Near-Field Characterization of Coupled-Cavity Waveguides on SOI

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Abstract *An adiabatic taper is proposed to couple light from a photonic crystal waveguide to a coupled-cavity waveguide. A Scanning Near-Field Optical Microscopy study is realized on these structures. This study permits to identify and to evaluate accurately the losses in the coupled-cavity waveguide.*

Introduction

Photonic bandgap structures are very promising for the integration of optical functions at the nanoscale level and particularly two-dimensional structures perforated in a slab waveguide. Coupled-cavity waveguides (CCWs) are composed of a series of strongly coupled cavities spaced by one or more holes. Those types of devices can provide interesting new features such as optical delay or dispersion compensators.

In reference 1, a method using an adiabatic photonic crystal (PC) taper was used to couple a light from a single-line defect waveguide (SLWG) to CCW. In this article, we realize a complementary study, using near-field optics microscopy (SNOM) to analyze the losses in the CCW.

Transmission measurements

The studied PC is composed of a triangular lattice of air holes etched in SOI. The lattice period is a = 0.445 µm and the hole radius is R = 0.115 µm. The SOI is composed of a 0.22 µm layer of silicon, stuck on a 1 µm layer of silica. Patterns were fabricated by deep-UV lithography (248 nm) followed by an Inductive Coupled Plasma (ICP) etching [2].

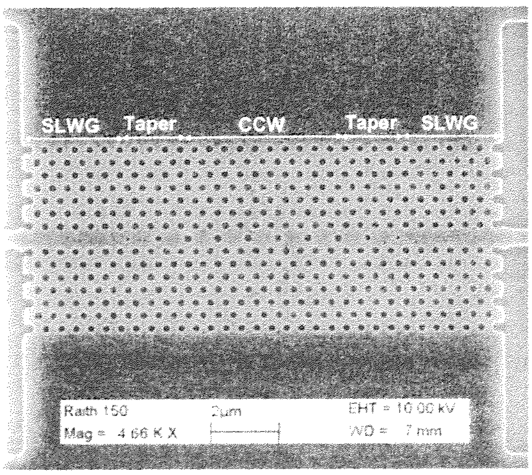

FIG. 1: SEM image of a 9-cavities-long structure with taper

Two types of devices were fabricated: some with a taper facilitating the coupling between SLWG and CCW and the others with no taper. This taper consists in a progressive variation of the radii of the spacing defects between the two first and two last cavities, in order to match the SLWG and the CCW modes. Fig.1 shows the example of a 9-cavities-long structure using input and output taper.

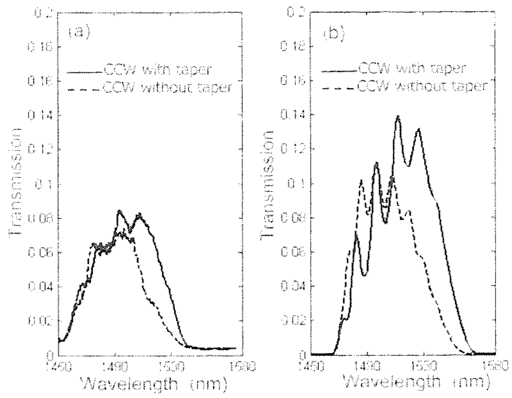

FIG 2: (a) Experimental and (b) 3D FDTD simulated transmission spectra as a function of the wavelength for a 15 cavities-long CCW and a 14-cavities-long taper/CCW/taper structure

Transmission measurements (fig. 2 a) were realized on structures with and without tapers. For wavelengths upper than 1500 nm, the transmitted power increases when the tapers are used. Those results present a quite good agreement with 3D FDTD simulations (fig. 2 b). The matching between experiments and simulations is not perfect due to the existence of sidewall roughness, not taken into account in the calculations.

However, the transmitted power remains low for all the wavelengths, meaning that the losses are rather high. Indeed, the CCW operates above the light cone so the cavities are intrinsically lossy.

Near field study

A SNOM study was realized in order to quantify those losses. The SNOM is a powerful technique which allows a local mapping of the electromagnetic field of a device under working conditions, with an optical resolution less than the wavelength.

Optical images were recorded for different injection wavelengths in the range 1500-1590 nm, on a 14-cavity-long structure with taper. Only the images corresponding to 1537 nm (fig. 3 a) and 1570 nm (fig. 3 b) are presented here.

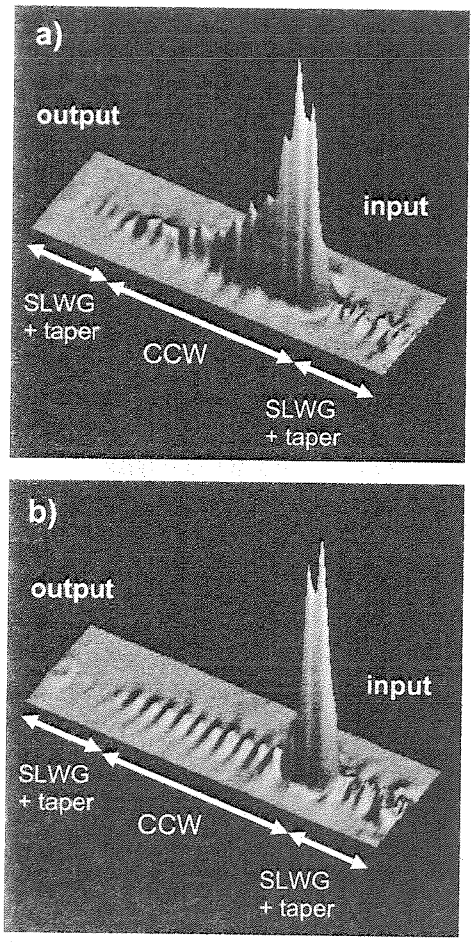

FIG. 3 : 3D view of the optical image of a 14-long CCW with taper recorded at a) 1537 nm and b) 1570 nm – Vertical unity is arbitrary – Image size at the basis : 6 x 19 µm

On these 3D views, the guided light can be clearly seen in the structure. For both cases, a small level of signal is recorded in the SLWGs and in the tapers. In the CCWs, over intensity points appear in the center of each cavity. Those over intensity points highlight the existence of resonant mode in the cavities. Those cavity modes can couple to radiative modes leading to high out-of-plane losses.

However, the evolution of the signal intensity as a function of the distance in the CCW is very different for the two wavelengths. At 1537 nm, the signal follows an exponential decay whereas at 1570 nm, the signal drops abruptly after the first cavities and then, a small propagative wave still remains. This difference shows that the origin of the losses is not the same in the both cases.

To analyze that, we calculated the ratio between the signal intensity in the CCW last cavity and the signal intensity in the CCW first cavity, for various wavelengths (fig. 4). This ratio strongly decreases when the wavelength increases and becomes very low for wavelengths upper than 1540 nm. Regarding the band diagram (not presented here), we notice that an odd mode exists in the CCW for these wavelengths, so the losses come from a bad coupling between this odd mode and the even mode of the SLWG. When we are under 1540 nm, the coupling losses are small because all the modes are even and the evolution of the signal is mainly due to propagation losses. This result confirms the transmission spectra in fig.2 where nearly no signal was transmitted above 1540 nm.

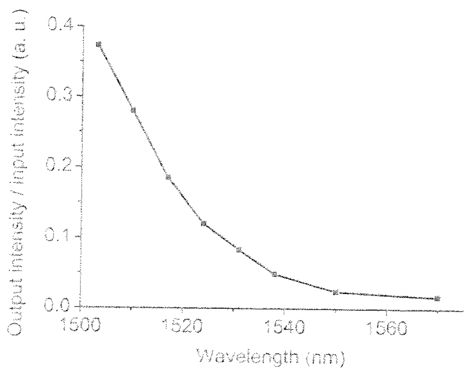

FIG.4: Ratio between the intensity in the last cavity and the intensity in the first cavity in the CCW

Conclusions

An adiabatic taper was developed to couple light from a single-line defect waveguide to a coupled-cavity waveguide. This taper increases the transmitted power of the structure but a SNOM study proved that this improvement is restricted by important out-of-plane losses in the CCW. For wavelengths inferiors to 1540 nm, the losses are mainly propagation losses whereas for wavelengths superiors to 1540 nm, they are mainly coupling losses.

References

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