Optimization of Two-Dimensional Photonic Crystals with Artificial Bee Colony Algorithm

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***Abstract*- We applied the Artificial Bee Colony algorithm for the complete band gap maximization of a two-dimensional photonic crystal. The band diagram and band gap calculation were carried out by the software MIT Photonic Bands, and these results were used in the algorithm's fitness function. The optimum structure was compared to the literature which used genetic algorithm, and it was observed a raise in the complete band gap of the photonic crystal.**

I. Introduction

Photonic Crystals (PhCs) are periodic structures formed by materials with different dielectric constants and can be used to control the flow of light. It can occur in 1, 2 or 3 dimensions [1]. Such PhCs may have photonic band gaps (PBG), which are frequencies where the light is prohibited to propagate, i.e., the PhCs act as a perfect mirror comprised of dielectric material. When the PBG is polarization independent, it is said that PhC has a complete PBG (CPB). In 2-D PhC the CPB occurs when the transverse electric (TE) mode band gap overlaps the transverse magnetic (TM) mode, and vice-versa.

Many optical components can be designed as filters, waveguides, among others, by the PBG engineering, once this region inhibits radiation losses [2]. Therefore, structures with large PBGs may be interesting to design novel wideband devices. Additionally, there are many factors that influence the formation of PGB, e.g.: lattice type, geometry, kind of material, symmetry reduction, and index refraction [1]. All these factors create a huge combinational problem, demanding a search mechanism that can explore in an efficient way the possibilities with the lower computational effort.

In this context, many research groups applied bio-inspired algorithms, as [3] where the genetic algorithm (GA) is used in the discrete domain to optimize CBG, [4] also uses GA for optimization through an inverse problem, in [5] it was used an immune artificial network, and [6] an artificial bee colony (ABC) algorithm for PBG optimization by inverse problem in the discrete domain.

Thus, this work aims to use the ABC algorithm in the continuum domain to maximize the CPB in a two-dimensional PhC, composed of air and silicon rods in a square lattice. The software MIT Photonic Bands (MPB)[7] was applied for the electromagnetic calculation.

II. Methods

The ABC algorithm [8] was inspired by the search food process made by swarm bees called foraging, and it is formed by three groups of bees: scouts, employees, and onlookers. In the beginning, the scout bees search randomly food sources (possible problem solution), next the employee bees explore the neighborhood of the sources found by the scouts. Using the sources' qualities of the employees, the onlooker bees choose which one will be explored (exploitation). When a source cannot be improved after a number *limit* of attempts, its employee bee becomes a scout bee; which will start to search for a new food source randomly.

In this work, each food source is a vector that contains the centers and radii of each rod of the PhC unit cell. The fitness function is given by the gap-to-midgap ratio (1):

$$fit = \left(E_{top} - E_{bottom}\right)/E_{middle}, \tag{1}$$

where E_{top}, E_{bottom} and E_{middle} are respectively, the lower frequency of the higher mode, the upper frequency of the lower mode, and the average between the two previous frequencies. The band diagram is calculated by MPB software.

The unit cell of the PhC was comprised by two silicon rods with index refraction n=3.476, filled by air, and organized in a square lattice. The results were compared with the ones in [3] for the two rods case.

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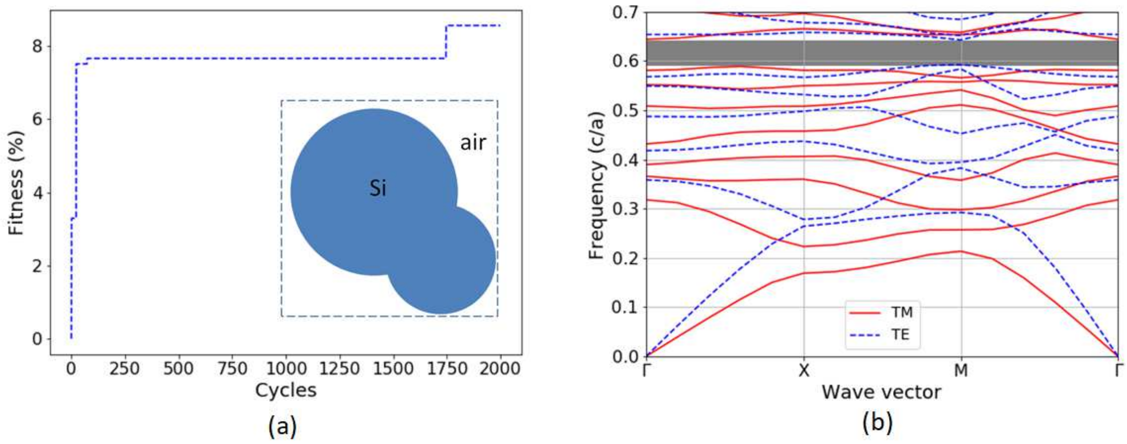

Fig. 1. a) Convergence curve of ABC algorithm. Inset shows the optimum unit cell obtained from the ABC code. b) Diagram band of the unit cell in a).

III. RESULTS

One PhC configuration can have more than one CBG and, in this work, it was considered always the larger one. For the diagram bands, the MPB has been configured to consider 15 bands in the calculations for TE and TM modes. In table I, it is depicted the ABC algorithm parameters and corresponding values.

TABLE I
PARAMETERS OF ABC ALGORITHM

Parameter	Value
Employee bees	10
Onlooker bees	10
Limit	10
Cycles	2000

In the convergence curve, shown in Fig. 1(a), one can observe that the best result was achieved around 1746 cycles; it suggests an even better result could be reached assuming more cycles. Inset shows the ultimate unit cell got from ABC code. The centers and radii of the rods are {P_1 (0.2022, 0.2305), $r_1 = 0.2281$} and {P_2 (-0.0703, -0.0641), $r_2 = 0.3410$}.

Fig. 1(b) shows the band diagram for the optimal PhC with a bandwidth of 8.17%. The PBG is located between 6th-7th TE mode and 8th-9th TM mode. The CBG obtained in [3] was 7.2% thus it becomes evident the better result of ABC that obtained a band gap structure nearly 13.5% larger.

IV. CONCLUSION

In this work, ABC was used in the continuum domain for optimizing the CBG for 2D PhC with two Si rods embedded in air. As result, it was obtained a structure with a larger band gap when compared with [3] that used GA. This showed the capability of the ABC algorithm to explore the search space avoiding the local optima for complex multimodal functions. Therefore, the ABC is an algorithm of simple implementation but with great optimization power, being an efficient way to search for PhCs with larger PBGs.

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