Nanophotonics and integrated optics
Photonic Crystal Cavities

This whitepaper gives a general overview on different concepts of photonic crystal cavities. Important figures such as the transmission, the mode volume and the quality factor are discussed. The presented information will help the reader to decide which type of photonic crystal cavities will be most suited for the application in view. A design example for a WDM channel filter is given in order to illustrate the design process for a photonic crystal cavity. Furthermore two experimental examples from recent research are shown to demonstrate the wide range of applications in which photonic crystal cavities could be used.

An optical cavity confines light at resonance frequencies and can therefore be regarded as an optical resonator. Optical resonators are characterized by two key parameters reflecting their ability to confine the optical energy temporally and spatially: The former is quantified by the quality factor Q and the latter by the mode volume V. The Q-factor is directly proportional to the decay time, a large value indicating long decay time. The mode volume measures the volume occupied by the optical mode, and a small value represents strong spatial confinement. Resonators are generally frequency selective elements and may serve as spectral analyzers and optical filters. Strong spatial confinement is also beneficial for lasing properties and nonlinear interactions.

Several types of optical cavities have been proposed. In this white paper we will discuss how to form optical cavities by means of photonic crystal lattice defects. This approach results in cavities with very high Q-factors and modal volumes in the order of a cubic wavelength.

Photonic crystals are artificial materials whose dielectric function exhibits spatial periodicity in one, two or three dimensions. In this paper, two dimensional periodic structures with finite extension into the third dimension, so called photonic crystal slabs, will be considered. Two dimensional periodicity can be realized by a regular lattice of air holes in a dielectric slab surrounded by air. Such structures can be produced with conventional two dimensional lithography techniques.

A dielectric slab in air can guide light due to total internal reflection. At constant frequency there is a discrete number of guided field profiles which are called modes. Every mode is described by its field distribution in the cross section orthogonal to propagation direction and by the in-plane wave number along the propagation direction. Modes with an in-plane wave number $k_\parallel > \omega/c$, where c represents the speed of light in vacuum, satisfy the total internal reflection condition and are confined in the slab. This principle is also presented in the figure 1. In this case the in-plane wave number is larger than the available wave number in air and light cannot couple out of the slab. Modes which violate this condition are said to lie inside the light cone ($k_\parallel < \omega/c$ is a cone in

the $\omega(k)$ presentation). A mode inside the light cone is extended in air and the energy can leak into the free space.
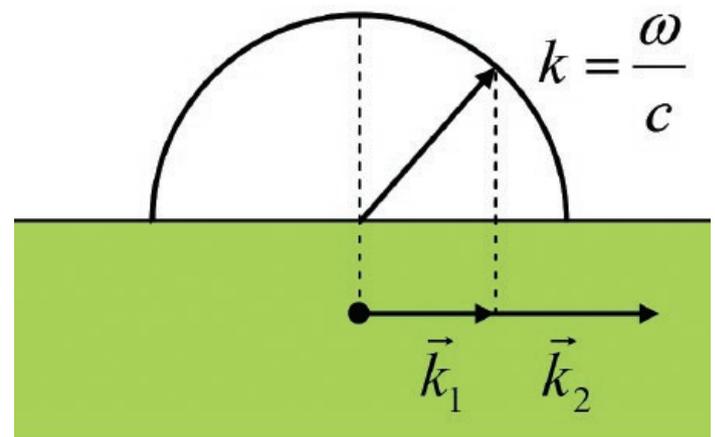
Figure 1 Explanation of the light line concept for light guiding in the slab. A mode with a wave vector length $k_1 < \omega/c$ is not guided and can couple out in the air around the slab. A mode with $k_2 > \omega/c$ is guided and the total internal reflection condition is fulfilled because no corresponding wave vector with the same tangential component exists in air

A periodically patterned slab can block propagation of certain frequencies in all directions. The propagation is prohibited if the periodicity, i.e. the lattice constant, is equal to the half wavelength of guided light at this frequency. The range of frequencies for which propagation is prohibited is called the photonic band gap. Typically a triangular arrangement of holes in the slab is used to obtain an omni-directional band gap.

However, the introduction of defects into the photonic crystal slab by a local distortion of the periodicity leads to the creation of states with frequencies within the band gap. These states form modes which are laterally confined by the surrounding photonic crystal. If the state also meets the requirement to have wave numbers outside of the light cone the defect mode is vertically confined and forms a photonic crystal cavity[1,2].

State of the Art

In the last years, the field of integrated photonic structures in general and silicon photonics in particular has attracted an increasing amount of attention[3,4]. A vast number of present and potential future applications have already been proposed. Some examples are nanolasers, compact optical interconnects or sensors. Since photonic crystal slabs are compatible with standard CMOS processing techniques they are very interesting candidates for implementing electric and photonic functionality on the same chip.

Photonic crystal cavities find applications in electro-optic modulation[5,6], all optical switches[7,8], optical storing[9,10], adiabatic frequency conversion[11] and nonlinear applications[12].

Types of Photonic Crystal Cavities

As mentioned previously, photonic crystal cavities can be used for various purposes. Which photonic crystal cavity is the best choice strongly depends on the application itself. For instance, in order to realize a narrowband filter for wavelength division multiplexing (WDM) applications the quality factor (Q-factor) and the transmission will be the most important criteria, while for laser applications a small mode volume is essential. In order to illustrate how the cavity design can affect these parameters the most common planar photonic crystal cavities will be described. Strengths and weaknesses of the different concepts are listed in table 1.

Point Defect Cavity

The simplest kind of photonic crystal cavity can be formed by introducing a point defect into the perfectly periodic photonic crystal slab. A point defect involves a modification of a single hole inside the crystal. The hole can be changed in size, dielectric properties or even be omitted. Figure 2 shows an example for point defect cavity formed by a single omitted hole.
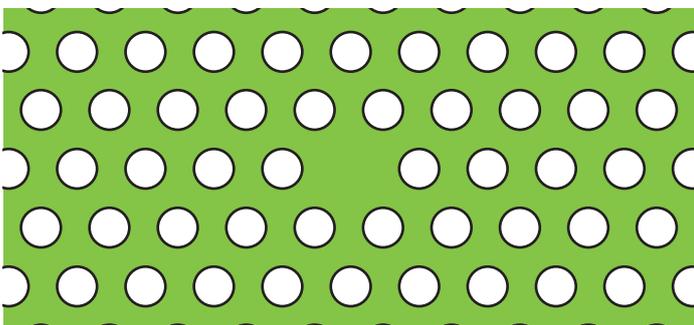
Figure 2 Photonic crystal point defect cavity created by removing a single hole from a photonic crystal slab. Silicon is colored green, air holes are white

As a result of the defect, the translational symmetry of the photonic crystal is broken. For appropriate defect dimensions and position, localized modes can arise which have frequencies inside the photonic band gap. Since for the unperturbed photonic

crystal no propagating modes exist inside the bandgap, energy stored inside a localized mode cannot be transported through the slab. Thus localized modes with frequency inside the bandgap are therefore laterally confined.

Propagating waves exhibit a field profile infinitely extending along the direction of propagation. The spatial distribution of the electric field and its wave vector distribution are linked by the Fourier transform. A propagating mode with an infinite field distribution along one direction leads to precise definition of the wave number. A spatially localized mode, in contrast, has a continuous k-vector spectrum which is proportional to the Fourier transform of the mode's electric field. A part of this continuous k-vector spectrum is necessarily inside the light cone and therefore is not confined by the total internal reflection of the slab anymore. This part of the k-vector spectrum can leave the cavity vertically[13].

Point defect cavities can have very small mode volumes. This property is interesting for integrated lasers where small mode volumes can reduce the pump threshold[14]. On the other hand, a small mode volume implies a strong lateral confinement of the mode and thus wide spectrum of wave vectors. In such a strongly confined structure, a considerable part of the k-vector spectrum is inside the light cone and thus leaky. This is the reason why the Q-factors achieved with point defect cavities are moderate compared to larger cavity concepts.

In most applications this type of cavity is coupled vertically simply by shining light on top. In-line coupling concepts exist but are only rarely used because the coupling waveguide distorts the symmetry of the point defect cavity and thus splits the resonances.

Line Defect Cavity

A line defect cavity can be understood as an extension of a point defect cavity. In this case the defect is extended over several lattice constants in a row. The same concepts as for the point defect cavity apply. The modes supported by a line defect cavity have similarity with standing waves inside a waveguide. The fields decay exponentially at the ends of the line defect. An example for a line defect cavity is given in figure 3.
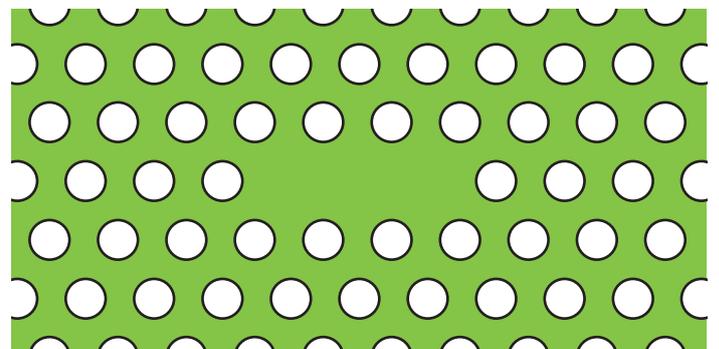
Figure 3 Photonic crystal line defect cavity created by removing several holes from a photonic crystal slab. Silicon is colored green, air holes are white

These cavities have larger mode volumes, therefore higher Q-factors would be expected, but in fact it has been reported that Q factors for this type of cavities are much lower than for point defects. As mentioned before, in order to be confined to the slab the in-plane k-vector has to lie outside of the light cone $\omega < c\,k_\parallel$. Zhang et al. have shown that the modes supported by line defect cavities have higher eigenfrequencies compared to point defect cavities with the same lattice constant[15]. By having a look at the light cone it becomes obvious that the leaky k-vector region increases proportionally to the eigenfrequency of the cavity. The fact that the leaky k-vector region is larger in this type of cavity limits the attainable Q-factor. The line defect cavity can also be modified to increase the Q-factor. The holes at the edges of the line defect can be slightly shifted to change the field distribution in such a way as to reduce the amount of energy in the light cone. A Q factor of 45 000 was demonstrated[13].

Like all photonic crystal cavities, line defects can be coupled vertically but also side coupled concepts have been demonstrated. The transmission spectrum of a side coupled cavity will look flat inside the pass band of the coupling waveguide. Dips will occur at the resonance frequency of the cavity. This type of cavity can be used as a compact WDM channel drop filter i.e. a single channel is filtered out while all the others are transmitted[16].

Double Heterostructure

The highest reported Q-factors have been achieved with so called double heterostructure cavities. A photonic crystal heterostructure consists of two photonic crystal line defect waveguides with different lattice constants. A double heterostructure consists of three line defect waveguides (see figure 4). As depicted in figure 5, a line defect waveguide can be formed by omitting an entire single row inside the bulk photonic crystal. The mode propagating inside the waveguide must have a frequency inside the band gap of the surrounding bulk photonic crystal. This will then yield lateral confinement of the guided mode.
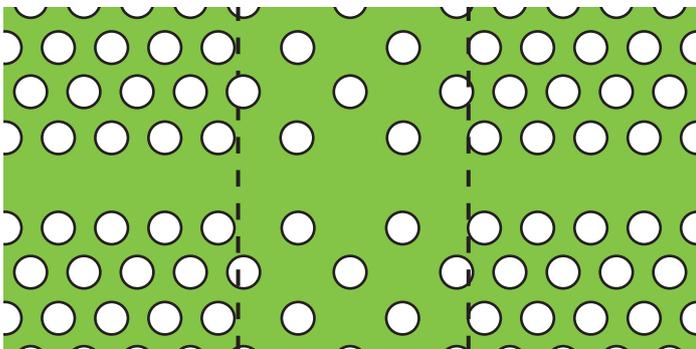

Figure 4   Photonic crystal double heterostructure cavity. Silicon is colored green, air holes are white
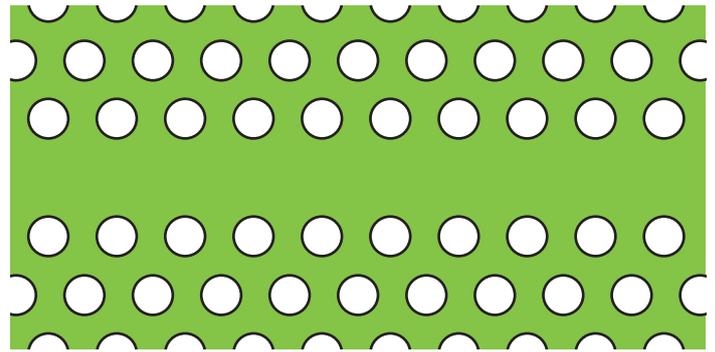

Figure 5   Photonic crystal line defect waveguide obtained by leaving out a row of holes. Silicon is colored green, air holes are white

By increasing the lattice constant of the bulk photonic crystal, the mode's cut-off frequency in the line defect waveguide can be shifted to lower frequencies. Figure 6 shows the band diagram of the line defect waveguide of figure 5 for two different lattice constants. It can be seen that a frequency interval exists in which the light can only propagate in the waveguide with larger lattice constant. This frequency interval is called the mode gap and is shown in the figure 6.
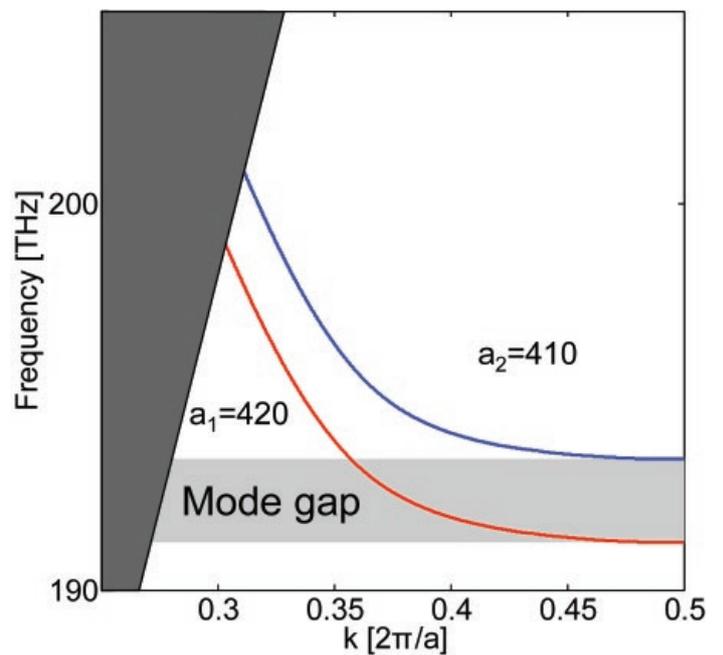

Figure 6   Band diagram of a line defect waveguide in a photonic crystal slab with a triangular lattice of holes. Blue and red curves correspond to modes of two waveguides with different longitudinal lattice constants. The light gray shade indicates the mode gap in which the mode can only propagate in the waveguide associated to the red curve. The dark gray shade shows the light cone

Since for frequencies inside the mode gap no mode propagation is permitted, waveguide sections with lower lattice constants act as reflectors for this frequency range. A cavity can be formed by a high lattice constant photonic crystal waveguide together with

low lattice constant waveguides at each side. The difference between the lattice constants should be kept as small as possible. This will minimize the out of plane scattering and increase the intrinsic Q-factor of the cavity.

As mentioned before, this type of cavity features highest Q-factors while still maintaining relatively small mode volumes. Q-factors as high as $2,5 \times 10^6$ have been experimentally demonstrated while the mode volume is in the order of one cubic wavelength inside the slab material[17]. Since double heterostructure cavities are comprised of photonic crystal waveguide sections, they can be coupled in transmission similarly to a Fabry-Perot resonator. In contrast to side coupled cavities, these transmission coupled cavities feature a sharp peak at resonance embedded inside a frequency interval with close to zero transmission. This type of cavity can possibly be used as an integrated WDM channel select filter or as a compact electro-optic modulator.

General Considerations about Losses

It has been mentioned before that photonic crystal cavities can generally be created by modifying one or several holes[13,18]. Due to the finite in-plane mode size, the cavity mode necessarily contains energy inside the light cone which can vertically leak out of the cavity. If the lateral dimensions of the surrounding photonic crystal slab are also finite, the defect mode can leak out in the lateral direction as well. Each of these decay mechanisms can be described by a Q-factor. Since the energy loss is inversely proportional to the Q-factor, the total Q-factor of the cavity is given by

$$\frac{1}{Q_{total}} = \frac{1}{Q_{vertical}} + \frac{1}{Q_{horizontal}} \quad . \quad (1)$$

While the horizontal Q-factor can be directly influenced by the size of the surrounding photonic crystal bulk, the optimization of the vertical Q-factor is less trivial. Several approaches have been proposed. The simplest one is the delocalization of the mode. The energy inside the leaky k-vector components is in this case reduced by expanding the cavity mode volume. For example, the delocalization can be achieved in longer line defect cavities or by the reduction of the perturbation at the defect[19], i.e. the decrease of the lattice constant mismatch for the heterostructure cavity. Larger spatial distribution leads to smaller wave vector spectrum and thus less wave vector components in the light cone. However, a greater mode volume is not desirable with respect to device miniaturization or in nonlinear applications involving high optical field strengths[8].

Another way to minimize the k-vector components inside the light cone is to tailor the symmetry of the Fourier transform of the cavity mode. A proper selection of the exact field distribution and of the defect size can lead to the creation of defect modes with odd symmetry with respect to planes normal to the directions of the dominant contributions in Fourier space[20]. Such components cancel out in the far field and do not radiate into the free space.

Cavity type\ Property	Quality factor (Theoretical)	Mode volume	Coupling
Point defect	$1 \cdot 10^6$	$0.7(\frac{\lambda}{n_{core}})^3$	Vertical
Line defect	$0.054 \cdot 10^6$	$1.2(\frac{\lambda}{n_{core}})^3$	Vertical, side coupled
Hetero-structure	$> 20 \cdot 10^6$	$1.2(\frac{\lambda}{n_{core}})^3$	Vertical, in transmission

Table 1: This table summarizes the most important figures for the presented cavity concepts. The values in the table are simulated results given for symmetric silicon slabs with triangular PhC arrangement of holes

Apart from the symmetry of the Fourier transform, the shape of the cavity mode's envelope function can be modified. Field envelopes with abrupt changes will produce a broad intensity distribution in k space. These contributions can be suppressed by providing a more Gaussian-like field envelope, which can be achieved by proper modification of the structure around the cavity[21].

As has been addressed before point defect, line defect and double heterostructure cavities differ substantially in Q-factor and mode volume. Table 1 gives the reader an overview on the important properties of different cavity concepts.

General Considerations about Coupling

In experimental situations it is often desirable to couple light into and out of the cavity via a conventional strip waveguide that has been fabricated on the same substrate as the cavity. By coupling the cavity to a waveguide, an additional loss mechanism is introduced which decreases the horizontal Q-factor. The vertical Q-factor is related to the horizontal Q-factor and to the maximal transmission T_{max} through the relation[22]:

$$T_{\max} = \left(\frac{Q_{total}}{Q_{horizontal}}\right)^2 = \left(\frac{Q_{vertical}}{Q_{vertical} + Q_{horizontal}}\right)^2 \quad . \quad (2)$$

From the preceding equation it becomes clear that a high transmission through the cavity is only possible if the horizontal Q-factor is much smaller than the vertical Q-factor. In other words, the leakage through coupling should be much larger than the leakage through vertical radiation in order to achieve transmission close to unity.

Design Example: Photonic Crystal Heterostructure

This example will illustrate the design process for a photonic crystal cavity. The task is to design a photonic crystal double heterostructure cavity which acts as a channel filter for WDM channels. The filter should have a 0.2 nm full width half maximum

bandwidth $\Delta\lambda$ at a centre wavelength λ_0 of 1550 nm. The equivalent Q-factor for this filter is given by $Q = \lambda_0 / \Delta\lambda$ = 7750. As substrate we assume a silicon on insulator (SOI) wafer with 220 nm silicon and 2 μm SiO₂ substrate. A triangular grid of air holes will be used for the bulk photonic crystal and the radius of the air holes is chosen to be *0.3a* with *a* the lateral lattice constant.

BAND DIAGRAM OPTIMIZATION OF A PHOTONIC CRYSTAL WAVEGUIDE

The first design step involves the optimization of the photonic crystal line defect waveguide. The waveguide should be designed such that the mode cutoff lies approximately in the center of the band gap. In the second step the lattice constant has to be adjusted such that the frequency at mode cut-off matches the desired resonance frequency.
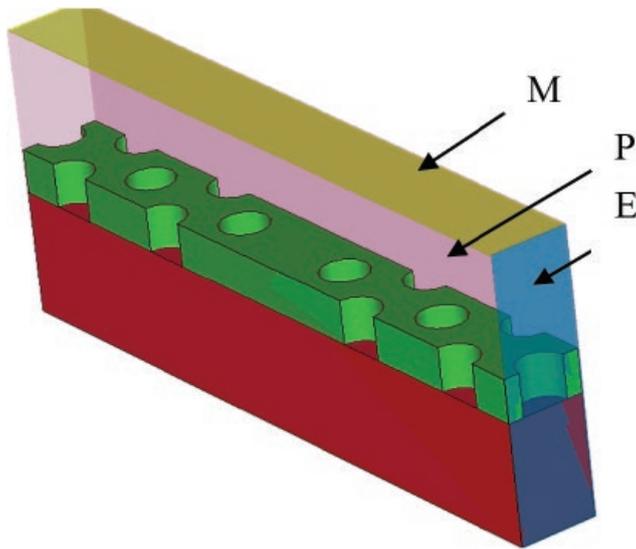

Figure 7 CST STUDIO SUITE® model of a single lattice cell with periodic boundary conditions (P) in propagation direction, electric boundary conditions (E) in lateral direction and magnetic boundary conditions (M) in vertical direction

In order to determine the band structure of the photonic crystal waveguide the eigenmodes of a single lattice cell are computed. The model of a single lattice cell is depicted in figure 7. The band structure can be obtained by calculating the eigenmodes for a single unit cell of the waveguide with periodic boundary conditions. These boundary conditions are applied in propagation direction to meet the symmetry conditions of the expected modes. The phase φ between the two periodic boundaries is related to the length of the k-vector in propagation direction of the mode by

$$k_x = \frac{d\varphi}{dx} = \frac{\varphi}{a}, \quad (3)$$

with *a* the lattice constant. Thus by changing the phase difference between the two periodic boundaries from 0 to π, all k_x smaller than $\frac{\pi}{a}$ are determined. The dispersion diagram of the line defect modes is obtained by plotting the calculated eigenfrequencies as a function of k_x.

Since the length of the simulation model in propagation direction is always one lattice constant it is useful to normalize the k-vector to $\frac{a}{2\pi}$. With this normalization the cutoff of the defect mode will always be at k_x=0.5, where the Bragg reflection condition is met for the waveguide.

For optimizing the structure, we first seek a defect configuration which ensures transmission close to the center of the band gap. The width of the line defect waveguide can be varied to satisfy this requirement. In a second stage, the lattice constant *a* is varied to match the required frequency. Figure 8 shows the band diagram of the optimized line defect waveguide. The band diagram was calculated with the eigenmode solver of CST MICROWAVE STUDIO®. It has been found that a defect width 1.05*a* and a lattice constant of 410 nm yield a waveguide transmitting close to the centre of the band gap with a cut-off at 1556 nm.
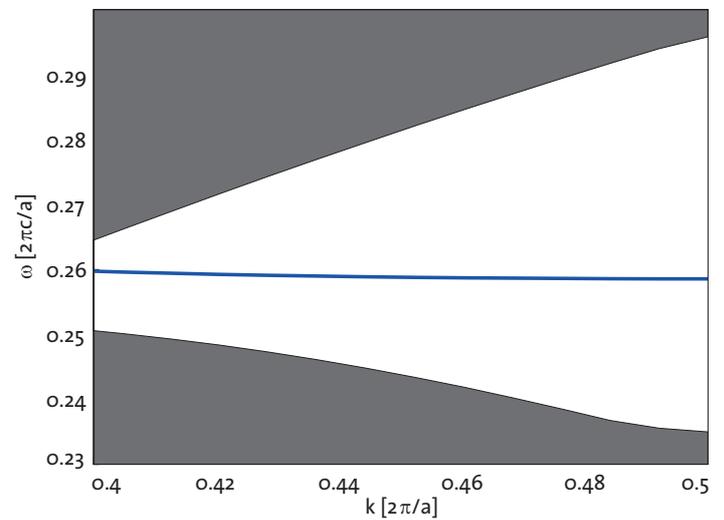

Figure 8 Band diagram of a waveguide with optimized parameter set. The blue line indicates the defect mode. The gray shades show the edges of the photonic band gap region

SIMULATION OF THE UNCOUPLED CAVITY

The next step in designing the cavity is to calculate the intrinsic Q-factor. The vertical Q factor is computed in a full 3D time domain simulation. In this example the FIT solver from CST MICROWAVE STUDIO® is used. A cavity region is modeled with the previously calculated lattice constant and a length of N lattice constants. It is assumed that the available fabrication process allows lattice constant changes of 10 nm, which corresponds to a minimum lattice mismatch of 2.3%. The mirrors will therefore have a lattice constant of 400 nm. The number of holes in all directions should be large enough in order to effectively suppress in plane leakage. The number of necessary lattice constants depends on the bulk crystal properties. In order to determine the necessary mirror length and number of lateral lattice constants the model can be expanded stepwise. If the Q-factor of the cavity does not change significantly anymore the model size is appropriate. In this example we choose a mirror length of 15 lattice constants and a

lateral photonic crystal of 8 lattice constants which have been found sufficient for intrinsic Q-factors below 50 000.

Perfectly matched layers at the boundaries of the simulation volume make sure that energy radiated from the cavity leaves the simulation volume without causing reflections. A small ideal current source (dipole) is used as excitation source because it does not affect the field after the excitation has finished. In order to couple energy into the cavity, the electric and magnetic fields of the resonant mode must be non-zero at the point of excitation. The nodes of the resonant mode follow the periodicity of the surrounding photonic crystal lattice. Exciting away from a node can therefore be ensured by placing the source slightly off-centered inside the cavity. Once the simulation is started, the source will fill up the cavity with energy. After the excitation has finished, the energy will start leaking out of the cavity and leave the simulation volume. The leakage rate is constant if there is one single resonance inside the simulation bandwidth. The Q-factor can therefore be calculated from the leakage rate by

$$Q = \omega \frac{W}{P} \qquad (4)$$

with ω the resonance frequency, W the stored energy inside the cavity and P the power loss per time unit. Figure 9 shows a typical time dependent leakage behavior. From the slope of the energy decay in logarithmic scale the Q-factor can be calculated.
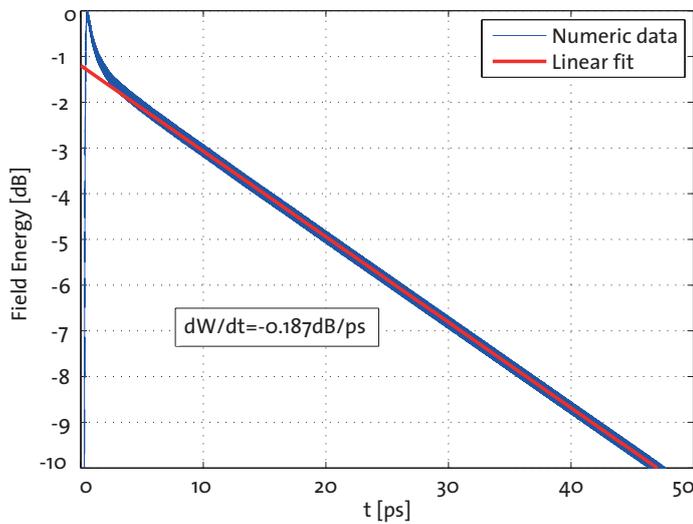

Figure 9 Energy stored inside the cavity as a function of time. A constant slope in the dB-plot indicates a constant leakage rate.

For the given application a high transmission through the device is essential. According to equation (2) the transmission is given by the ratio of total and horizontal Q-factor. In order to achieve high transmission at resonance, the vertical Q-factor should be significantly higher than the horizontal Q-factor. A good rule of thumb is to choose the vertical Q-factor at least 3 times larger than the horizontal Q-factor.

If one of the two Q factors is significantly lower than the other, it follows from equation (1) that the total Q will be dominated by the lower one, while the influence of the higher Q factor becomes negligible. The total Q factor is therefore expected to be close to the horizontal Q for a large vertical Q. At this step we choose a vertical Q-factor of 25000 as a target value, which is slightly larger than three times the desired total Q-factor of 7750. By varying the cavity length N*a* we find that a cavity with a length of 2 lattice constants already shows a vertical Q-factor of 27450 which is sufficient for the desired application.

SIMULATION OF THE COUPLED CAVITY

Since the designed cavity is supposed to work in transmission, it is necessary to couple the cavity to a waveguide. For the coupled cavity the same model as before can be used as a starting point. Since defining a waveguide excitation inside a photonic crystal waveguide is not trivial, it is easier to attach a strip waveguide to the photonic crystal waveguide and excite the strip. Figure 10 shows the model of the coupled cavity.
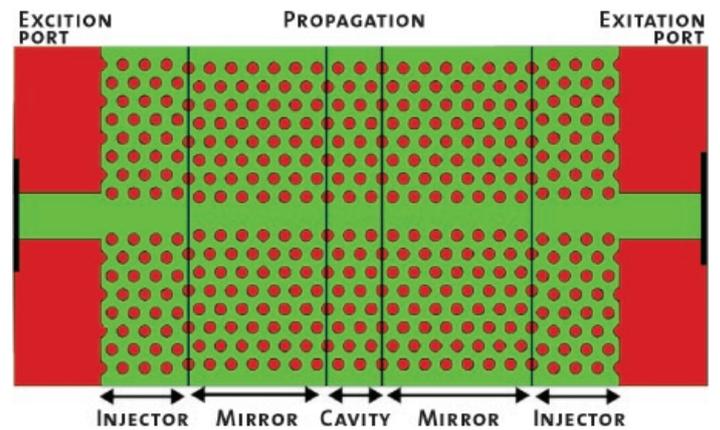

Figure 10 Schematic model of the coupled cavity. Propagation direction as well as input and output ports are indicated

In the numerical model a waveguide source is used. This waveguide source automatically computes the modes in the waveguide's cross section. The strip waveguide can directly be excited with the desired field profile of the waveguide mode which prevents reflections. The strip waveguide is coupled first in the photonic crystal waveguide section with a larger waveguide width, which is called injector. Otherwise strong scattering from the photonic crystal reflector is observed. Like in the previous section, the Q-factor can be calculated from the energy decay inside the simulation volume. In addition, the transmission shows the position of the resonance and the insertion loss of the cavity. Time domain simulations also offer the possibility to calculate field profiles of the cavity mode. These can be used to determine the mode volume if necessary. Figure 11 shows the field profile of a resonant mode as an example. If the field presentation scaled such as to visualize small field amplitudes, the direction of the light scattered out of the cavity can be observed. In our case scattering in the substrate is dominant due to vertical asymmetry of the structure.
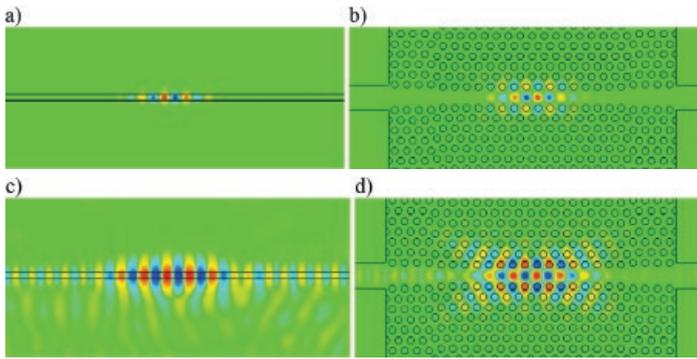
Figure 11 Vertical component of the magnetic field of the resonant cavity mode. Plots a) and c) show the vertical magnetic field component along the direction of propagation in linear and logarithmic scale respectively. Out of plane loss into the silica substrate can be seen in the logarithmic plot. Plots b) and d) display the mode profile in the slab plane in linear and logarithmic scale respectively

To adjust the Q-factor, the mirror length is reduced stepwise until the desired Q-factor value of 7750 is reached. In this example the result closest to the desired Q-factor is 9720, which corresponds to a mirror length of 7 lattice constants on each side.

EXPERIMENTAL EXAMPLES
AIR BRIDGE CAVITY FOR NONLINEAR APPLICATIONS

Figure 12 shows a scanning electron microscopy (SEM) picture of a photonic crystal heterostructure cavity for nonlinear optical applications. Like in the previous example this cavity has been integrated on a standard SOI wafer. The oxide below the photonic crystal slab has been removed with a hydrofluoric acid-wet etch step to create a vertically symmetric structure. The Q-factor was designed to be around 100,000.
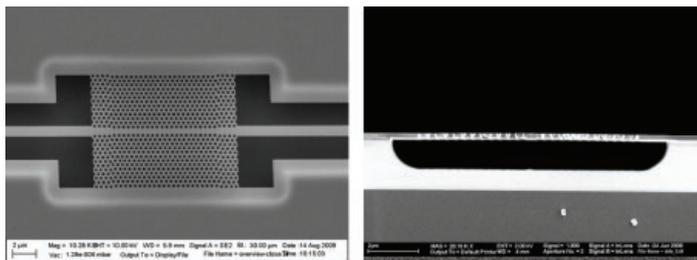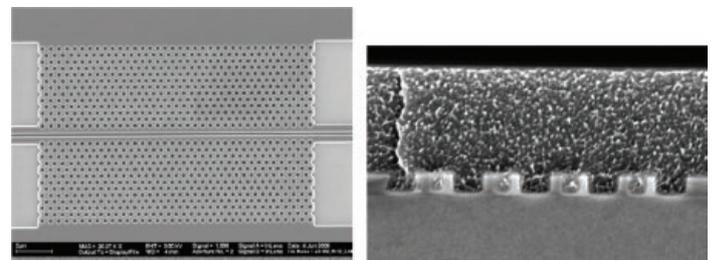

Figure 12 Scanning electron microscope picture of under etched photonic crystal heterostructure: top view (left) and side view (right). The five lattice constants at input and output represent injection sections not discussed in this paper. The section with a slightly different lattice constant in the middle of the waveguide cannot be recognized with this resolution

At such high Q-factors the intensity enhancement inside the cavity is so strong that even with moderate laser powers nonlinear effects can be observed. The properties of the cavity can be changed by the light itself due to two photon absorption, Kerr effect and free carrier plasma dispersion.

SLOTTED HETEROSTRUCTURE CAVITY FOR EO-MODULATION

Another interesting application of photonic crystal cavities involves the combination of high-Q silicon photonic crystal resonators and nonlinear electro-optic polymer. Electro-optic polymers have the property to change their refractive index proportionally to an external electric field. This effect is called Pockel's effect.

Introducing a slot into the photonic crystal cavity yields an intensity enhancement of the optical electric field components inside the slot. The slot can be filled with nonlinear electro-optic polymer. A polymer infiltrated photonic crystal is shown in the SEM picture in figure 13. By applying a static electric field to the slot it is possible to shift the refractive index of the polymer inside the slot and thus the effective cavity length. As a result, the transmission peak of the cavity is shifted.

Figure 13 Scanning electron microscope picture of a slotted photonic crystal heterostructure cavity: top view (left); view of the cleaved sample from the side demonstrates polymer infiltration of the holes (right)

Wülbern et al. [5,6] have shown that this concept can be used to produce electro-optic modulation. The RF bandwidth of the fabricated structure is estimated to be 100 GHz at less than 1 V driving voltage. At the same time this sort of device requires only a very small area, which makes it suitable for chip to chip or even intrachip communication.

SUMMARY

This paper provides a very general overview of the field of planar photonic crystal cavities. The reader has been introduced to the most frequently used terms in the field, as well as to the most important equations describing the properties of a photonic crystal cavity.

A short summary of the most frequently used types of photonic crystal cavities is given and their strengths and weaknesses are listed. A hands-on example illustrates how the design approach to a specific given project may look like.

Finally, two application examples are described. These examples show that the discussed structures can be applied in various fields and offer interesting possibilities for both scientific and application based problems.

GLOSSARY

Band diagram: The band diagram displays the frequency of a mode as a function of the wave vector.

Bragg condition: In a periodic stack of high and low refractive index materials the Bragg condition is met when reflected waves from each interface interfere constructively.

Coupling: (Vertical, in transmission, from the side): in a lossless system energy between a cavity and the outside world can only be exchanged by means of coupling. Available coupling schemes are vertical coupling, side coupling and transmission coupling.

Dielectric mirror: An arrangement of typically periodic alternating high and low refractive index regions which reflects almost 100% of light at certain frequencies. For comparison, metal mirrors have intrinsic absorption losses of several percent.

Fabry Perot resonator: A cavity formed by a dielectric slab placed between two reflecting surfaces.

Free carrier plasma dispersion effect: Refractive index change due to injection of free carriers. Free carriers in a semiconductor can be modeled as plasma.

Full width half maximum (FWHM): The frequency difference between the two points of the spectrum where the transmission of the cavity drops to half of the maximum transmission.

Heterostructure: A junction of two different photonic crystal lattices, typically with different lattice constants.

Kerr effect: Nonlinear refractive index change due to high power optic fields.

K-vector: Wave vector.

Lattice constant: Periodicity of the photonic crystal unit cell.

Light cone: The light cone comprises all frequency and wave vector tuples that violate the total internal reflection criterion, i.e. satisfy $\omega > ck_{\parallel}$. c and $k_{\parallel}$ represent the speed of light in vacuum and the wavenumber in the plane of the slab (the in-plane wave number), respectively.

Mode gap: A mode gap is created when two photonic crystal line defect waveguides with different lattice constants are adjoined. The mode gap is referred to as the frequency range where only one of the two defect waveguides exhibits a guided mode.

Mode volume, effective mode volume: In cavities with metal mirrors such as hollow waveguide resonators the mode volume can be defined by the physical dimensions of the resonator. In dielectric cavities the fields decay exponentially as they penetrate the mirror. In such cases it is more appropriate to define an effective volume. A very common definition for the effective mode volume is the volume within which the field amplitude is larger than 1/e of the field maximum.

Nodes of resonant mode: Cavity modes are standing waves. Nodes can be found where the amplitude of the optic field is zero.

Two photon absorption: Nonlinear absorption process where two photons are absorbed at the same time.

Quality-factor or Q-factor: The Q-factor is defined as $Q = \omega \dfrac{W}{P}$ with ω the center wavelength of the cavity, W the energy stored in the cavity and P the energy loss per a period of one light oscillation. An alternative derivation for the Q-factor is the center frequency of the cavity divided by the full width half maximum bandwidth. A large Q-factor value indicates a long decay time of the energy stored in a resonator.

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Author
Stefan Prorok, *Technische Universität Hamburg-Harburg*

CST AG
Bad Nauheimer Str. 19
64289 Darmstadt
Germany

info@cst.com
http://www.cst.com

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