Thin-film (DE)MUX based on step-like spatial beam shifting

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Using spatial beam shifting a single dielectric stack can demultiplex multiple WDM channels. We demonstrate in theory and experiment that a compact, cost-effective (DE)MUX with flat-top passbands and low loss can be achieved.

WDM systems create a strong need for compact wavelength multiplexing and demultiplexing devices that can be manufactured cost-effectively. We focus here on thin-film structures, as they are easy to fabricate with well-known technology. In contrast to typical dielectric interference filters though, we use group velocity effects to separate multiple beams of different wavelengths with a single multilayer structure. Fig. 1 shows a schematic of our device. Polychromatic light is incident under an angle onto a dielectric stack. The dielectric stack is designed such that beams of different wavelength are spatially shifted along the x-direction upon reflection. The spatial offset between different wavelengths is increased by performing multiple bounces through the structure. This device concept is by no means limited to three channels. Depending on the dispersion characteristics of the dielectric stack and the beam size more channels can be multiplexed or demultiplexed.

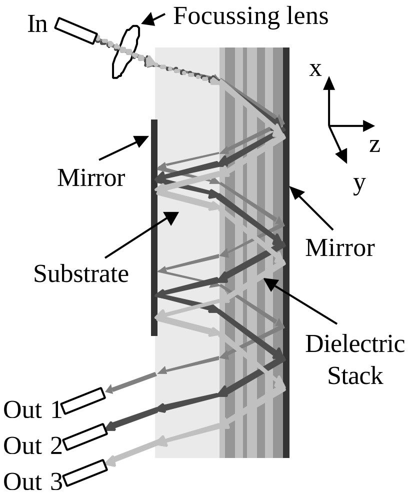

Fig. 1. Schematic of 3-channel demultiplexer.

Previously we have discussed two different types of dielectric stacks with high spatial dispersion. In [1] we have shown that the photonic crystal "superprism effect" of a periodic dielectric stack results in high spatial dispersion close to the stop-band edge and can be used for demultiplexing. Such a periodic dielectric stack exhibits a non-linear spatial shift along the x-direction with wavelength. Therefore, if the outputs *Out 1, Out 2*, and *Out 3* in Fig. 1 are equally spaced, the channel spacing cannot be equal in wavelength. In order to obtain equal channel spacing, we introduced in [2] a non-periodic dielectric stack exhibiting a linear shift with wavelength and thus constant dispersion. Since the beam shifts linearly with wavelength, the beam has a different center position for each wavelength. Thus, only the center wavelength of the first channel is exactly centered on *Out 1*. If the channel drifts to an off-center wavelength, the beam position changes and the coupling efficiency to *Out 1* is reduced. In the case of a Gaussian beam profile the passband shape is also Gaussian for a device with constant dispersion. To allow for a drift in the channel wavelength, we ideally want a step-like shift with wavelength. In this case all beams within a first wavelength interval exit the structure at position *Out 1*, all beams in the second wavelength interval exit at *Out 2*, and so on. This type of step-like shift with wavelength corresponds to a flat-top passband, since a drift in the wavelength does not result in loss.

A thin-film device exhibiting a step-like shift with wavelength can be designed employing methods similar to the ones described in [2]. Numerical refinement [3] is used to gradually improve the performance of a start design until the structure matches the desired characteristics sufficiently well. To prevent reflections off the interface between the substrate and the dielectric stack, we use a "tapered" Bragg stack as the start design [4]. In such a Bragg stack the periodicity is slowly "turned on" by increasing the amount of high index material in each period. The desired dispersion characteristics were solely obtained using numerical refinement. We also tried analytical coupled-cavity design techniques [5,6], but did not achieve good results due to the large number of cavities needed to approximate a step-like function.

We designed and experimentally tested a 3-channel, 66-layer device consisting of alternating layers of SiO_2 (n=1.46 at 830 nm) and Ta_2O_5 (n=2.06) with a total stack thickness of 13.4 µm. Under an incidence angle of 48°, the step-like shift with wavelength is clearly visible as seen in Fig 2. The steps are sufficiently high to separate the different channels by their beam width.

Furthermore, we designed a 4-channel flat-top device with 20-nm wavelength spacing around 1550 nm, which is particularly well suited for coarse WDM. This device has 100 layers. Only the first 80 layers were modified during refinement to obtain the desired dispersion characteristics. The last 20 layers were fixed as a Bragg stack to achieve high reflectance. The lowest reflectance is 96% after a single bounce, corresponding to a maximum intrinsic reflection loss of 28% after eight bounces. More periods could be used to further decrease the loss due to transmission. This device likely has negligible absorption loss. Fig. 3 plots the theoretical performance of the obtained 4-channel design.

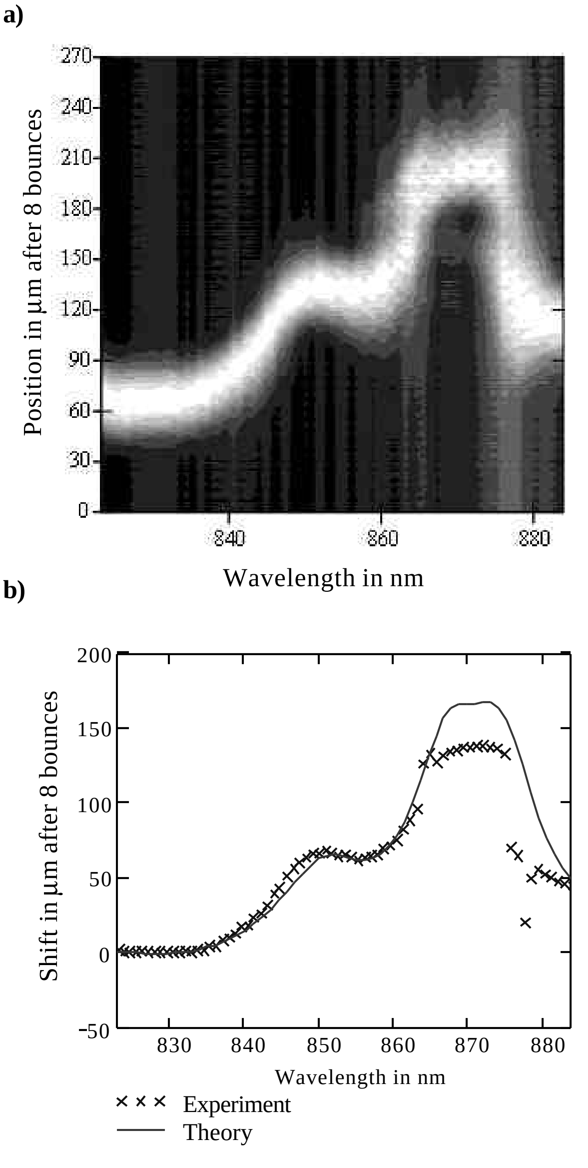

Fig. 2. a) Experimental results for a 66-layer, 3-channel demultiplexer using 8 bounces through the structure, an incidence angle of 48°, and p-polarized light. The intensity of the exiting beam is plotted as a function of the wavelength and the position along the x-axis. The peak intensity is normalized to unity for each wavelength. . The loss in this experiment was high, as coatings with only 50% reflectivity were used as mirrors. b) Good agreement between theory and experiment is obtained for the first two steps. The disagreement for the last step is most likely due to fabrication uncertainties.

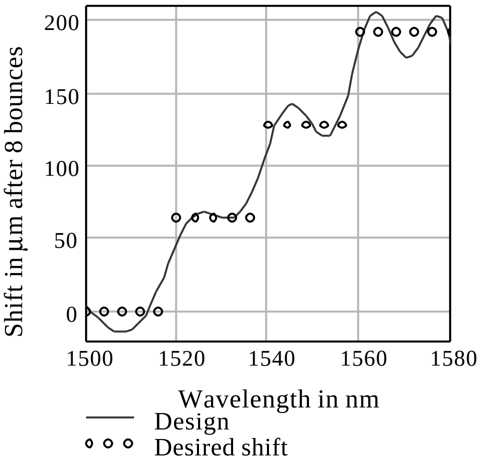

Fig. 3. Theoretical design of a 100-layer, 4-channel (DE)MUX to be used with 8 bounces through the structure at 45°-incidence angle, and with p-polarized light.

In conclusion we explained how a multi-channel, compact, flat-top, low-loss wavelength (DE)MUX can be designed using just a single dielectric stack.

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