UCRL-JC-129154
Preprint

Simple Fabrication of WDM Filters for Byte-Wide, Multimode Cable Interconnects

R. J. Deri, S. Gemelos, H. E. Garrett, R. E. Haigh,
B. D. Henderer, J. D. Walker, and M. E. Lowry

This paper was prepared for submittal to
Integrated Photonics Research Conference
British Columbia, Canada
March 30 – April 3, 1998

November 24, 1997

Simple fabrication of WDM filters for byte-wide, multimode cable interconnects

R. J. Deri, S. Gemelos, H. E. Garrett, R. E. Haigh,
B. D. Henderer, J. D. Walker, and M. E. Lowry

Lawrence Livermore National Laboratory
7000 East Avenue, mailstop L-145
Livermore, CA 94550
deri1@llnl.gov

Abstract

We demonstrate a simple approach to fabricate add/drop WDM filters for byte-wide multimode fiber ribbon cable with low loss (1.0 dB) and small footprint.

Simple fabrication of WDM filters for byte-wide, multimode cable interconnects

R.J. Deri, H.E. Garrett, S. Gemelos, R.E. Haigh, B.D. Henderer, J.D. Walker, and M.E. Lowry
Lawrence Livermore National Laboratory, Livermore, CA 94550

Parallel optical interconnects over multimode fiber (MMF) ribbon cable are emerging as a robust, high-performance data link technology [1,2,3]. This technology has primarily been implemented as single wavelength, point-to-point links, and can be significantly enhanced by wavelength division multiplexing (WDM) to increase both point-to-point bandwidth as well as create more complex interconnect topologies and routing approaches. The combination of byte-wide transmission for high channel bandwidth with WDM for interconnect routing is particularly attractive for ultrascale computing platforms[4]. Research in this area suggests that WDM transceivers for point-to-point links can be realized.[5,6] Exploiting the potential richness of WDM networks, however, also requires a low-loss routing fabric which includes small footprint add/drop multiplexers. Low insertion loss is critical for this technology because the transceivers exhibit link power budgets well below that of telecom WDM systems and because the multimode fiber cabling precludes the use of optical amplifiers. While high-performance filters can be realized for <u>single-fiber</u> applications[7], achieving high-performance devices with <u>ribbon cable</u> is significantly more complicated. Complications arise from the MMF's high NA=0.275 and large core (62.5μm), which render <u>array</u> collimation difficult, and the difficulty of maintaining good filter performance at the high angles of incidence needed to minimize loss in a 3-port (2-output) device. Here we demonstrate a suitable approach to fabricating such filters, which is simple, involves primarily passive alignment, and provides high performance and connector alignment. We demonstrate a dual wavelength link through a cascade of eight WDM filters.

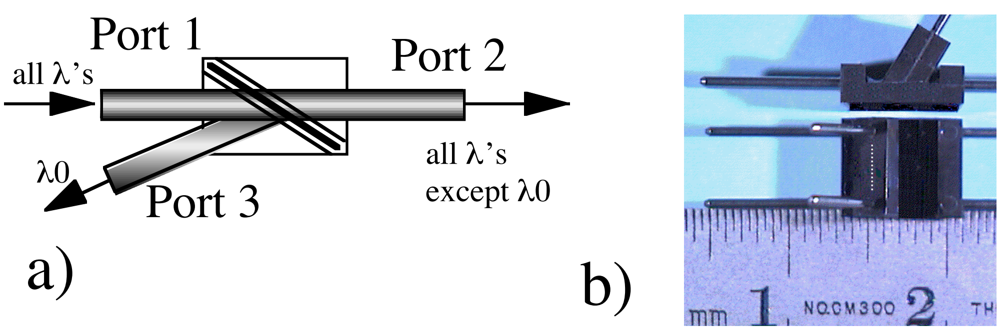

Fig. 1: Filter schematic (a) and photograph (b) showing top and side views with guide pins.

Our filters are 3-port devices suitable for add/drop multiplexing, which employ thin film interference filters sandwiched between MMF ferrules as shown in figure 1. In contrast to previous reports of related devices,[8] we employ high index materials for the filter coating to minimize bandpass spreading and polarization sensitivity while maintaining a substantial angle of incidence (30 degrees) to ease optomechanical packaging, and use commercially available "MT" connector ferrules to maintain fiber alignment. These ferrules use injection molded plastic to provide low cost, precision optical positioning of 12 parallel fibers via passive (guide-pin) alignment, [9] and are frequently used for transceiver and cable connectorization. Guide pin alignment enables 95% passive assembly of our filter, and can therefore provide low cost filters with available ferrule technology. Since the filter body is built from ferrules, the devices are already aligned for external connectors. This approach yields a small filter footprint (7.8x6.4x5.7 mm^3) which is limited by ferrule size.

Filter assembly begins by populating three MT ferrules with 62.5µm GRIN core MMFs and preparing endfacets with a wafer saw. Facets are cut to 30º (ports 1, 2) or 60º (port 3) in the filter region and a thin film interference filter is then epoxied onto one 30º face. Port 1 and 2 ferrules are then epoxied together, using completely passive, guide pin alignment. Wafer sawing exposes the fiber-filter interface to enable access for port 3, and the port 3 ferrule is aligned with guide pins providing angular registration and position registration perpendicular to the three fiber plane (fig. 1a). In this procedure, care is required only in controlling the depth of the port 3 exposure saw cut and in longitudinal alignment of port 3 along the port 1-to- port 2 axis. Saw cut depth is controlled via microscope inspection during the cutting. We positioned port 3 longitudinally using active alignment-- which could be eliminated with a modified ferrule body design.

Device insertion loss depends strongly on diffractive loss during propagation outside the MMFs near the filter. Small gaps between all three ferrule faces are required to minimize loss; this is achievable for port 3 only for larger angles of incidence.[8] However, filter response is degraded at high incidence due to polarization dependence and angular dependence of the center wavelength, which is exacerbated by both large MMF NA and filter tilt. We overcome this problem with high-index filter material (AlGaAs) which is compatible with 30º tilt. For this first demonstration we used filter layers consisting of 31 quarter-wave AlGaAs layers sandwiched between TaO_x single-layer AR coatings. The AlGaAs was grown by MBE on a GaAs substrate, which was removed by selective etching. Our filters were designed for a ≈40 nm add/drop band about 840 nm (fig. 2), for compatibility with commercially available byte-wide transceivers with moderate wavelength tolerances.

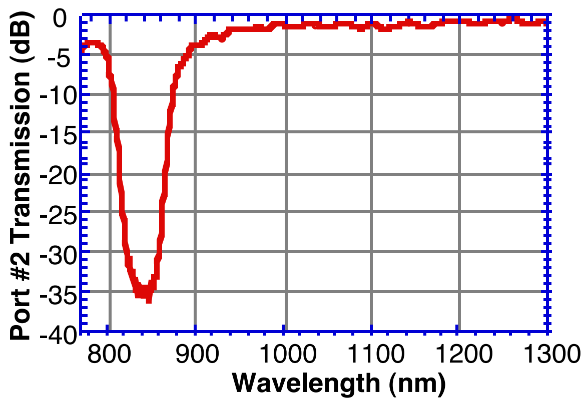

Fig. 2: Typical filter wavelength response for port 2 transmission.

Fabricated filters exhibit steep skirts, low insertion loss and good crosstalk isolation. The filters exhibit steep skirts (fig. 2) and a weak polarization dependence of the bandwidth (≈7 nm), which are not achievable with low index layers at 30º tilt. Insertion losses for our first two batches of filter modules are shown in Table I. The mean fiber-to-fiber insertion loss between ports 1 and 2 is 1.0 to 1.1 dB, with the best fibers exhibiting just under 0.7 dB loss. Filter loss uniformity is rather low, with standard deviations ≤0.12 dB for batch #2. (The somewhat higher nonuniformity of batch #1 reflects an imperfect cleaning procedure which was improved for batch #2.) Uniformity on port 2 is very important because it impacts the maximum number of filters which can be serially cascaded in ring networks. The devices exhibit excellent wavelength crosstalk rejection in port 2, and acceptable rejection in port 3. The port 3 values, which we believe are limited by AR coating quality, can be improved by cascading an additional in-line (2-port) filter.

Potential diffractive loss in these filters raises concern about mode selective loss (MSL), which can introduce bit error rate floors in MMF systems. We measured the effective MSL in our devices by comparing the fluctuation in monochromatic laser light transmission due to fiber agitation against that induced by known mode selective losses created by a variable, index-matched gap between two fiber endfacets. Because the filter MSL was quite low, it was determined by measuring the MSL of multi-filter cascades. This experiment detected MSL for port 1-to-port 2 transmission at 1310 nm, and MSL= 0.3 dB for port 1-to-port 3 transmission at 850 nm. This mode selective loss is quite low, and not expected to impact link performance.

Table I: Measured filter performance at 850 and 1310 nm

Batch	Module	loss 1-2 (dB) (mean±sigma)	loss 1-3 (dB) (mean±sigma)	Crosstalk 1-2 (dB, worst)	Crosstalk 1-3 (dB, mean)
#1	#1	1.08±0.35	1.30±0.28	-33.2	-12.2
#1	#2	0.99±0.36	1.30±0.40	-35.8	-11.2
#2	#3	0.99±0.07	0.94±0.12	-34.6	-15.2
#2	#4	1.12±0.12	1.24±0.09	-34.6	-15.0
#2	#5	1.18±0.08	1.17±0.08	-36.5	-14.9
#2	#6	1.03±0.05	2.12±0.12	-32.5	-14.6

We used these filters to demonstrate a dual wavelength link with commercially available, byte-wide transceivers at 850 and 1310 nm. 2^{23}-1 PRBS signals at 500 and 1000 Mbit/s/fiber for the two wavelengths respectively, were routed through a serial cascade of up to eight filters and ≈40m of 62.5µm core, GRIN fiber. This link exhibited 10.3 dB insertion loss and yielded a bit error rate below $1 \cdot 10^{-14}$, including crosstalk effects between different wavelengths and different fibers in the ribbon cables. Shaking of the fiber to induce potential error rate floors from MSL had no effect, indicating that the filters introduce negligible mode selective loss.

In conclusion, we have demonstrated a simple fabrication approach for compact, high-performance WDM filters which are compatible with existing byte-wide transceivers. The filters are constructed from widely available ferrules to minimize alignment and connectorization costs, and exhibit low loss, sharp skirts, reasonable crosstalk suppression, and a negligible mode selective loss ≤0.4 dB. Here we demonstrated filter bandwidths of ≈40 nm; simulations show that our design is suitable for channel separations as small as 15-30 nm, and 5-10nm with some modification. This technology directly enables several interesting WDM interconnects, such as chordal rings. More significantly, its combination with recent advances in byte-wide WDM sources (eg: [6]) will enable byte-wide WDM fabrics with appreciable source routing capability and high channel bandwidth.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48, and was partially supported by ARDC funding.

References

[1] Y.-M. Wong et al., *J. Lightwave Technol.* LT-13, 995 (1995).
[2] M. Lebby et al., *Proc. 1996 Electron. Components & Technol. Conf.*, p. 279 (1996).
[3] K. S. Giboney, *Proc. SPIE Optoelectron. and Packaging IV* (February 1997).
[4] R.J. Deri et al., *Proc. 3d Massively Parallel Proc. using Opt. Interconn.*, p. 62 (1996).
[5] S.Y. Hu et al., in *Proc. 1997 IEEE LEOS Annual Mtng.*, paper TuJ4 (1997).
[6] C. Chang-Hasnain, in *Proc. 1997 IEEE LEOS Annual Mtng.*, paper WJ1 (1997).
[7] L. Aronson et al., presented at *OFC '97* (postdeadline paper).
[8] H. Yanagawa et al., *J. Lightwave Technol.* LT-7, p. 1646 (1989).
[9] T. Satake et al., *Proc. 1994 Electron. Components & Technol. Conf.,* p. 994 (1994).