Nanophotonics course examination, December 10th 2013

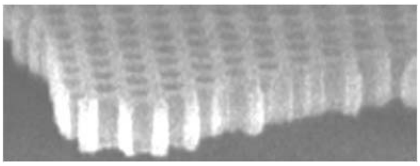
Part of H. Benisty (periodic structures and photonic crystals)

Duration 1h30. All documents allowed.

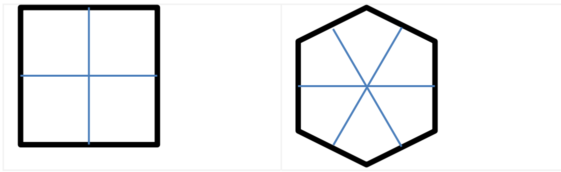
There are 5 to 6 questions on each paper:

→I would strongly advise that after 35 nm on the first paper, you try to see the other ones.

Article APL Vico-Triviño 2012



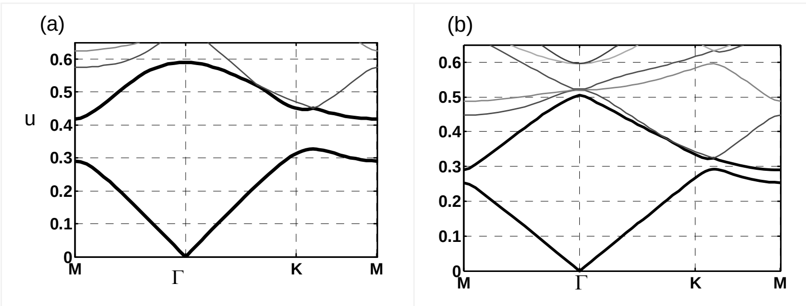
A1) [2D photonic band gap]



a) What is the shape of the first Brillouin zone for this lattice among these two proposed ones?

b) Why was the chosen lattice preferred to the other one in the context of in-plane light confinement?

A2) Here are two typical band structures calculated in 2D, for an array of holes in a fictive material of index **n=2.3,** for two different hole sizes.



a) What is the abscissa ? (base your answer on question 1)

b) What is the ordinate "u" in general?

c) What is its value if we consider photons 2.7 eV (→ 460 nm) for the period in the article?

d) About the omnidirectional bandgap: in which case (a) or (b) is it present ?

e) Does the other case correspond to holes smaller or larger than those of the article?

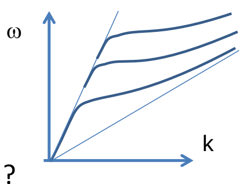
f) Can you comment on two remarkable changes of the bandgap between '*a*' and '*b*' : change of gap width and change of gap position ?

g) In the good case, which is the *u* region where cavity modes will appear?

A3) In the spirit of the index dispersion problem addressed by Fig.3b of the paper, draw on a scheme the generic evolution expected for the band structure if a shorter wavelength than 2.7 eV (see above) is considered, say 3.05 eV. Indicate in which *u* range it would be valid given the period used in the article.

A4) In all the above, a 2D picture was used, based on the effective index n_{eff} of the slab to avoid modelling the vertical dimension.

A5) The dispersion scheme for a given slab waveguide in air is reminded here:

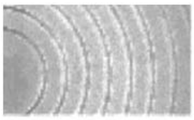


a) What is the relation of the ratio ω/k to n_{eff} ?

b) How do the represented branches evolve for a thicker slab ?

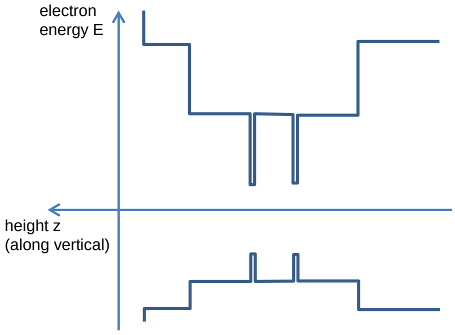
c) What happens then to the band structure ('*a*') above, (the one on the left) ?

Article APL Labilloy 1998



B.1- Energy diagram :

The growth sequence is AlGaAs/GaAs/QD/GaAs/AlGaAs (AlGaAs meaning Al_xGa_{1-x}, QD =Quantum dot). Here is a sketch of electron energies and hole energies as a function of z:



a) The energy gap of GaAs is 1.42 eV (→ 890 nm wavelength). Is absorption of red photons in GaAs possible?
b) Is it realistic to represent all quantum dots as identical wells (as done above) ?

B.2 Light-line

The circular trenches projected along a radius can be seen as a periodic structure of typical period Λ=600 nm. We want to know whether such a periodic structure has its operation point above or below the light line of the structure.

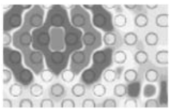
The effective index of the waveguide mode is n_{eff}~3.3 for the 1000 nm wavelength.

a) What is the value of the in-plane guided wavevector (also called propagation constant) k_g as a function of n_{eff} and λ ?
b) What is (literally) the wavevector G characteristic Λ=600 nm of the grating action ?
c) What are the various scenario for the successive harmonics $k_m=k_g-mG$ (m= integer) ?
d) Show that one of these cases operates above the air light line .
e) Was it welcome or not to operate above the air light-line in this kind of experiment?

B.3 Purcell effect

a) What is the typical spontaneous recombination time τ_{sp} of electron hole pairs ?
b) What are the two characteristics of a microcavity that can influence τ_{sp} (Purcell effect) ?
c) Is a mirror operating above the light line a good choice for a high quality factor Q ?

C-ARTICLE APL Nozaki 2008

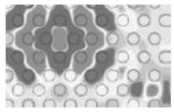


C1) <u>Laser with exit guide.</u>
Why is the exit guide formed in the "passive" area of bandgap "1.3 µm" while the laser is formed in the area "active", "1.55 µm" ?

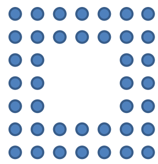
C2) <u>Hole shift</u>: Is the shift of the holes constituting the H0 cavity very critical : If they were more shifted away from each other than done in the paper (*s/a*=0.17), what would happen to the mode frequency ?

C3) <u>Radiation diagram</u>: Looking at the band diagram and at a typical 2D bandstructure, explain the privileged orientation along the ΓK directions (denoted ΓJ in the paper) rather than ΓM (denoted ΓX) of the laser radiation diagram as follows,
(Refer to the band general structure seen in the example of A2):

Assume that the cavity mode is close to the upper or to the lower edge of the bandgap; argue about the mode spatial structure due to this proximity, and consider the propagation expected for the modes near the closest band edge in each case.



C4) <u>Square cavity design</u>: Let us look at a different cavity design for a laser. It is based on a square lattice of holes in which a set of 3x3=16 holes for instance are removed:
(More holes are useful to get more power).
Taking some inspiration from paper B, cavity modes can then be built in two different geometries
(you can even recourse to ray optics).



Explain why some frequencies would then rather exit by the corners, and other frequencies by the middle of the sides.