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► **To cite this version:**

Romain Peretti, Guillaume Gomard, He Ding, Loïc Lalouat, Christian Seassal, et al.. ABSORPTION ENHANCEMENT IN DISORDERED PHOTONIC CRYSTALS: A PHOTONICS POINT OF VIEW. PHOTOVOLTAIC TECHNICAL CONFERENCE - THIN FILM & ADVANCED SILICON SOLUTIONS 2013, May 2013, Aix en provence, France. hal-00826813

HAL Id: hal-00826813

<https://hal.science/hal-00826813>

Submitted on 29 Jun 2013

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ABSORPTION ENHANCEMENT IN DISORDERED PHOTONIC CRYSTALS: A PHOTONICS POINT OF VIEW

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1) Context and Study motivation

Photonics Crystals (Ph.C.) have a great potential to enhance the photovoltaic cells absorption for both solar [1, 2] and indoor devices [3]. The so-called slow Bloch modes can be used for that purpose as they allow reaching absorptions as high as 100% at a single chosen wavelength [4, 5]. To go further, two goals should be achieved: to get as much modes as possible per wavelength unit [6, 7], and to make those modes absorb as much as possible.

If the second point can be reached using Ph.C., the first one is really difficult to obtain with a strictly periodic structure which cannot fill the spectrum with enough modes to reach a high efficiency on a spectral range as broad as the one of the solar spectrum. That is why several groups have designed and analysed not strictly periodic structures [8, 9, 10, 11]. To summarize their main conclusions, adding disorder in photonic structures can enhance the absorption in the device even more than for a purely periodic and optimized Ph.C.

In this communication, we focus on this result by explaining why the broadband absorption enhancement is higher in the disorder case compared to the periodic one using the intermediate case of multi-periodic structures.

2) Description of the approach and techniques

To perform this study, we consider altogether theoretical, simulation and experimental approaches, in the case of a simple absorbing layer that will be etched with a single periodic, a multi-periodic or a random pattern. The layer is made of hydrogenated amorphous silicon (a-Si:H) deposited on a silica substrate. The thickness (194 nm) and the optical indices of the a-Si:H layer are measured by ellipsometry. . The photonic structure is presented on fig 1.

First of all, we analysed the single periodic Ph.C., considered as the reference structure; whose band diagram is shown on fig 2. It should be noted that this single mode Ph.C. is not optimized for broad band absorption, since there is only one mode in the wavelength range of interest. However, it is a good candidate to investigate the link between periodic and non periodic structures.

Then, we introduced several perturbations on this single periodic structure, by changing it to a multi-periodic structure (considering a supercell constituted of 3 periods of the initial structure). These perturbations are depicted on fig

3.: A is the single periodic structure; B is a multi-periodic structure with a perturbation called “+” and keeping the symmetry of the Ph.C.; C is a perturbation that breaks the square symmetry of the Ph.C. into a rectangle one. Finally, D is the pseudo-disorder perturbation.

3) Results / Conclusions / Perspectives

Several Finite Difference Time Domain simulations were performed for different magnitudes of perturbation on B, C and D structures. These simulations show that additional modes appear with multi-periodicity for B and even more for C and D; even in the case of the smallest perturbation. Then increasing the perturbation will change the modal properties, mainly by reducing the quality factor of the modes.

We analyzed this result theoretically and demonstrated that new modes appear and are related to other k-points on the single periodic band diagram (fig 2.), depending on the size of the multi-periodicity. We also show that the coupling of the mode will depend on the symmetry of the perturbation; as a result, a non-symmetric perturbation will be more useful for light-trapping than a symmetric one.

We finally introduced a multi-periodic perturbation in an optimized Ph.C. and showed numerically an increase of the absorption up to 2%. This indicates that the disorder or pseudo-disorder approaches may further improve the light-trapping compared to a purely periodic Ph.C.

To go further, we plan to use E-Beam lithography to elaborate samples to compare pseudo-disorder to real disorder, so as to fill the gap between periodic structures and disordered ones.

To conclude, we analyzed various kinds of perturbations in PhC structures, and their potential to introduce additional modes. We were able to predict the wavelength of the new modes for small perturbations. This provides guidelines for the design of novel photonic structures integrated in solar cells in order to obtain the best light-trapping structure. In future work, the numerous degrees of freedom will be exploited, including the size of the multi-periodicity. The influence of the size will be compared to that of the super cell, but also to the magnitude of the perturbation.

This work was supported by Orange Labs Networks contract 0050012310-A09221. L.L. acknowledges the European Union (EU) for financial support through the project PhotoNVoltaics (Grant Agreement No. 309127). H. Ding acknowledges the China Scholar ship Council (CSC).

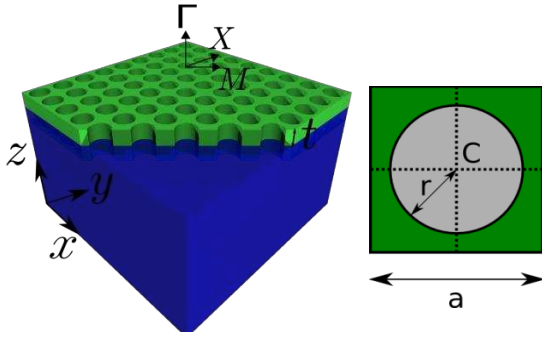


Figure 1: Left, scheme of our structure, right Top view scheme of the 2DCP

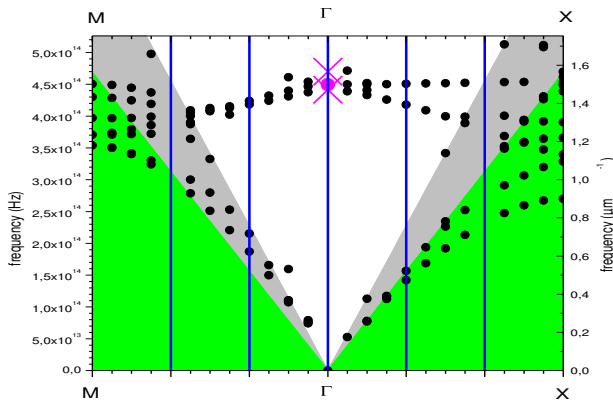


Figure 2. Band diagram of the structure without perturbation. In gamma, the coupling mode helping the absorption is in a big purple round and the non coupling modes in purple cross.

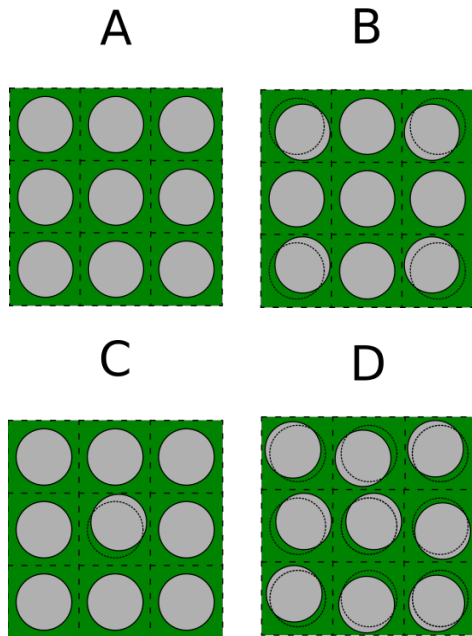


Figure 3. 3x3 2DCP; A without perturbation, B with '+' perturbation, C with non symmetric perturbation, D with pseudo random perturbation

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