OPTIMIZATION OF OADMs BASED ON GRATING-ASSISTED MODE CONVERSION IN NULL COUPLERS

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Abstract: The performance of a fully optimised OADM, based on null couplers and tilted Bragg gratings, is studied. The device exhibits drop action with < -40dB channel cross-talk and shows < -40 dB backreflections at the input port.

Introduction
High performance optical add-drop multiplexers (OADMs) are critical components for wavelength division multiplexing (WDM) Technology. To date most of the OADM designs have relied on narrow-band reflective Bragg gratings for the wavelength selection and an interferometric structure to achieve the channel routing /1,2/. In these configurations the exact position of the grating(s) is quite important and post-tuning is often required /3/. Furthermore, due to grating intra- and out-of-band dispersion the useful bandwidth of the OADM is usually smaller than the bandwidth of the grating.

Another OADM configuration relies on non-interferometric, grating-assisted couplers. In this case the grating can be either confined in only one core /4/ or extended in both of them /5/. In the latter, a tightly fused asymmetrical fibre coupler has been used in conjunction with a tilted grating, in order to minimise back reflections in the input port. However, the need for an optimised coupler, optimum grating tilt and grating extent have not yet been addressed. In this paper, we present, for the first time, fully optimised designs of OADMs that rely on grating assisted mode conversion in null couplers /6/. The optimisation process involves three different optimisation steps, namely, the grating tilt angle and extent, the degree of V-number asymmetry between the two waveguides, and the shape of coupler taper region.

Device Principle of Operation
The schematic of the proposed OADM is shown in the inset of Figure 1. The null coupler consists of two coupled dissimilar single-mode waveguides. In the absence of the grating, the null coupler does not cross-couple optical power. Light from the larger (smaller) V-number input waveguide excites only the even (odd) lowest-order mode at the coupler waist and appears uncoupled at the output waveguide with the same V-number. The presence of a tilted Bragg grating, in the coupler waist, cross-couples power predominantly from the even (odd) lowest-order forward-propagating "waist" eigenmode to the odd (even) backward propagating counterpart, depending on excitation port. The operation of the OADM depends critically on the degree of excitation of even and odd modes at the coupler waist. Optimum operation requires the efficient excitation of only one waist eigenmode.

Waveguide-Asymmetry & Taper-Shape Optimisation
It is first realised that the waveguide asymmetry and the coupler taper shape affect the relative degree of even and odd mode excitation. It is shown that for a linear taper shape and waveguide-to-waveguide separation angle of ~1deg, in order to achieve even/odd-mode power extinction ratio of < -30 dB (at the waist), the required V-number asymmetry ratio (V_S/V_E) should be less than ~ 0.83. For similar waveguide asymmetries and coupler overall dimensions, an optimised S-shape taper results in power extinction ratio smaller than about ~ 55 dB, over a bandwidth of 50 nm. The taper-shape optimisation is achieved by employing a variational technique /7/.

Tilted-Grating Optimisation
In addition to aforementioned even-odd (e-o) mode cross-coupling at the coupler waist, such a grating can provide strong backreflections through even-even (e-e) and odd-odd (o-o) mode interactions. Such backreflections appear at the input port and can be minimised, or even eliminated, by properly tilting the grating with respect to the waist axis.

Figure 1 : Coupling coefficient versus grating tilt angle (Inset : Null Coupler configuration).

Figure 1 shows the grating coupling coefficients for e-e, e-o and o-o mode interactions, as a function of the grating tilt angle. The waveguides have NA of 0.26 and thicknesses d_1 = 3 μm and d_2 = 2 μm, respectively. The waist thickness is d_w = d_1 + d_2 = 5 μm. For a high performance OADM, the e-o interaction should be maximised while the o-o and e-e interactions should be kept to a minimum (ideally zero) level. Figure 1 shows that, for a tilt angle of ~ 4.5 deg, the e-o coupling constant is maximum while the o-o counterpart is zero (optimum tilt angle). The e-o coupling constant, however, has an appreciable value. This implies that exciting the OADM from port 2 (input port) will result in efficient drop action (in port 1) and negligible backreflections (in port 2). However, exciting it from port
3, although it will result in efficient add function (port 4), it will inevitably show strong backreflections (in port 3). This implies that efficient add and drop operation requires the use of only one isolator. At this point, it should be emphasized that separating the two waveguides at the waist region, i.e. if $d_w > d_i + d_o$, does not result in o-o coupling coefficient, for any tilt angle, and severely compromises the device performance.

The optimum grating tilt angle is shown to be affected by the transverse extent (width) of the grating $d_i$. Figure 2 shows the optimum tilt variation as a function of the grating width (normalised to the waist width $d_w$). Extending the grating into the waist cladding area, not only results in stronger coupling strength (not shown), but also reduces the optimum tilt angle. Such a reduced grating tilt angle is expected to reduce significantly coupling into radiation losses. On the other hand, restricting the grating in the waist area, as is the case of photosensitive-core, fused fibre devices, results in increasingly larger optimum tilt angles with adverse short-wavelength radiation losses.

**Figure 2: Optimum tilt angle -vs- normalised grating width.**

**OADM Reflection Spectra**

Full reflection and transmission spectra of optimised OADMs have been calculated using local-normal-mode and transfer matrix analyses. Each coupler taper length was 2.5 mm and the waist length was 2mm. The rest of the parameters were similar to the ones in Figs 1 and 2. The grating had a length of 2 mm, refractive-index modulation depth of $1 \times 10^{-6}$ and a raised-cosine apodisation profile. The grating was covering the entire waist region and the optimum tilt angle was $-4.5$ deg. Waveguide 2 is the input port, while waveguide 1 is the drop port (see inset in Fig.1).

**Figure 3: OADM reflection spectra (Linear-shape coupler taper).**

Figure 3 shows the spectrum of the dropped channel (solid line) and backreflected light (dotted line), for a linear coupler-taper shape. Figure 4 shows similar spectra for an optimised S-bent coupler taper shape. In both Figures, the level of peak A of the backreflected light is determined by the magnitude of the o-o coupling coefficient (see Fig. 1) and is minimised by using optimum tilt angle. The level of the remaining peaks B & C, of the backreflected light, and the secondary peak D, of the dropped spectrum, depend on the residual excitation of even mode at the coupler waist. As already mentioned, this residual excitation depends on the waveguide asymmetry and the coupler taper shape. Use of linear tapers (Fig. 3) limits the residual excitation and, therefore, the the peaks B and D to about $-30$ dB. Use of optimised S-bent tapers (Fig. 4), on the other hand, reduces peaks B and D to levels below $-55$ dB. Peak A, as expected, is unaffected by the taper shape.

**Figure 4: OADM reflection spectra (Optimised S-shape coupler taper).**

**Conclusions**

We have thoroughly studied the performance of optimised OADMs based on null couplers and tilted Bragg gratings. We have shown that maximisation of the device performance involves three optimisation steps. Firstly, the waveguide asymmetry ($V_2/V_1$) ratio should be optimised in order to minimise the unwanted-mode extinction ratio at the null coupler waist. Secondly, the coupler taper shape should be optimised in order to further minimise the aforementioned extinction ratio. Thirdly, the grating tilt angle and relative width can also be optimised to give negligible backreflections at the input port and minimise radiation losses. We have shown that keeping $V_2/V_1$ at $-0.8$ and employing an optimised S-bent coupler taper, the unwanted-mode extinction ratio at the coupler waist is kept at $-55$ dB. Finally, a fully optimised OADM is shown to provide a drop channel with cross-talk better than $-40$ dB. The backreflections at the input port are also kept below $-40$ dB. The grating position does not affect the device performance.

These results show that the proposed high performance OADM configuration can meet the stringent telecom specifications. Since the relative width of the grating is great importance, the device can be best implemented in integrated optics form. FHD planar technology combined with UV waveguide- and grating-writing techniques can be well suited for a practical device implementation.

**References**