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POLARIZATION-INDEPENDENT WDM CHANNEL DROPPING FILTERS

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Abstract: We show how polarization-independent wavelength filters can be realized using asymmetric directional couplers. Simulations demonstrate that excellent polarization behavior can be achieved with practical tolerances without sacrificing filter bandwidth or insertion loss.

Introduction: Increasing interest in WDM systems is creating significant demand for wavelength demultiplexers, including "channel dropping filters"[1] to extract a single wavelength channel from a stream of multi-wavelength data. A popular filter design employs asymmetric directional couplers, either with or without a grating inserted between two coupled waveguides (fig. 1).[2-6]. This device selects a single wavelength channel, determined by the phase matching condition relating the modal indices n_{top} and n_{bot} for the two coupled waveguides:

$$n_{top}(\lambda_0) - n_{bot}(\lambda_0) = p\,\lambda_0 / \Lambda \qquad (1)$$

where λ_0 is the filter peak wavelength, Λ is the grating period for grating-assisted devices, p is an integer, and p=0 for devices without a grating. Several vertical coupler filters have been demonstrated on III-V semiconductors, because this approach enables precise control of the waveguide thicknesses and indices as well as monolithic integration with transmitters or receivers.[3-6] Recently, integration of these filters with photodetectors [7] and/or optical amplifiers [8,9] has been demonstrated for optical receiver applications. A major obstacle to using such chips is the polarization sensitivity of the asymmetric coupler. Typically, polarization-induced changes in filter wavelength λ_0 exceed the filter bandwidth,[3-6] resulting in an extreme polarization sensitivity which is incompatible with conventional single mode fiber communications. Here we demonstrate that the polarization sensitivity can be almost eliminated without compromising other features of the filter. Results are presented for devices without an integrated grating, but the same techniques can be applied to achieve polarization-insensitive grating-assisted filters as well.

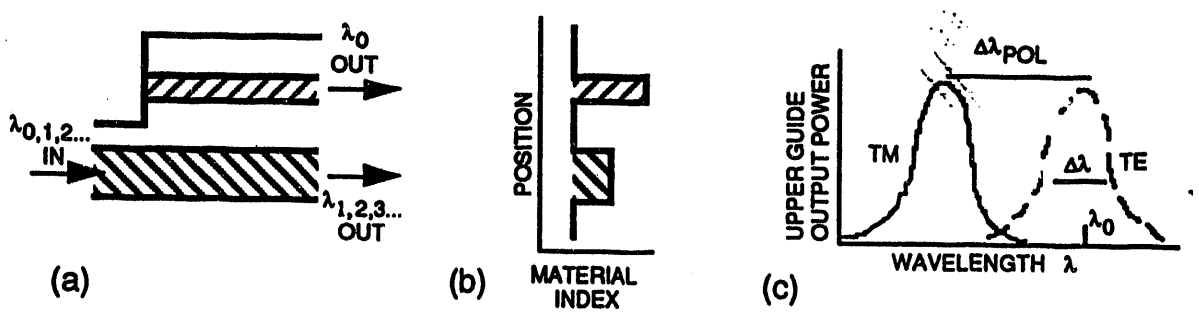

Fig. 1: Asymmetric coupler filter schematic (a) along propagation direction, (b) transverse index profile, and (c) filter response. Waveguide core material is indicated by cross-hatching in (a) and (b).

Design Approach: The polarization dependence of vertical asymmetric couplers on GaAs or InP results from the intrinsic waveguide birefringence, most of which results from the narrower waveguide. Our basic approach is to replace the core of the thicker waveguide with a multiple quantum well (MQW), for which the effective material birefringence [10] is selected to compensate the birefringence of the upper guide. Achieving practical tolerances, however, requires additional design strategies to minimize birefringence changes from variations in layer thicknesses or indices. Design rules to achieve this tolerance will be presented at the conference.

Based on these rules, we have designed two Al_xGaAs filters for λ_o=827nm (fig. 2). Filter performance was evaluated using conventional eigensolving algorithms to determine planar guide modal indices n. The filter bandwidth and polarization sensitivity are evaluated from $\Delta\lambda_{POL}=\Delta n_{POL}/\sigma$ and $\Delta\lambda=0.8\ \lambda_o/\sigma L$, where L is the coupler beat length, $\sigma=\partial n_{top}/\partial\lambda-\partial n_{bot}/\partial\lambda$ is the differential dispersion, and $\Delta n_{POL}=n_{top}(TE)-n_{bot}(TE)-n_{top}(TM)+n_{bot}(TM)$. [2,3,4]

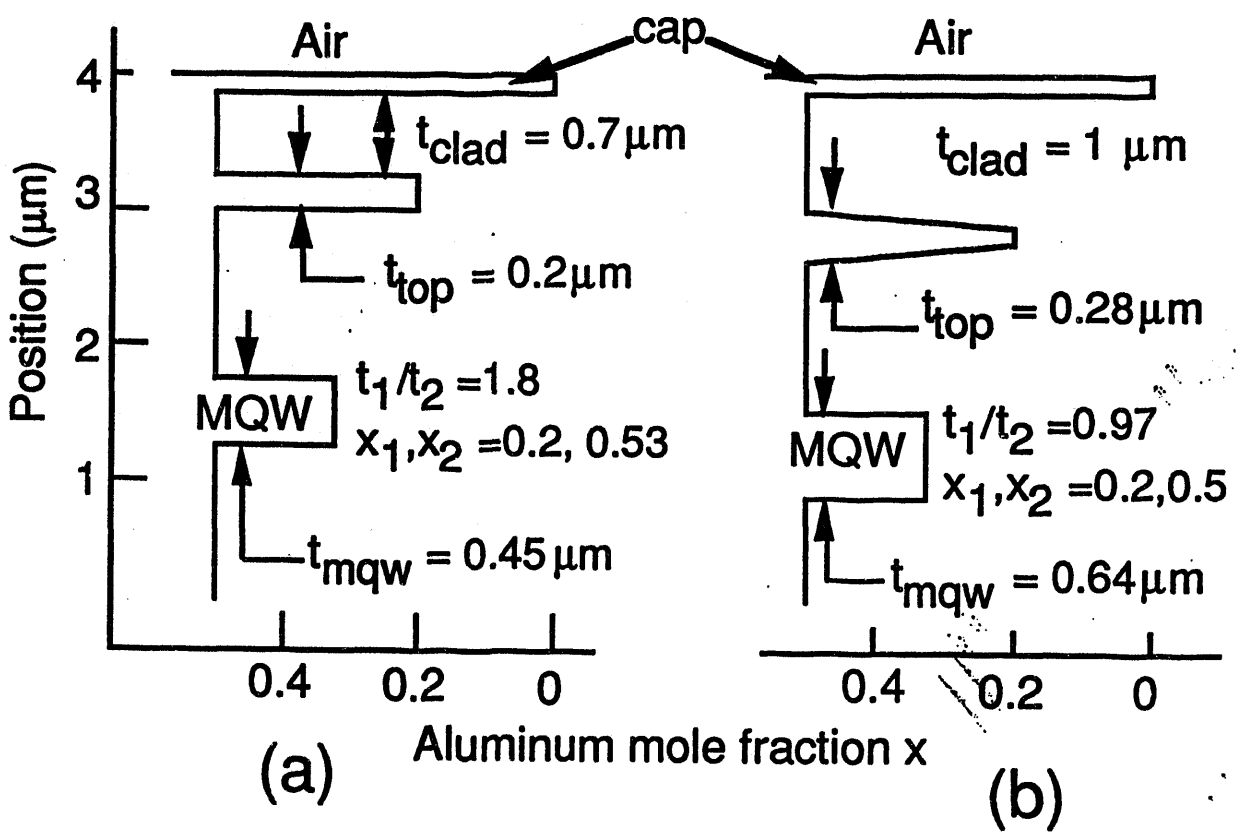

Fig. 2: Polarization-insensitive channel dropping filters. Schematics show transverse structure (composition vs. position). The devices use a top waveguide core with x=0.2 and either abrupt (a) or graded (b) index steps. The bottom waveguide consists of a multilayer MQW (alternating layers of x1 and x2 composition and thickness ratio t1/t2), and the cladding and substrate consist of x=0.5 bulk alloy. The topmost layer is a 60 nm GaAs cap layer.

Results: The filter of fig. 2a (employing only abrupt index changes) exhibits $\Delta\lambda$=2.9 nm FWHM for L=3.8 mm. This bandwidth is comparable to previous reports for polarization-sensitive devices,[3] and can be significantly reduced by using grating-assisted coupling.[5,6] Table I lists tolerances on layer thicknesses and Al_xGaAs composition x to maintain $\Delta\lambda_{POL}/\Delta\lambda$ <0.25, which corresponds to ≈1 dB of polarization sensitivity. These tolerances are achievable using today's epitaxial growth technology, indicating that such a device is practical to fabricate.

Polarization-insensitive designs based on abrupt index changes (fig. 2a) require that one MQW constituent have an index below that of the waveguide cladding (Al mole fraction x=50% in fig. 2a). The tolerance shown in Table I for $Al_{0.5}GaAs$ compositional variation assumes that both the x=50% cladding and the x=53% MQW constituent vary in the same manner due to errors in epitaxial growth. This assumption is reasonable due to the very similar compositions of the two materials. However, not shown in Table I is the precise control necessary for the relative compositions of these two materials: x_{clad}-x_{MQW} must not exceed 5×10^{-3}. We believe that such control is achievable using current epitaxial techniques, but it will clearly requires state-of-the-art technology.

Table I: Tolerances to achieve $\Delta\lambda_{POL}/\Delta\lambda$ <0.25 for the two designs of fig. 2*

Design	Abrupt Index Changes	Graded Index Changes
upper cladding thickness t_{clad}	>±13 %	>±13 %
upper core thickness t_{top}	±8 %	±11 %
lower core thickness t_{MQW}	±11 %	±13 %
MQW well-to-barrier thickness ratio t1/t2	±10 %	±7 %
$Al_{0.2}GaAs$ composition Δx	±0.042	±0.074
$Al_{0.5}GaAs$ composition Δx	±0.040	±0.070

*considers single parameter variations, not simultaneous multi-parameter variations

A design based on graded index changes (fig. 2b) can alleviate the compositional control issue associated with the abrupt index change design. Grading the index profile in the upper waveguide reduces its birefringence, which enables the cladding material to be used as an MQW constituent. Using a sinusoidal grading, the design of fig. 2b achieves $\Delta\lambda$=3.7 nm FWHM for coupler length L=2.5 mm. Table I shows that the tolerances for this design are practical using today's epitaxy technology. Notably, composition tolerances become much less severe (Δx = 0.04 causes $\Delta\lambda_{POL}/\Delta\lambda$ =0.06).

Fig. 3 shows the filter response calculated for this device with a propagation simulation using a supermode basis set,[3,11] which has accurately simulated other vertical coupler devices.[11] The device clearly exhibits polarization-insensitive behavior ($\Delta\lambda_{POL}/\Delta\lambda$ <0.06). In contrast, the conventional device shown in fig.3, which uses a bulk AlGaAs alloy for the lower waveguide core, is highly polarization sensitive. Fig. 3 also shows that the device insertion loss is small (< 0.2 dB) for both polarizations.

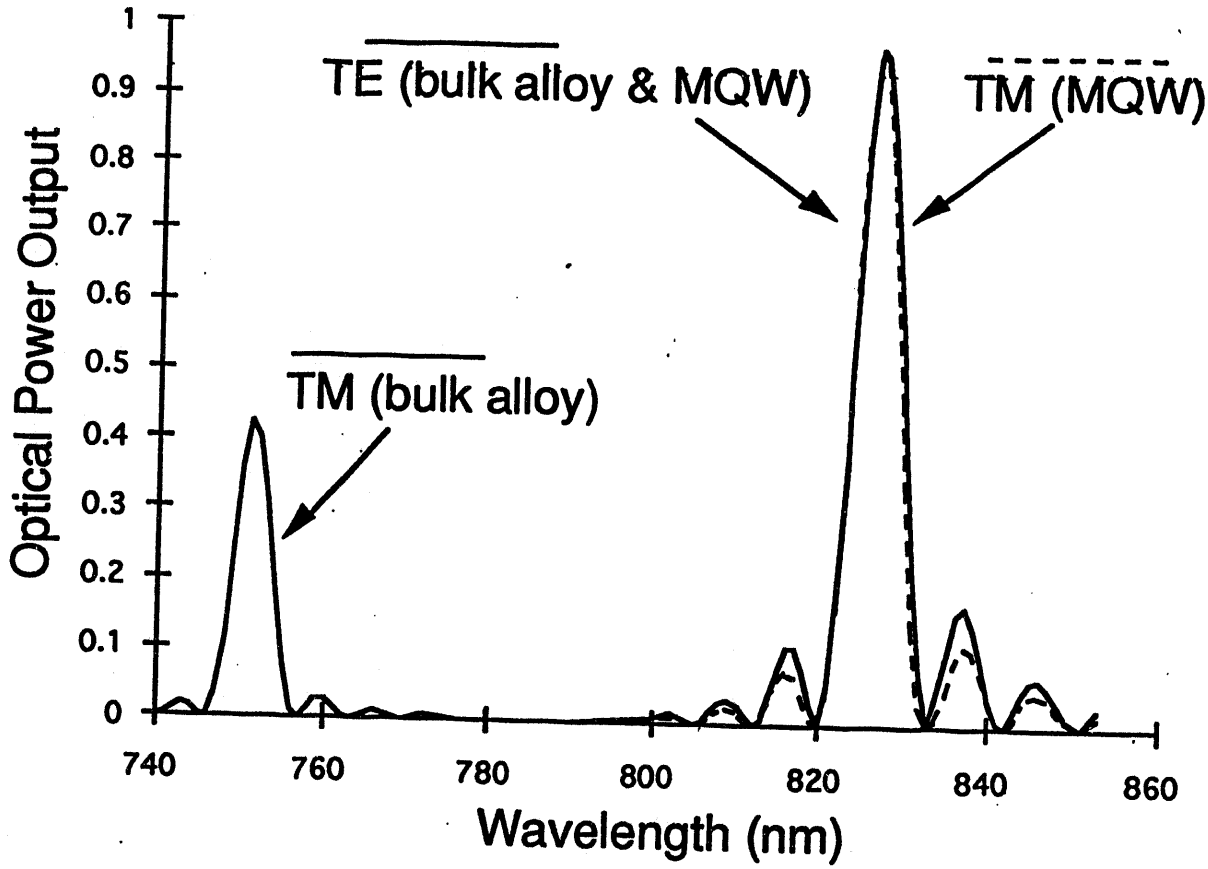

Fig. 3: Filter response calculated for the device of fig. 2b (solid curve TE, dashed curve TM) and for the same device with the lower waveguide core replaced by bulk AlGaAs alloy (solid curves TE, TM). Simulations do not include material dispersion.

Conclusion: We have described a design approach to achieve polarization-insensitive WDM filters based on asymmetric directional couplers. Simulations confirm that our design leads to polarization-insensitive behavior, and show that practical fabrication tolerances are achieved. The method can be used both with and without grating-assisted coupling, and should result in the realization of monolithic WDM receiver chips and optically preamplified WDM receiver chips.

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