Compact, Low Cost Chip Scale Triplexer WDM Filters

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Abstract: A high-index contrast PLC branching delay line filter realizes WDM filters for FTTP triplexer applications. The filters achieve low loss and high extinction ratios, while the ultra-compact dimensions of 1mm x 4mm accommodates thousands of chips a 6” silicon wafer.

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Introduction

Fiber to the Home (FTTH) and fiber to the premise (FFTP) is poised to be a substantial growth opportunity for the North American optical telecom market, bringing substantial gains in bandwidth directly to the end user. In order for this to become a near term reality, the cost of triplexer transceivers needs to be pursued aggressively. Of the components that go into transceiver modules, the WDM component remains one of the most expensive, and its cost reduction one of the most challenging. Today, the WDM triplexer is constructed from bulk thin film filters which are manually assembled. In order for aggressive cost reductions to occur, bulk optics needs to be replaced by solid state components.

Thin film filters have very desirable spectral characteristics, and their replacement has not been met with great success. In many instances, the bulk chassis has been replaced by a PLC optical bench [1], yet manual assembly of the TTFs into the PLC remains. In an attempt to bring an entirely solid state and batch fabricated technology to bear, a number of PLC based solutions have been investigated, mainly theoretically. These include planar lens and diffraction gratings [2], AWGs [3], and Echelle gratings. Due to the nature of the spectral characteristic, these types of solutions are inadequate to achieve the broadband performance required. For instance, a triplexer requires a 100 nm passband centered near 1310 nm, a 20 nm band centered at near 1490 nm, and a 10 nm band at 1555 nm. Simultaneously, the incoming rejection ratio needs to be below -55 dB at 1550 nm, and isolations below -60 dB between several ports.

These demanding filter characteristics are best synthesized using a systematic filter approach composed of cascadable building blocks. Cascaded Mach-Zehnders in so called Fourier transform filters, or lattice form tapped delay lines [4], are ideally suited, if one can accommodate a sufficiently large number of stages. We use a high index contrast PLC platform to synthesize the required spectral characteristics [5]. The high index contrasts allows for sharp, sub 100 μm bends, and thus a compact arrangement of filter stages.

Fabrication

The functional circuit diagram of the triplexer is depicted in Figure 1a, while the physical circuit layout is shown in Figure 1b. The filter comprises a cascade of asymmetric Mach-Zehnders having various differential delay lengths. The differential delay lengths and directional coupler coupling coefficients are synthesized to yield desired wideband spectral characteristics. The PLC circuit is fabricated from Hydex^{TM}, a low loss, high index contrast glass material system that uses conventional silicon processing technology [5]. The index contrast for this device is 17% (a core with an index of 1.70, and a clad with an index of 1.45). The waveguides have square cross sections of approximately 1.5 μm. The propagation losses at this high index contrast are below 0.15 dB/cm at all wavelength bands of interest. Both the PDL and birefringence are also low, and a polarization diverse scheme is not required here. The high confinement waveguides require a low loss mode transformer in order to match the input fibers' roughly 10 μm spot size. In this first case our conventional mode transformers were used, which at the time were only optimized for the C-band of wavelengths. Ideally, only one mode transformer is required for the input fiber, while the output waveguides at 1490 nm and 1550 nm bands can terminate directly into detectors, thus saving any additional mode transformational loss. The input laser at 1310 nm has its own unique spot size, and a mode transformer different from the fiber may be required. This is possible in the technology but has not been implemented here. Instead, additional and identical mode transformers are used here on all ports to facilitate testing. The component is completely passive, requiring no post-fabrication thermal trimming. Figure 2 shows a picture of a

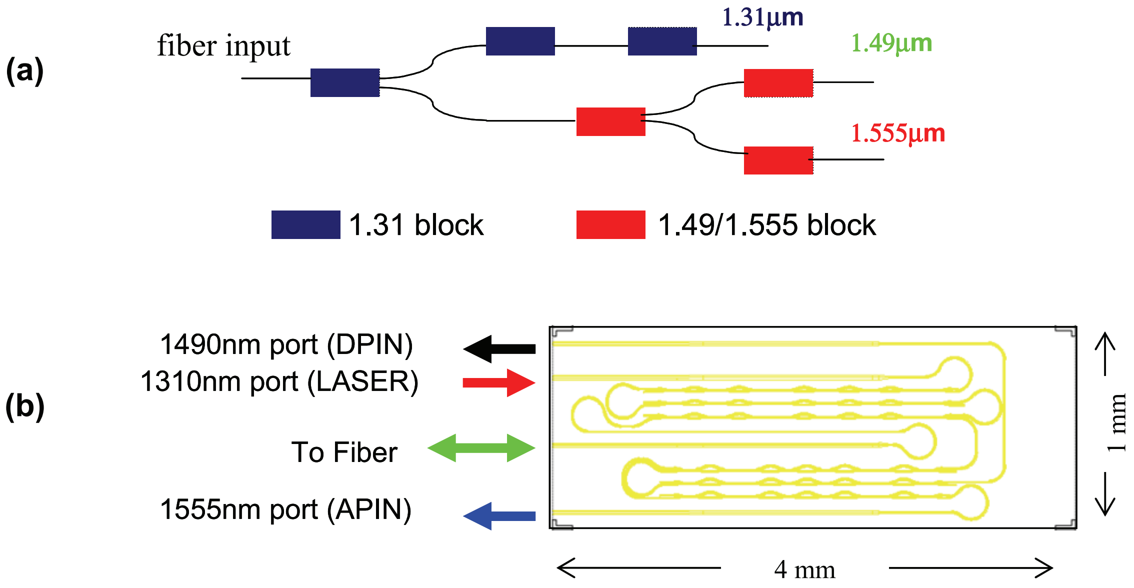

Figure 1 – (a) Functional schematic of the tapped delay triplexing filter. The filter comprises a number of sub-blocks for the three bands of interest. (b) Circuit layout of the PLC chip, showing the input fiber port, and the three wavelength ports.

fabricated chip. The chip with mode transformers included, measures 1 mm x 4 mm. A standard 6” silicon wafer can accommodate more than 3000 chips.

Optical Performance

The optical performance at all three wavelength ports of a typical triplexer chip of Figure 1b is shown in Figure 3. The data was taken by the unpolarized sources of the Agilent HP-86142A OSA in order to acquire the data over a wavelength range of 1250 nm to 1680 nm. Note that the OSA source had a dead zone at 1450 to 1500nm, and the high extinctions reported below were also verified by swept lasers at these specific wavelengths. The target specs were to have a 100 nm bandwidth at the 1310 nm laser wavelength (going from 1260 nm to 1360 nm), have a 20 nm bandwidth at the 1490 nm DPIN channel (going from 1480 nm to 1500 nm), and to have a 10 nm bandwidth at the 1555 nm APIN channel (going from 1550 nm to 1560 nm). Simultaneously, a deep extinction ratio of below -55 dB was required at the 1310 nm port to input signals at the APIN and DPIN wavelengths. All these specs are hit in the current device as shown in Figure 3. In fact, statistically over 50 measured devices, the extinction ratio at the 1310 nm laser port to 1555 nm and 1490 band light was -55 dB, with a 1.5 dB standard deviation. Likewise, the extinction ratio at the 1490 nm DPIN port to 1555 nm input light was below -40 dB. The extinction ratio at the 1490 nm port to 1310 nm light was designed to be -17 dB (over a 100 nm band), and is also met.

A comparison of the theoretical to measured performance is shown in Figure 4. There was a uniform shift in band center wavelengths between theory and measured performance. This shift was used as the only theoretical fitting parameter. The shift was observed for all devices, and can be taken out in a subsequent fabrication run by biasing the refractive index, the deposited film thickness, or the Mach-Zehnder arm lengths. More importantly in these devices, is that the high extinction ratio be maintained. The fiber-to-fiber insertion loss measured at the APIN 1555 nm port was 2.5 to 3.2 dB. Two mode transformers account for 2 dB of this loss (typically two mode transformers account for 1.5 dB, except for a printing error in this case). In use, one mode transformer would be eliminated at the output end of this device when end-fired into a detector. In that case, the expected fiber-to-detector loss would be roughly 1.75 dB. The fiber-fiber insertion losses at the

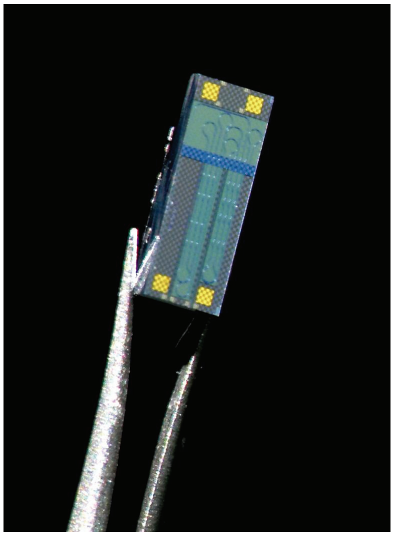

Figure 2 – Photograph of a fabricated triplexer WDM chip