Title: Investigation of a channel-add/drop-filtering device using acceptor-type point defects in a two-dimensional photonic-crystal slab

Author(s): Asano, T; Song, BS; Tanaka, Y; Noda, S

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Type: Journal Article
A channel-drop-filtering device using point and line defects in a two-dimensional photonic-crystal slab is investigated. The efficiency to drop light from a line-defect waveguide to the free space via a point-defect cavity is found to be more than 45%, which is very close to the theoretical maximum of the device. The reverse function of the device (channel-drop-filtering) is also demonstrated, where photons incident on a point defect from free space are resonantly trapped and transferred to a line-defect waveguide nearby. The spectrum and polarization characteristic of the add-filtering completely agree with those of the drop-filtering. The results indicate that two-dimensional photonic slabs are very promising for realizing ultrasmall optical functional devices. © 2003 American Institute of Physics. [DOI: 10.1063/1.1592890]
defect. In precise view, the interference pattern overlaps with the envelopes are different between the add and drop spectra. We considered that it is due to the deference in the light path of the two measurements [see insets of Figs. 2(b) and 2(c)]. To confirm this, we measured the add spectrum by measuring the emission from the right facet [Fig. 2(d)]. It is clearly seen that the add spectrum is identical to the drop spectrum, when the exact reverse light path is utilized.

The add efficiency is investigated by considering the following two factors, (A) internal coupling efficiency between the point defect and waveguide, and (B) external coupling efficiency between the free space and the point defect. The former (A) is the ratio of energy distributed to the waveguide from the point defect, and is estimated to be about 50% (considering the sum of the energies which propagate to both directions). It is because the experimentally obtained drop efficiency of ~50% means that the coupling between the point defect and waveguide is equal to that between the point defect and free space. The latter (B) is determined by the overlap between the electromagnetic field pattern of the incident light beam and that of the light radiated from the point defect because light propagation path is reversible. Since the light beam is incident from only one side of the slab and its solid angle is narrower than the radiation pattern of the defect [see Figs. 3(c) and 3(d)], the external coupling efficiency is estimated to be about ~4%. Therefore, the efficiency of the add operation is considered to be smaller than that of the drop operation at present. The coupling between the point defect and the incident light beam would be improved by employing point defects that can emit light to only one side of the slab with a narrow radiation angle. This argument can also be applied to the drop operation to improve the collection efficiency of the light dropped from the point defect.

We also investigated the polarization characteristics of the add and drop operations in the sample. At first, the polarization-selected images of the dropped light were measured for the polarization (electric field) directions parallel...
Fig. 3(a) and perpendicular [Fig. 3(b)] to the waveguide. A single strong spot and two very weak spots can be seen in Figs. 3(a) and 3(b), respectively, which indicates that the dropped light is almost linearly polarized and that the polarization direction is parallel to the waveguide. We also calculated the radiation pattern from the point defect of the device by using a three-dimensional finite domain time derivative method. Figures 3(c) and 3(d) show the polarization-selected radiation patterns at the observation plane, which is distant from the slab surface by $4a$. The experimental and the theoretical results agree well each other when we consider the fact that the observable radiation angle is restricted by the numerical aperture of the lens (N.A. = 0.4) utilized in the experiments. It may be strange that linearly polarized light is observed for the circularly symmetric defect, but the reduction of the symmetry due to the existence of the waveguide accounts for the appearance of the linear polarization. It is interesting that a line defect distant from a point defect can have considerable effect on the emitted light. Polarization control by changing the shape of the defect itself has been already reported by several groups, including us.\textsuperscript{8,10–12}

For the add operation, we measured the edge emission intensity by changing the polarization direction of the light irradiated to the point defect. The edge emission became maximum (minimum) when the polarization direction was parallel (perpendicular) to the waveguide. The polarization characteristics of the add operation were shown to be identical to those of the drop experiments.

In summary, the channel-drop device with a circular acceptor-type point defect has been precisely investigated. The light dropping efficiency has been shown to be more than 45% by the quantitative experiment. Also, channel-add-filtering operation of the device has been demonstrated experimentally. Polarizations of the light emission from and injection to the circular point defect have been shown to be linearly polarized, contrary to expectation based on the symmetry of the point defect. Although the acceptor-type defect investigated here has relatively small $Q$ factor of $\sim 500$, which is insufficient for the actual applications, it is considered that the $Q$ factor can be increased by tailoring the defect geometry.\textsuperscript{10,13} We believe that the results are very encouraging for the application of the 2D PCs to very compact components aimed for the optical communication systems.

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