 4. Fig. 5 shows the optical spectral response. It was found that only λ_1, λ_3, and λ_4 were selectively dropped. Also, the transmittance of the optical signals was about -14 dB. This value is equal to the sum of the insertion losses of one OLIVE switch and two AWGs. The obtained crosstalk of this OADM was -35 dB, and this value is consistent with the crosstalk of the AWG itself. This means that if the optical characteristic of the crosstalk in the AWG were improved, then the OADM with lower crosstalk could be achieved, because the crosstalk of OLIVE is lower than -50 dB.

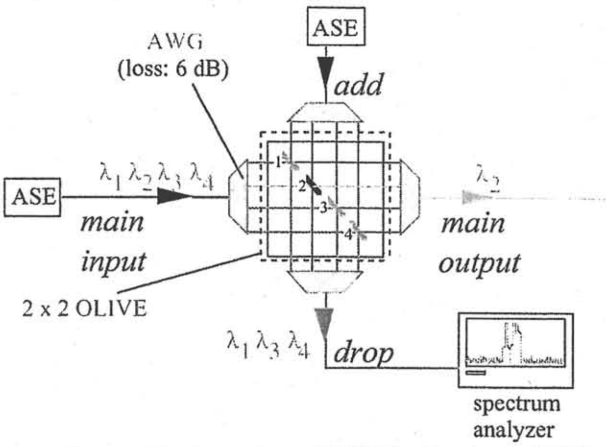

Fig. 4 Configuration of OADM using 2 x 2 OLIVE.

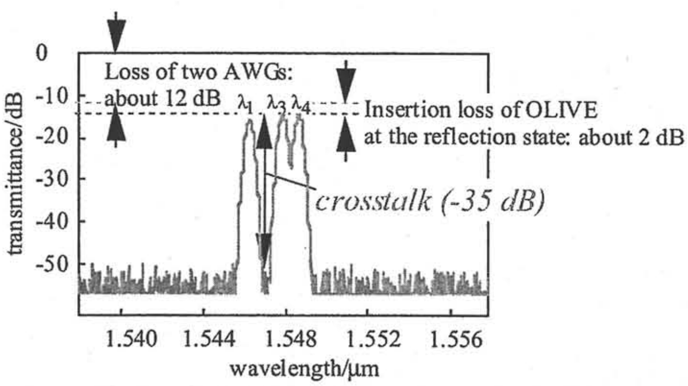

Fig. 5 Optical spectral response in OADM.

5. Summary

In summary, the OLIVE exhibits low insertion loss, low crosstalk (<-50 dB), a high extinction ratio (>50 dB), polarization insensitivity (<0.2 dB) and low wavelength sensitive operation (<1 dB), and has a self-latching function and long-term reliability. Also, the switching operation took 6 ms, which makes the OLIVE suitable for application to OXCs and OADMs.

References

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