Leaky modes of 2D photonic crystals evaluated by angular reflection azimuthal spectra

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Sub-wavelength structures represented by photonic crystals are of great interest today. In a photonic planar structure there are guided modes and there is also an effect of leaky modes, which can be detected experimentally in reflectivity spectra. We propose azimuthal spectra measuring at single wavelength instead of the angle resolved reflection spectra evaluation to identify the peaks.

1 Introduction

Nowadays, an attention is paid to sub-wavelength photonic structures – photonic crystals (PhC), which can modify light propagation through them [1]. Like electrons in crystals, PhCs exhibit band structure effects for guided modes and in addition also external coupling. Energy transfer to the leaky modes occurs when in-plane component of the „background“ light wavevector equals the leaky mode wavevector. It can be manifested by the appearance of sharp resonances in external reflectivity spectra, as it was shown experimentally [2]. These resonances can be used to sample the bandstructure of leaky modes in the PhC.

2 Experiment

In the presence of periodical structure in the photonic crystal light can be guided at such a planar waveguide at defined guided modes. When the diffraction condition related to the wavelength, lattice constant and mode propagation angle is satisfied, the guided mode can radiate out from the structure and such radiate mode is called leaky mode. On the other hand these modes can couple with external radiation being quasi-guided modes which gives rise to resonant features in reflectivity spectra. To determine the positions of these leaky modes the reflectance spectroscopy can be used with white light illumination [2].

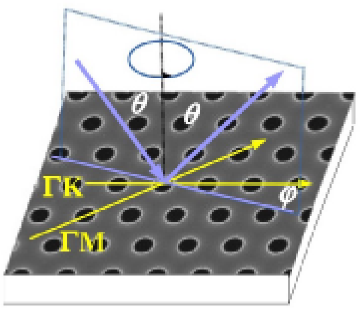

Fig. 1 *Reflectance spectrometry measurement of the angle resolved reflectivity spectra.*

The structure used consists of 1080 nm thick Al_2O_3 layer ($n = 1.72$ at $\lambda = 633$ nm) grown on silicon substrate ($n = 3.84$). The layer is patterned with periodic honeycomb lattice of deep holes (lattice parameter p = 300 nm, hole diameter d = 80 nm).

Surface reflectivity spectra along both the photonic crystal symmetry directions (ΓM, ΓK) were recorded, varying the angle of incidence θ in 1 degree (Fig. 1).

By such an angle resolved reflectance spectroscopy a set of spectra in visible region was obtained. For 2D structures we are concerned about surface layers or slabs with thickness from submicron to micron values, so the reflectivity spectra are strongly modulated by Fabry-Perot (FP) interference fringes.

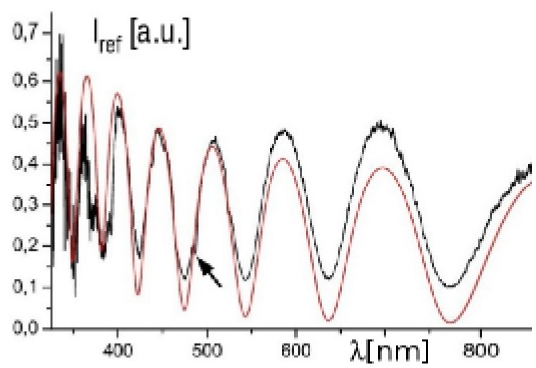

Fig. 2 *Both the measured and fitted course of the FP fringes in Al_2O_3 PhC planar waveguide ($\theta = 30°$, ΓK, TE).*

In fact, the spectral features are formed by mutual folding of FP interference and excited resonant states of the photonic crystal. In experiment, such an effect can decrease fairly reliability of resonant peaks identification namely for 2D structure made of nanorods cylinders where most of the interface area - a dielectric-ambient area is the air.

As seen in Fig. 2 visibility of the resonant peaks in separate spectra is low and the identification of the leaky modes positions is troublesome. Mapping of

DGaO Proceedings 2015 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2015-B015-3

submitted: 29.Jun.2015 published: 21.Aug.2015

the spectral data vs angle of light incidence, provides better view on the trends of leaky modes (Fig. 3).

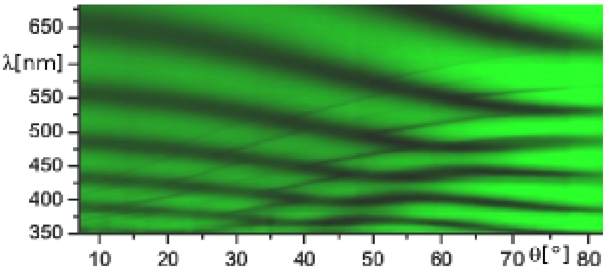

Fig. 3 *Traces of leaky modes structure visualized by mapping of the set of angle-resolved spectra for various angles of incidence (ΓM direction, TE polarization).*

Nevertheless, some of the applications of 2D PhC structures need the evaluation of guided resonances also for directions out of the main symmetry directions ΓM, ΓK. As it is expected, for hexagonal structure the variations with periodicity of 60° can be supposed.

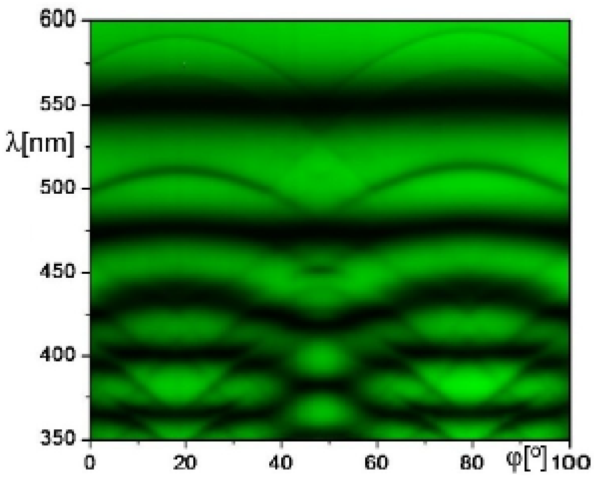

Fig. 4 *Mapping of the azimuthal spectra obtained by spectroscopic reflectometry (θ =60°, TE polarization).*

Up to now, little work has been done regarding azimuthal angle (φ) development of energy transfer to the PhC leaky modes out of the main symmetry directons. The azimuthal dependence of the radiative modes spectra is e.g. key factor for assessment of emission pattern when a physical phenomenon of light extraction from inside of planar waveguide is studied [3]. Another promising result of the angle-resolved specular azimuthal reflectance technique is the possibility to enhance the experimental leaky modes identification reliability.

To obtain more complex information we proposed measurement of such azimuthal spectra. In the optical setup of white light reflectance spectrometry, the sample of PhC was rotated in 1-degree steps, whereby complete set of spectra for two azimuthal angles sectors of 60° at defined angle of incidence was recorded as Fig. 4 illustrates. The traces of radiative modes are clearly identified.

Moreover, using a laser source of monochromatic light (450 nm) azimuthal angle dependence of the specular reflected intensity has been recorded by oscilloscope while the PhC sample rotated dynamically around the axis perpendicular to its surface. Different dependences were obtained for various angles of incidence. To illustrate them, some chosen records are shown in Fig. 5.

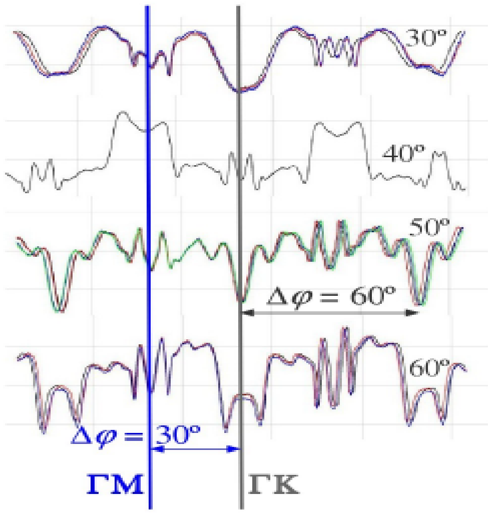

Fig. 5 *Some records to illustrate the photo-electronic reading of reflected azimuthal spectra.*

There are two parts of the records that change strongly with the angle of incidence, which represents the in-plane component of incident light wavevector. Each of them repeats in 60° as supposed by taking into account the hexagonal structure of the PhC.

3 Conclusion

Mapping of the azimuthal spectra resulting from mutual folding of FP interference and excited resonant states of PhC slab, obtained by spectroscopic reflectometry, was performed the first time. The photo-electronic reading of the reflected azimuthal spectra at $\lambda = 450$ nm was realized and proved considerably better resolving power than the standard angle resolved spectroscopy.

References

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