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Thin film interference filters for 25 GHz channel spacing

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1. Introduction

Optical demultiplexing of 25 GHz spaced channels presents a number of challenges to the optical DWDM component designer. In particular, technical challenges around insertion loss, chromatic dispersion, and filter squareness have prevented the adoption of thin film interference filter technology for 25 GHz or 50 GHz channel spaced systems. This paper discusses the first experimental results of five and six cavity thin film optical filters for 25 GHz spaced DWDM systems. Power penalty due to dispersion is simulated for a cascade of eight 25 GHz six cavity filters. Thin film filters are shown to be a practical solution for optical multiplexing and demultiplexing for 25 GHz channel spaced DWDM systems.

2. Thin film filter background

Thin film optical filters are grown in vacuum deposition chambers using physical vapor deposition (PVD) techniques. They are in general composed of alternately varying high and low refractive index layers that form coherently stacked Fabry-Perot resonant cavities. Design techniques to create low ripple multi-cavity thin film filters are well known.[1,2] For the 25 GHz designs used in this paper, each cavity has roughly 40 layers. Typical thin film coating materials are metal oxides such as tantalum pentoxide and silicon dioxide. The spacer (cavity) layers for the designs in this paper are silica. Substrates are selected for a high Coefficient of Thermal Expansion (CTE) to provide passive temperature stabilization.[3] The number of cavities in the design gives a good indication of the squareness, or "Figure-of-Merit" (FOM) of the filter. For this paper FOM is defined as the 0.5 dB bandwidth divided by the 25 dB bandwidth.

One of the more challenging issues with the fabrication of high cavity count 25 GHz filters is the growth of thin films with sufficiently low optical loss required by the high normalized electric field within the filter. Normalized fields can reach values as high as 800 within the central cavities. Besides creating simple insertion loss, absorption and scatter in thin film resonant cavity filters also create wavelength dependent loss that has the effect of rounding the amplitude response of 25 GHz filters.

3. Experimental Results

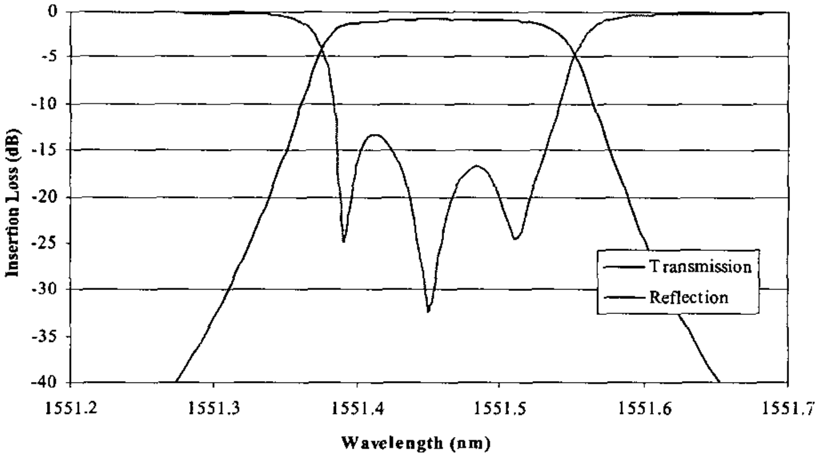
Five and six cavity 25 GHz filters were grown using a proprietary PVD deposition process. A measured spectral scan of the five cavity filter is shown in Fig. 1. Tabulated values of theoretical and measured results for both a five cavity and a six cavity filter are shown in Table 1. Theoretical insertion loss (IL) values in the table assume an absorption coefficient (k) of 2 ppm. Spectral measurements were made at normal incidence using Agilent's 81640a swept laser.

The high resonance of thin film filters produces a wavelength dependent phase shift on transmission that manifests itself as chromatic dispersion (CD). The power penalty due to CD on real world transmission systems is difficult to predict as the CD values vary across the passband. In general, for symmetrical amplitude bandpass filters, the CD passes through zero near or at the center of the bandpass filter, which is typically where the carrier signal strength is largest. Measured CD on a packaged 25 GHz five cavity filter is shown in Fig. 2. The CD was measured using Agilent's 86037c CD measurement system.

Power penalty due to filter amplitude and CD was simulated using a OC192 NRZ pseudo random binary sequence with repeat length of $2^7 - 1$ generated using commercially available optical modeling software as shown in Fig. 3. The model assumed the modulated signal was transmitted through an eight filter cascade. The performance of the filter was modeled as a dispersion power penalty for a range of filter detuning from perfect centering of the signal source. An amplitude-only power penalty as a function of wavelength decentering with no phase effects was generated. Also shown is the effect of dispersion-only power penalty as a function of wavelength decentering. Excess loss of the filter is not included in the analysis as it is contained in the total link power budget. The conclusion of this simulation is that for up to OC192 data rates, the power penalty derived from CD effects dominates over the amplitude driven power penalty and can be kept at manageable levels.

4. Optical bandwidth budget

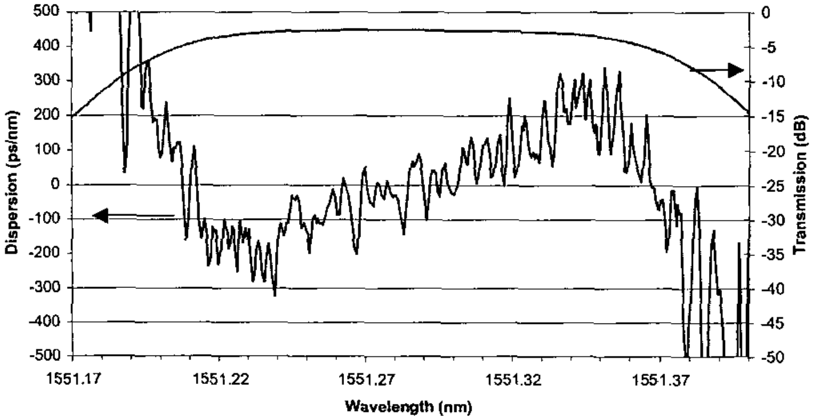
As signal bandwidth increases as a fraction of channel width, the tolerancing budgeting becomes more complex. For 100 and 200 GHz channel spacing and OC48 data rates, the optical bandwidth of each modulated laser is a small fraction of the filter bandwidth and could be neglected when designing a filter's 0.5 and 25 dB bandwidths. For 25 GHz channel spacing and OC192 data rates, however, each laser's optical bandwidth is a sizeable fraction of the filter's 0.5 dB bandwidth. Further, allowances for filter cen-



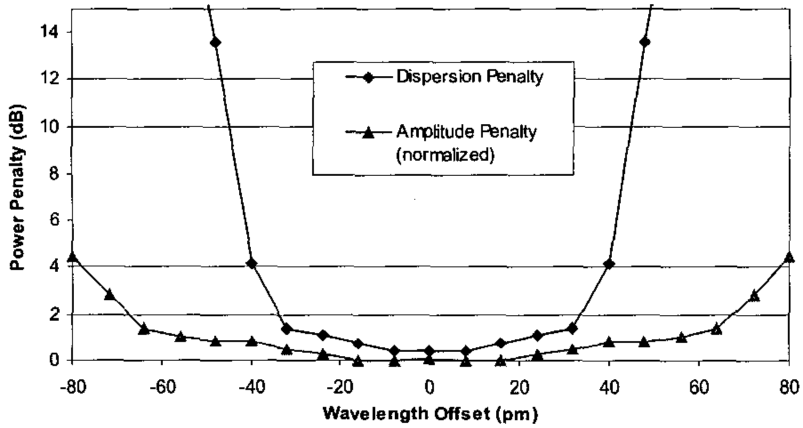
ThC5 **Fig. 1.** Five cavity 25 GHz measured spectral results.

ThC5 **Table 1.** **Experimental data on 5 cavity and 6 cavity filters.**

Filter	IL (dB)	0.5 dB BW (pm)	1 dB BW (pm)	25 dB BW (pm)	FOM (%)
5 cavity measured	0.65	129	151	275	47
5 cavity theoretical	0.63	145	155	276	53
6 cavity measured	0.50	167	186	304	55
6 cavity theoretical	0.73	155	178	262	59



ThC5 Fig. 2. Amplitude function and CD of packaged 5 cavity 25 GHz thin film filter.



ThC5 Fig. 3. Calculated power penalty of OC192 signals due to dispersion and filter amplitude function as a function of filter or signal source decentering. The simulation transmits through eight cascaded six cavity 25 Ghz filters.

ter wavelength drift over operating temperature, aging, and measurement uncertainties, as well as laser drift, must be made. These sources of wavelength centering error must be added to the required clear channel bandwidth to obtain the necessary filter bandwidth budget. For example, a clear channel bandwidth requirement may be 100 pm while adding the various centering errors may give a total 0.5 dB bandwidth budget of 150 pm.

Adjacent channel crosstalk budgets are complicated by signal modulation broadening as well. Adjacent channel rejection of 25 dB is interpreted as allowing no more than –25 dB of either adjacent channel total (modulated) power to transmit through the filter. The weighted combination of the adjacent channels spectral function and the filter slope through the adjacent channel then determines the allowable 25 dB bandwidth. Additionally, various sources of wavelength centering error must be subtracted from that value to obtain the necessary filter bandwidth budget. For example, the 25 dB bandwidth requirement may be 2 channels minus the weighted clear channel bandwidth, or 325 pm, while subtracting the various centering errors could give a total 25 dB bandwidth budget of 275 pm. Thin film filters have an advantage over other technologies in that non-adjacent channels are strongly rejected and can be ignored.

5. Summary

Thin film interference filters using five and six cavity designs are shown to be a suitable and practical method to demultiplex 25 Ghz channel spaced data signals for up to OC192 data rates. Experimental results show good agreement with theoretical values and low overall loss and square filter functions. Chromatic dispersion and group delay of the filters are shown to be manageable at OC192.

References

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3. H. Takahashi, "Temperature stability of thin-film narrow bandpass filters produced by ion-assisted deposition", Proc. SPIE 2253, 1343 (1994).