898

Narrow-Band Waveguide Taps Using Photonic Surface Modes Supported by Multilayer Dielectric Stacks

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Abstract

The photonic surface modes supported by multilayer dielectric stacks are highly dispersive. They can therefore be used to design mode-selective taps and narrow-band notch transmission filters for waveguide applications.

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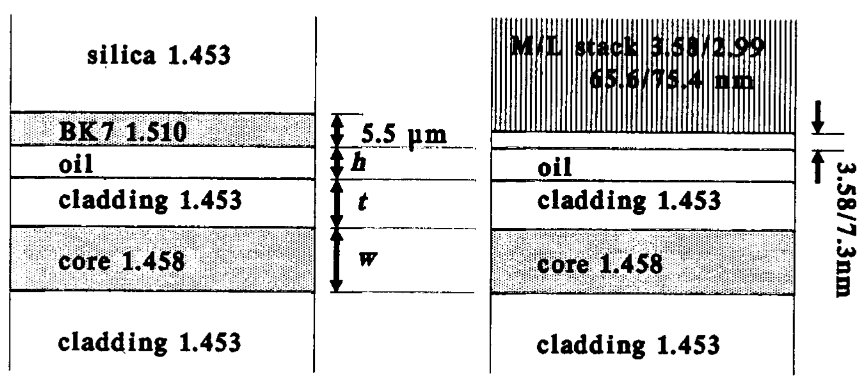
A necessary element, in applications where a widely tunable narrow-band filter is required (e.g., over wavelength at fixed mode index, or over mode index at fixed wavelength), is a structure that supports highly dispersive guided modes whose index may be varied at fixed wavelength. These requirements are satisfied by the photonic surface modes (PSM's) supported on multilayer



i) ii)

Figure 1. The structures used in the calculations leading to Figures 2 and 3. Evanescent coupling occurs across the low index oil layer. Note that the last layer of the multilayer stack has an index of 3.58 and a thickness of 7.3 nm.

dielectric stacks. PSM's are guided by the interface between a multilayer stack and a low index external medium[1,2,3,4]. They appear within the photonic band gap or stop-band of the stack, and are confined by total internal reflection and Bragg reflection. A number of special features set them apart from normal waveguide modes. Only one PSM appears per stop-band, and since each stop-band can cover a wide span of effective indices, substantial ranges of quasi-single-mode operation exist. Since it is the Bragg condition that determines the approximate effective index of the PSM's, the average index of the stack can be high, while still permitting phase matching to, for example, a low-index fibre mode. This means that the functionality of the high index III-V system can potentially be married, for example, to low index glass fibre optics. Finally, PSM's are highly dispersive with wavelength and very sensitive to the index of the external medium, suggesting applications to narrow-band channel dropping filters and mode-selective couplers - both of which are addressed in this paper. The advantages of using PSM's over less

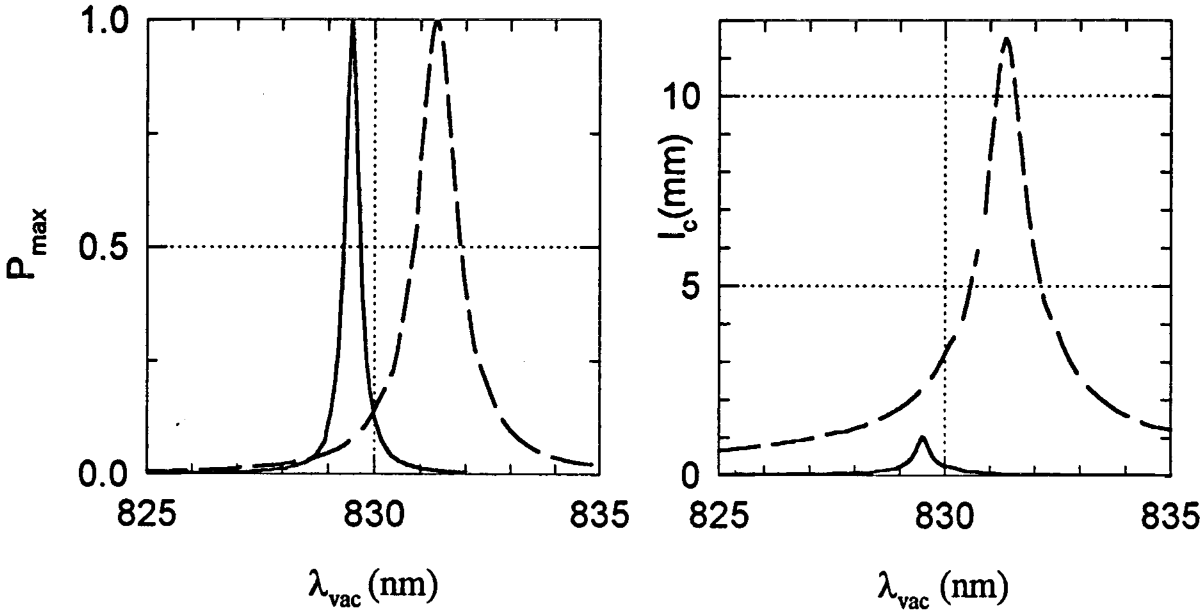


Figure 2i. The maximum coupling achievable as a function of wavelength for PSM (full line, $n_i=1.415$) and multimode waveguide (dashed line, $n_i=1.38$) devices ($h=1\mu m$, $t=2\mu m$, $w=2.2\mu m$).

Figure 2ii. Device length at which the maximum coupling of Figure 2i is achieved

dispersive modes (such as those supported by multimode planar waveguides) are also illustrated.The dispersion relation of the PSM's is easily derived using a translation matrix formalism; the details of this derivation are available elsewhere[1]. PSM's form in the range $\beta > kn_e$ (k is the vacuum wavevector and n_e is the index of the external medium), where the propagation constant β lies within the stop-band of the stack; β may be tuned over the full stop-band width (and beyond, thus suppressing the PSM) by altering the optical thickness of the final layer of the stack, or by varying the index of the external medium. Both TE and TM polarised PSM's can form, often with widely different values of β.

In Figure 2, the wavelength sensitivities of coupling from a single-mode planar waveguide to i) a PSM and ii) a higher order mode of a high index planar waveguide are explored. Both structures (see Figure 1) are designed for phase matching at around 830 nm. The maximum coupling, and the coupling length at which this is achieved, are plotted. Note that The PSM device offers more effective narrow-band operation.

In Figure 3, the mode selectivities of coupling from a dual-mode planar waveguide to i) a PSM and ii) the highest order mode of a high index planar waveguide are explored. Tuning is achieved by varying the index n_i of the intervening region. Note that, for a change of 0.006 in n_i, the rapid modal dispersion of the PSM allows tuning between the 0th and the 1st order mode, whereas in case ii) only the 0th mode can be phase-matched for the same range of n_i. The cross-talk, i.e., the coupling from the unwanted mode when tapping out the desired one, is excellent.

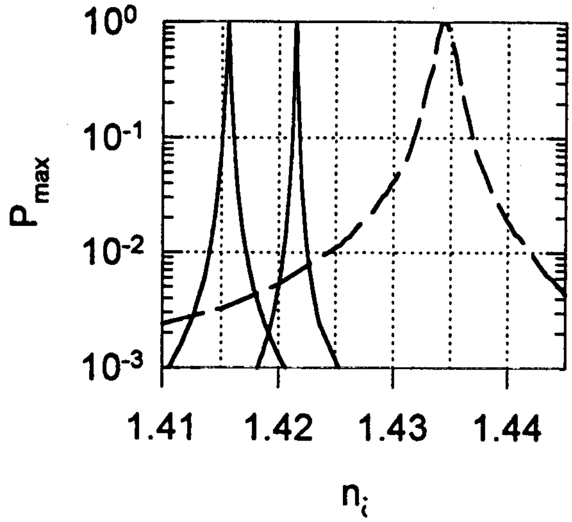


Figure 3. Maximum coupling versus n_i for a dual-mode waveguide coupled to i) a PSM (full lines) and ii) a multi-mode waveguide (dashed lines). The other parameters are λ_{vac}=830nm, h=2μm, t=1μm, w=5μm.

Discussion & Conclusions

A fibre tap, coupling out a small amount of power in a narrow band around a tunable wavelength, while permitting all the rest to propagate through unchanged, would have important applications as a local receiver in wavelength division multiplexing schemes. The analysis presented in this paper shows that FWHM bandwidths of 0.3 nm should be easily achievable at 830 nm in an AlGaAs stack. Similarly, selective *mode* coupling at fixed *wavelength* from multimode fibres would have useful applications in mode-division multiplexing (MDM). Unsuccessful attempts have been made to achieve MDM using long-range surface plasmon-polaritons supported by a thin metal layer deposited on the side of a side-polished fibre[5]. This device suffers from poor modal selection as the mode order decreases, leading to significant cross-talk from higher order modes when the device is phase-matched to the fundamental. In addition, high losses are incurred owing to high absorption in the metal, and only TM polarised light can be coupled out. Although (as in the example in Figure 3) planar dielectric waveguides could be used in place of the metal (reducing insertion loss and permitting TE polarised light to couple out), mode selection requires much larger changes in n_i than in the PSM device.

In summary, the dependence of PSM effective index on both wavelength and external refractive index is much stronger than for long range surface plasmon-polaritons and conventional planar waveguides. This means that PSM's have great potential in MDM and WDM fibre systems.

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