M. Gerken, B. E. Nelson, and D. A. B. Miller, "Thin-Film Wavelength Demultiplexer Based on Photonic Crystal and Group Velocity Effects," Paper IFH2, OSA Conference on Integrated Photonics Research 2002, Vancouver, BC (July 17-19, 2002).

Thin-film wavelength demultiplexer based on photonic crystal and group velocity effects

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Abstract: We experimentally observe the "superprism effect" in a periodic thin-film structure acting as a one-dimensional photonic crystal. The design of non-periodic structures exhibiting a linear shift with wavelength in the EDFA C-band is discussed.

OCIS codes: (260.2030) Dispersion; (060.4230) Multiplexing; (230.4170) Multilayers

WDM systems create a strong need for compact wavelength splitting devices that can be easily manufactured. Here we demonstrate the capability of group velocity effects in multilayer dielectric structures to provide wavelength splitting. In contrast to typical dielectric interference filters, in this approach, one multilayer structure can separate multiple beams of different wavelengths. We demonstrate beam shifts with wavelength in a periodic multilayer stack; such a structure can also be viewed as a one-dimensional photonic crystal. We also extend the analysis to design non-periodic structures with superior wavelength splitting properties.

One-dimensional [1,2], two-dimensional [1], and three-dimensional [3] photonic crystals exhibit strong dispersion at wavelengths close to the stop band (i.e., the reflection band in such a structure when used as a mirror). This "superprism effect" can be used to spatially separate beams of different wavelength. We focus on one-dimensional structures, as they are easy to fabricate with well-known technology allowing for compact, cost-effective WDM devices. Fig. 1 shows a schematic of our periodic thin-film device. Light is incident onto the dielectric stack from the substrate side. Close to the stop band, different wavelengths propagate at different angles within the periodic stack. Thus, beams of different wavelength are spatially separated along the x-direction. In order to achieve a higher separation, multiple bounces can be performed in the stack.

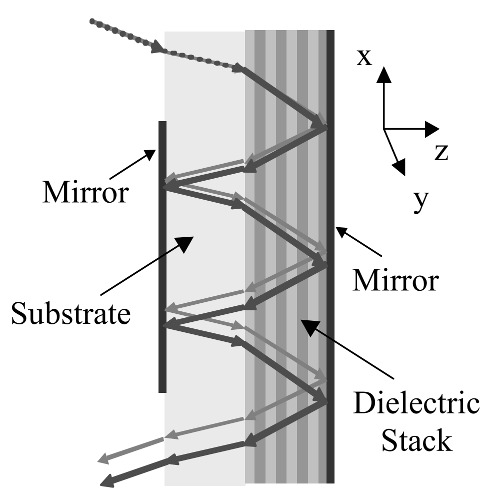

Fig. 1. Device Schematic. Different wavelengths propagate at different angles within the dielectric stack and are spatially separated.

We experimentally verified the spatial shift with wavelength using a 100-period dielectric stack consisting of alternating layers of SiO_2 (n=1.45 at 880 nm) and Ta_2O_5 (n=2.09) with a total stack thickness of 30 μm. The beams were incident at a 40° angle and focused to a 6.2 μm spot size at the exit interface. In Fig. 2 the observed shift along the x-direction is shown. Also plotted is the expected shift calculated using Bloch theory. Good agreement between experimental and theoretical results is obtained.

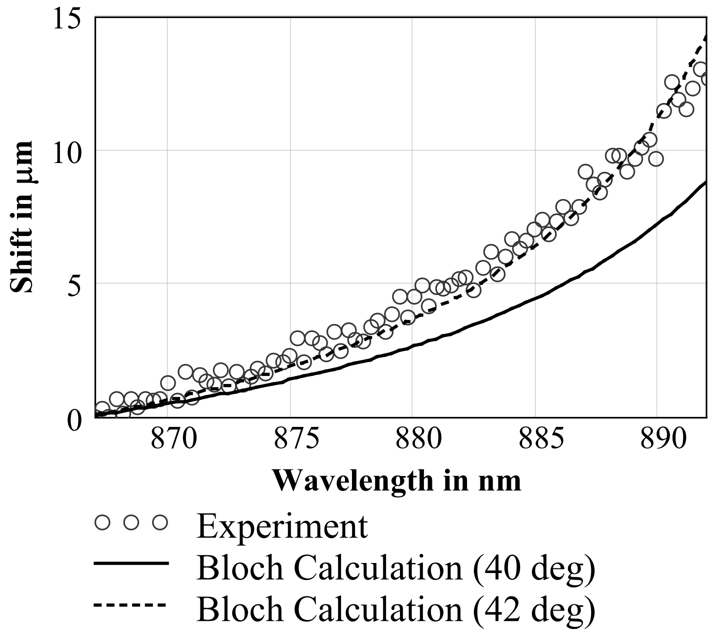

Fig. 2. Shift along the x-direction as observed in experiment and calculated theoretically. The slight offset may be explained by an error of 2 degrees in the incidence angle.

For practical devices a linear shift with wavelength is desirable. Unfortunately, the shape of the shift cannot be modified much for a periodic stack, as the only degrees of freedom are the choice of materials, the period length, and the distribution of the materials in the period. Non-periodic thin-film structures, on the other hand, offer much more design flexibility, since all layer thicknesses can be chosen independently.

To achieve a design with a linear shift as a function of wavelength, we used a double-chirped structure [4] as the starting design and optimized the design using well-known refinement techniques [5]. Fig. 3 plots the theoretical results for this non-periodic thin-film structure showing a linear shift with wavelength over the EDFA (erbium-doped-fiber-amplifier) C-band. Furthermore, the stack and the substrate are impedance matched to avoid reflections off the front of the stack. This allows for several bounces within the structure. Hence, this thin-film device is capable of multiplexing or demultiplexing multiple equally spaced wavelength channels in a single device.

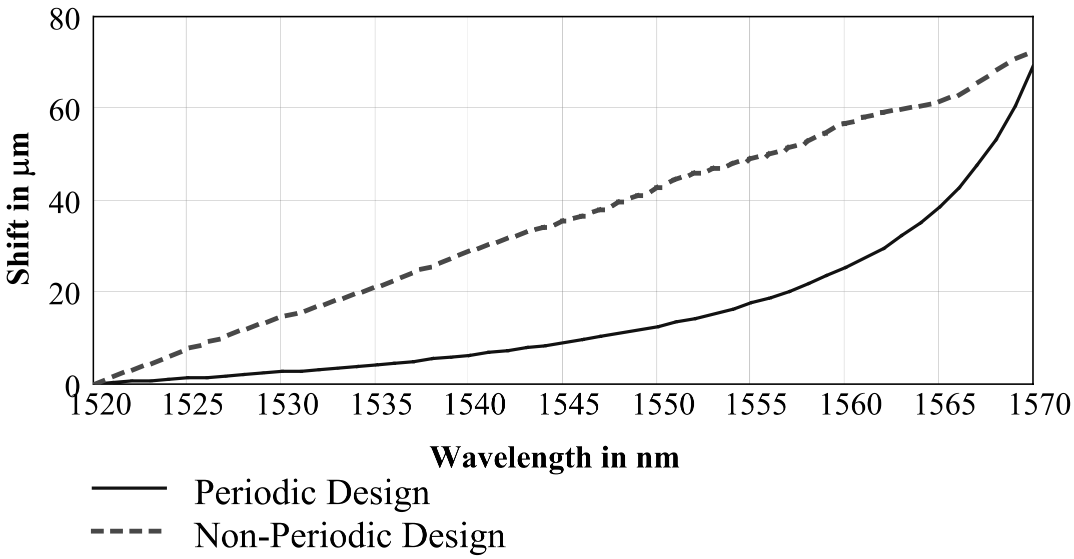

Fig. 3. Theoretical comparison of the shift along the x-direction obtained with the periodic and the non-periodic design.

This work was supported by the DARPA Optocenters Program. We are pleased to acknowledge A. Zheng and P. J. Anthony of JDS Uniphase for the growth of the sample. Martina Gerken acknowledges support of the Sequoia Capital Stanford Graduate Fellowship.

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