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Linear optical properties and photonic mode dispersion in GaAs/AlGaAs photonic crystal slabs

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Abstract

GaAs/AlGaAs photonic crystal waveguides with unconventional tilted-square lattices and different filling factors are fully investigated by means of variable angle reflectance spectroscopy, which yields the photonic band dispersion, and theoretical calculation of both reflectance spectra and photonic band structure.
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In the last few years there has been considerable interest in two-dimensional (2D) photonic crystal waveguides, also known as photonic crystal slabs, as they can be used to control the propagation of light in the visible and near-infrared spectral range [1]. Recently, it was shown [2] that a complete 2D photonic gap can be achieved in a square lattice of rotated square rods in a range of filling factors near to the close-packing condition. In this work, we present the experimental and theoretical investigation of 2D tilted-square lattice photonic crystals patterned in a GaAs/AlGaAs waveguide.

The waveguide, grown in a horizontal LP-MOCVD system, was characterized by near-normal incidence reflectance and spectroscopic ellipsometry: as a result the values of 576 nm for the GaAs core and of 1.63 μm for the $Al_{0.25}Ga_{0.75}As$ cladding thicknesses were obtained. The waveguide was patterned using X-ray lithography with a gold mask previously prepared by electron-beam lithography, obtaining samples with the same lattice (tilted-square, lattice constant $a = 500$ nm), but different basis. In order to keep the guiding properties of the structure, both the core and part of the cladding were etched.

Here we present the spectroscopic characterization of two samples: RUN3, whose basis is a dielectric pillar (side $0.51a$, filling factor $f = 0.26$) and L2, whose more complicated basis is a square air ring in dielectric (internal side $0.32a$, external side $047a$, filling factor $f = 0.88$).

The photonic band structure was derived analyzing the variable angle-reflectance spectra of the samples, a method firstly developed by Astratov and coworkers [3]. The spectra were taken in the 0.5–1.5 eV region

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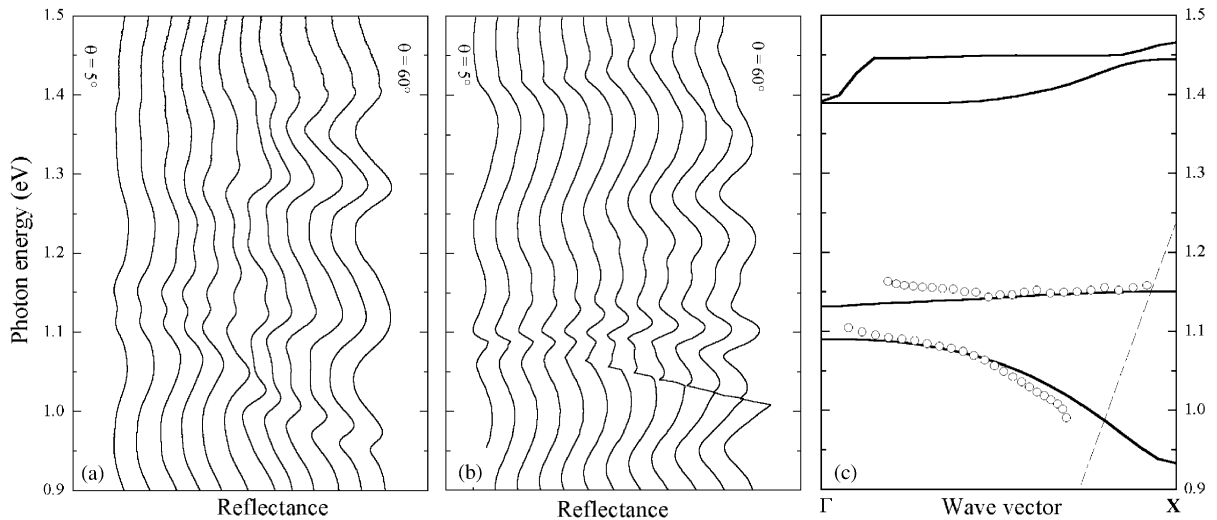*E-mail address:* patrini@fisicavolta.unipv.it (M. Patrini).

Fig. 1. TE reflectance spectra along *G–M* direction for sample RUN3: (a) experimental, (b) calculated, and (c) photonic bands of sample L2: calculated (solid line) and determined from the experimental reflectance spectra (dots). Dashed line: dispersion of light in GaAs.

using a Fourier transform spectrophotometer and the angle of incidence was varied from 5° to 60° with step 5° and accuracy of ±1°. Reflectance measurements were performed along the Γ–X and the Γ–M lattice directions using a silver mirror as a reference [4].

The spectra (Fig. 1(a)) show several sharp features superimposed on a multiple interference pattern: a large period interference due to the core layer and a short period one due to the core plus the cladding. We interpreted the narrow peaks as due to the coupling of the incident radiation to the quasi-guided (leaky) modes of the patterned waveguide. Given the angle of incidence (and thus the parallel wave vector of the impinging beam) and the position in energy of these features, one can obtain the photonic band structure of the sample.

In Fig. 1(b) and (c) the reflectance spectra of RUN3 sample simulated using a scattering matrix method and the corresponding band structure, as calculated solving the Maxwell equations of the system on a finite basis of plane waves [5], are shown. There is an overall good agreement between calculated (lines) and experimental (dots) results.

In particular, sample L2 shows very sharp features and its band structure is quite similar to the one expected for the unpatterned waveguide: this behavior is fully consistent with its high dielectric fraction. The width of the peaks can be related to the radiative and dissipative losses of the modes of the waveguide, in this respect L2 sample reveals better guiding properties. RUN3 sample has instead a low dielectric fraction, and thus broader features and a greater warping of the photonic bands, leading to the opening of a pseudogap above 1.1 eV.

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