

Fully Integrated NxN MEMS Wavelength Selective Switch with 100% Colorless Add-Drop Ports

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Abstract: A high density wavelength selective switch based on the integration of array waveguide grating and MEMS technology is reported. We demonstrate a fully integrated wavelength reconfigurable optical add/drop multiplexing with 100% colorless add/drop ports.

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1. Introduction

Wavelength selective network subsystems such as dynamic gain equalizers, reconfigurable optical add/drop multiplexers, and wavelength selective switches are becoming extremely important for next generation network systems [1]. These wavelength selective network subsystems offer transparent wavelength-layer signal regulation, re-direct, and re-routing. Liquid crystal based devices have been used for dynamic gain equalizers, 2x2 or 1xN wavelength selective switches [2]. However, it is difficult to realize multi-port wavelength selective switches using liquid crystal devices. Micro-Electro-Mechanical System (MEMS) analog mirrors offer a simple and elegant way in steering optical signals and are becoming the key enabling devices for wavelength selective active optical networking systems. Large-scale photonic cross-connect switches with larger than 320x320 ports have been developed with ultra-low optical loss [3]. By integrating optical wavelength demultiplexer/multiplexers into a large-scale optical switch, one can build a multi-port wavelength selective switch with 100% add-drop wavelength ports.

Integrated approaches that use a diffraction grating and analog MEMS mirrors have been proposed and demonstrated. One approach is to build a 1xN multi-port wavelength selective switch, which combines a wavelength demux, a 1xN switch for each wavelength, and N wavelength multiplexers in a small package [4-6]. These 1xN multi-port wavelength selective switches use a diffraction grating to separate different wavelengths and two-dimensional deflected analog mirrors to steer the wavelength slices to different output ports. Another approach is to build an NxN wavelength selective switch using two diffraction gratings and two parallel two-dimensional deflected analog MEMS mirrors [7]. The other integration approach uses stacked planar lightwave circuits (PLC) and MEMS micro-mirror array in a hybrid combination to form the core of a wavelength selective switch. A wavelength selective switch featuring 72x72 wavelength channels has been demonstrated to have 20 dB insertion loss [8].

Although the above mentioned integrated wavelength selective switches provide flexible wavelength cross-connect functionality, it is highly desirable to integrate up to 100% add/drop functionality into the system so that any individual wavelength can be added or dropped locally. In this paper, we demonstrate an NxN wavelength selective cross-connect switch with 100% add drop ports using stacked array waveguide grating (AWG) PLC and 3-D MEMS mirror array. We demonstrate the hybrid integrated wavelength selective switching system with 200 colorless add/drop ports.

2. Fully Integrated High Density Wavelength Selective Switch Architecture

The MEMS mirror and AWG demux/mux chips are integrated together to form a high-density wavelength selective switching core with additional add-drop ports. Fig. 1 shows a schematic diagram of an integrated NxN wavelength selective switch with up to 100% colorless add-drop ports. The demultiplexed optical signals from the AWG chips are routed by MEMS mirrors to the appropriate output WDM port or drop ports. The signals from add ports can be routed to any output WDM ports. In this dual plane architecture, two sets of 3D MEMS mirror arrays are used for accomplishing the desired switching configuration. An alternative single plane architecture design is shown in Fig. 2, where a reflective folding mirror is used at the symmetry point of the optical path to reflect back to the appropriate mirror element, and then back into the appropriate output ports. In the single MEMS plane design, only one set of 3D MEMS mirror array is used. Hence, both the packaging complexity and alignment complexity are reduced. In our demonstration, we use the single MEMS plane design as shown in Fig. 2. The stacked AWG chips are attached with a lens array to collimate the optical beams. Another fiber collimator array is used as the add/drop ports. Since the switching signals are demultiplexed signals, they can be added from or dropped to any add or drop

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ports. This functionality is very important for a flexible dynamic network. A photograph of the fully integrated wavelength switching assembly is shown in Fig. 3.

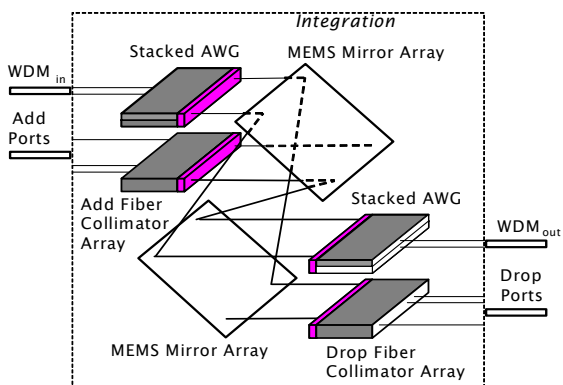


Fig. 1. The schematic of the dual-plane architecture NxN wavelength selective switch with add/drop ports

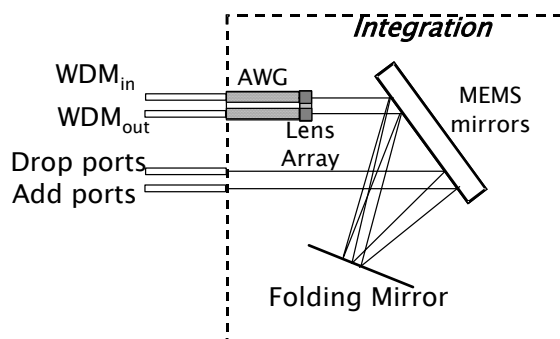


Fig. 2. Schematic diagram of the single-plane architecture NxN wavelength selective switch with add/drop ports

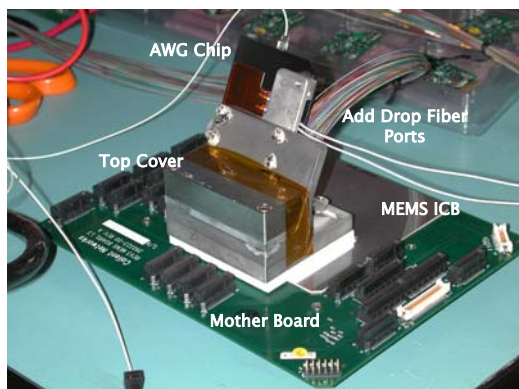


Fig. 3. Photograph of the integrated single plane core wavelength switch.

3. Experimental Results

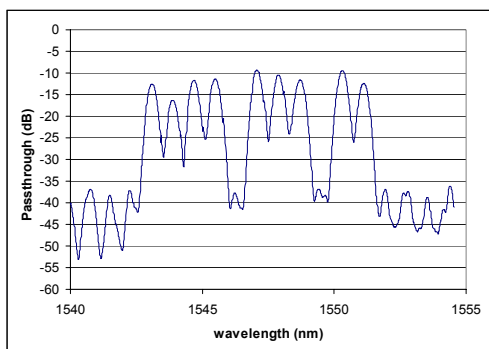


Fig. 4. The wavelength selective switch pass through path insertion loss spectrum

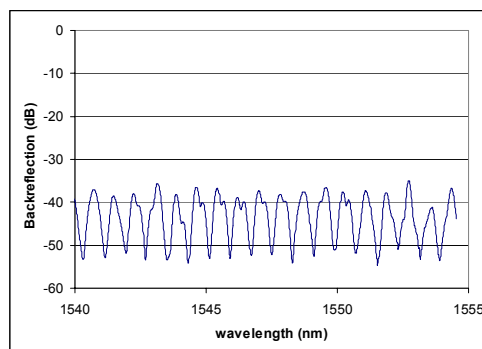
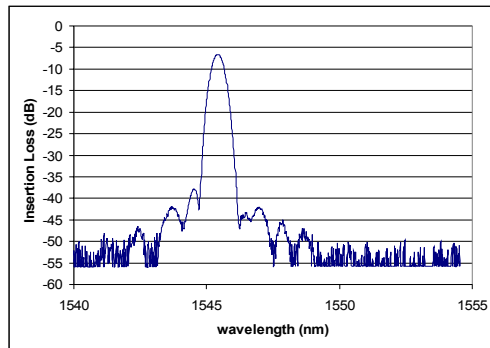


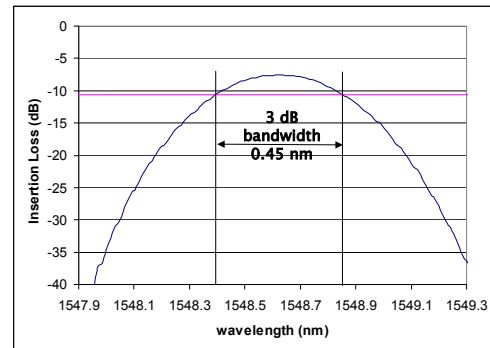
Fig. 5. The optical backreflection spectrum for the input WDM port.

The fabricated core switch is a wavelength reconfigurable optical add/drop multiplexer (ROADM) with about 200 add/drop ports, of which 16 colorless add and 16 colorless drop ports were tested. The AWG has 40 wavelength channels with 100 GHz channel spacing. The AWG chips used in the system have a Gaussian passband with ~2 dB insertion loss. Fig. 4 shows the measured optical insertion loss for the pass-through channels using a broadband ASE source when 9 pass-through channels were set up. The insertion losses are from 9.3 dB to 15 dB. The higher loss paths are due to the MEMS mirror control and microlens optimization. We believe that less than 10 dB insertion loss for all channels is feasible with improved manufacturing processes. The back-reflection for the input optical is about -37 dB for the worst case, as shown in Fig. 5.

Fig. 6 shows the dropped channel spectrum measured at the drop port. The overall drop channel passband spectrum indicates that there is a maximum -30 dB optical crosstalk from adjacent channels, as shown in Figure 6(a). Fig. 6(b) shows a 0.45 nm 3 dB passband for the measured drop channel. The add port has similar passband response as the drop port. Fig. 7 shows a 0.33 nm 3 dB passband for a pass-through channel, which is narrower than the add/drop channel due to fact that the optical signal passes through the AWG one time for add/drop port, but twice for the pass-through channels. Note that in our experimental demonstration Gaussian profile passband AWGs were used, wider passband will be achieved by using flat-top passband AWG chips. Fig. 8 shows two wavelengths added to the output WDM port, with an intentional 10 dB optical power difference



(a) The drop channel passband at wavelength 1548.62 nm.



(b) The 3 dB passband to be 0.45 nm.

Fig. 6. The drop channel passband of one particular wavelength channel.

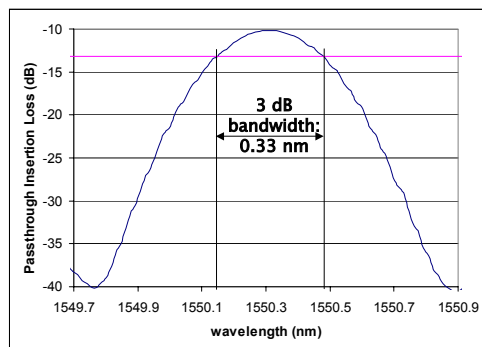


Fig. 7. The passband of a typical pass-through channel.

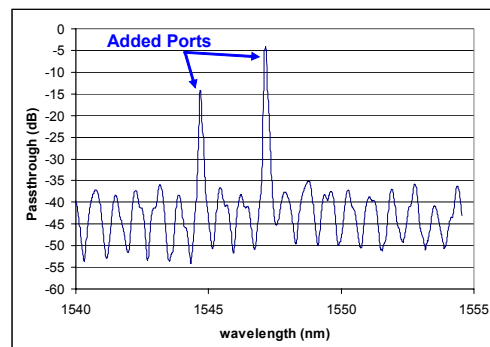


Fig. 8. Two added ports are shown with different power levels.

4. Summary

In this paper, we demonstrated an integrated high density wavelength selective switch based on the integration of AWG chips and 3-D MEMS technology. This wavelength selective switch was used to form a wavelength reconfigurable optical add/drop multiplexer with 100% colorless add/drop functionality.

5. References

1. Paul A. Bonenfan and Mark Loyd Jones, "OFC 2003 Workshop on Wavelength Selective Switching Based Optical Networks, J. of Lightwave Technology **22**, 305-309 (2004).
2. A.R. Ranalli, B. A. Scott, and J. P. Kondis, "Liquid crystal-based wavelength selectable cross-connect," ECOC 1999.
3. Xuezhe Zheng, Volkan Kaman, Shifu Yuan, Daniel Xu, et al., "3D MEMS Photonic Cross-connect Switch Design and Performance", IEEE Journal of Selected Topics in Quantum Electronics **9**, 571-578 (2003).
4. Jui-C Tsai, Sophia Huang, Dooyoung Hah, Hiroshi Toshiyoshi, and Ming C. Wu, "Open-Loop Operation of MEMS-Based 1xN Wavelength-Selective Switch With Long-Term Stability and Repeatability" IEEE Photonics Technology Letters **16**, 1041-1043 (2004).
5. J.C. Tsai and M.C. Wu, "1xN² Wavelength-selective switches with high fill-factor two-axis analog micromirror arrays", OFC 2004, Los Angeles, Paper MF42 (2004).
6. D.M. Marom, D.T. Neilson, D.S. Greywall, N.R. Basavanahally, P.R. Kolodner, Y.L. Low, F. Pardo, C.A. Bolle, S. Chandrasekhar, L. Buhl, C.R. Giles, "Wavelength-selective 1x4 switch for 128 WDM channels at 50 GHz spacing," OFC 2002 PostDeadline papers, FB7-1, (2002).
7. O. Sogaard and J.P. Heritage, "Multi-wavelength cross-connect optical switch," US Patent 6,389,190 B2 (2002).
8. R. Ryf et al., "Scalable wavelength-selective crossconnect switch based on MEMS and planar waveguides," 27th European Conference on Optical Communication, 30 Sept.-4 Oct. 2001, ECOC '01, Volume 6, 76 - 77.

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