UDC 53.06; 51-73

GENETIC ALGORITHM, BEES ALGORITHM AND EXTENDED BEES ALGORITHM EFFICIENCY COMPARISON FOR X-RAY REFLECTOGRAM DECODING APPLICATION

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A comparison of experimental data processing with genetic algorithm, bees algorithm and extended bees algorithm was carried for data obtained with relative double wave x-ray reflectometry. Different precision ratio for film thickness interpretation was discovered when different algorithms were applied. It was found that extended bees algorithm demonstrates sufficiently higher precision compared with two other algorithms.

Keywords: genetic algorithm, bees algorithm, extended bees algorithm, function variation depending.

Introduction

This paper presents the investigation results of experimental relative dual-wavelength X-ray reflectometry data decoding accuracy for different computation algorithm applied for real single-layer structures on the silicon substrate.

Lately for the X-ray reflectometry the evolutionary algorithms of data decoding such as genetic algorithm (GA) [1], annealing simulation method [1], extended genetic algorithm and some other modifications of genetic algorithm [2] have been used. According to the standard genetic algorithm set of layer parameters of a studied structure is considered as a genome, which may mutate. Selection of genes structure parameters of the i.e. at every evolution step should meet specified selection rule, for example, data processing error decrement.

Later a new evolutionary algorithm called the Bees Algorithm (BA) was developed [3]. This paper is about comparison of different algorithms efficiency including genetic algorithm when applied to a number of test functions with the number of variables from 2 to 10. According to this study, in 80% of cases the efficiency of the new algorithm, i.e. reduction of iterations number, exceeds efficiency of other evolutionary algorithms, including GA.

We consider this is due to fixation of a genome of the best species (bees) which will not vary until better species are found. Such fixation may be preset by a specific combination of parameters values or proportion of the layer parameters, which can’t be changed deliberately for the specified interval of values. It looks somewhat like one of the modifications of the GA, in which the best species are not changed during a long time (elite). However, when the ordinary GA is applied, the genome mutation for both species (cross-breading) is applied, that may result in decreased efficiency of the algorithm in certain cases (the computation time will be increased).

Experiment

We have used the bees’ algorithm for solution of the task of decoding X-ray reflectograms, obtained on simulated structures. As a result we have discovered that the bees’ algorithm makes it possible in a number of cases to reduce an error 1.5 - 2 times as compared with the classical genetic algorithm during the same computer time (Fig. 1).

Genetic algorithm used for computation efficiency comparison is that one describes in electronic library of Massachusetts Institute of Technology. The results obtained have proved perspective of continuation of research of the bees’ algorithm.

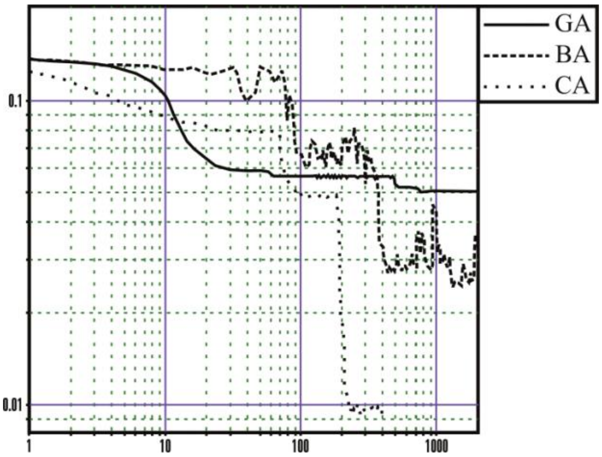

Fig. 1. Objective error function variation depending on the number of iterations for three evolutionary algorithms applied to four layer structure with 2 and 3 g/cm^3 densities of alternating layers.

Later the Extended Bees Algorithm has been developed (XBA). Implementation of XBA for decoding of simulated and real structures resulted in following:

1) In the case of the simulated structures, the new XBA algorithm demonstrated a vanishing error with number of layers from 1 to 7 and total superiority over the classic GA and non-modified bee algorithm (Fig. 2).

2) In the case of real structures (platinum films upon silicon substrate) XBA has also demonstrated the best results.

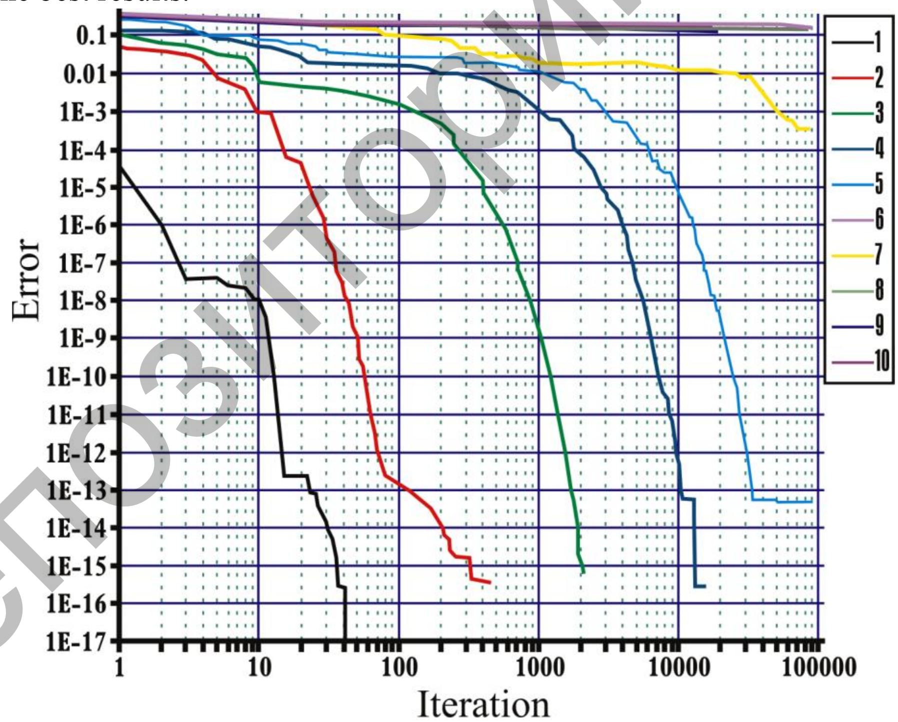

Fig. 2. Objective error function variation depending on the number of iterations for XBA algorithm applied to multilayer structure with 2 and 3 g/cm^3 densities of alternating layers.

For both algorithms the term “bee” is considered an object that describes multi-layer structure with all its features in terms of number of layers, their thickness, and interface roughness. XBA major difference compared to common BA is that it takes into consideration a current error function meaning at defining search area for next computation iteration.

In our case a normalized error function was used. Studied reflect grams were obtained for real metal layer structures within the access angle range varied from 0 to 1^{o}. Species number used for GA and bees' number applied for computation with BA and XBA were 256. Error tolerance level was established as 0.1.

Data obtained with all algorithms computations are presented at Fig.3-Fig.6.

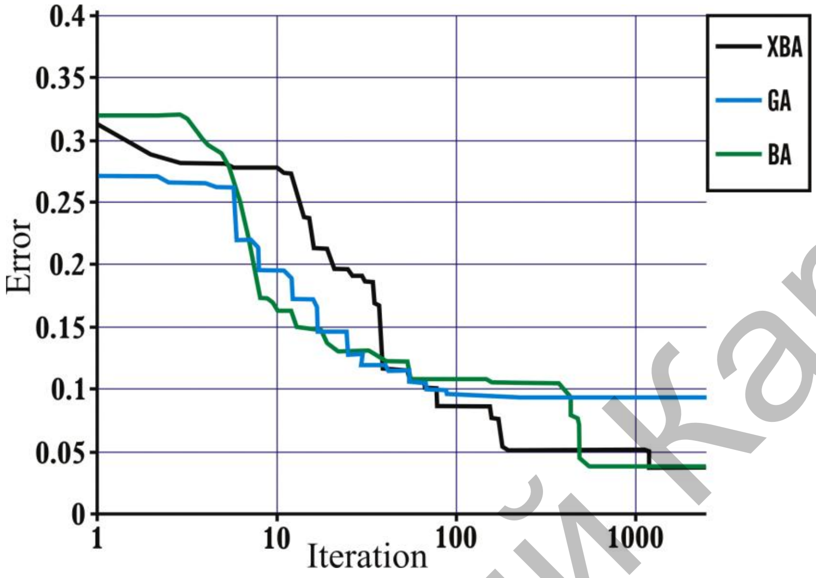

Fig. 3. Objective error function variation depending on the number of iterations for three evolutionary algorithms applied to 3.5 nm platinum layer upon silicon substrate.

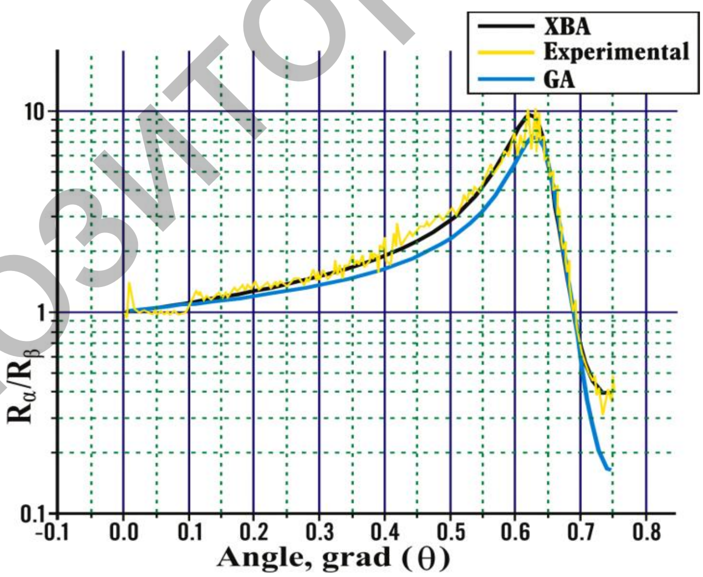

Fig. 4. 3.5 nm platinum layer upon silicon substrate experimental reflectogram compared to calculated reflectograms obtained with 2000 computation steps of XBA or GA.

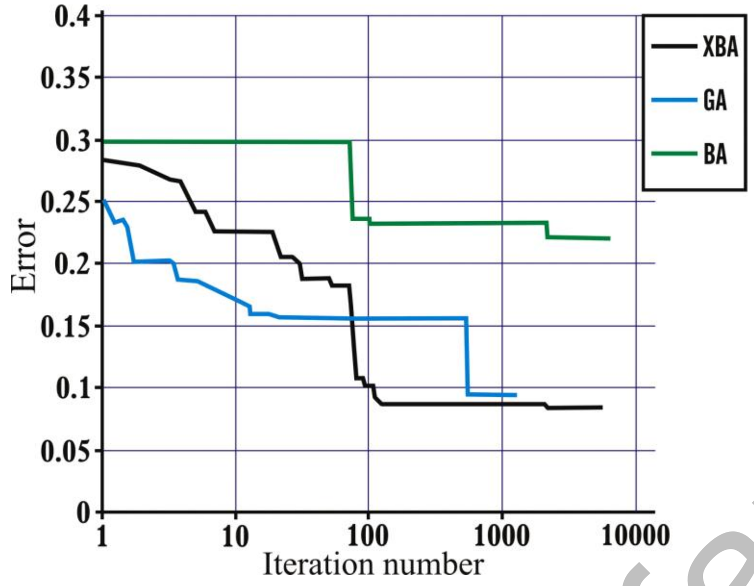

Fig. 5. Objective error function variation depending on the number of iterations for three evolutionary algorithms applied to 6.5 nm platinum layer upon silicon substrate.

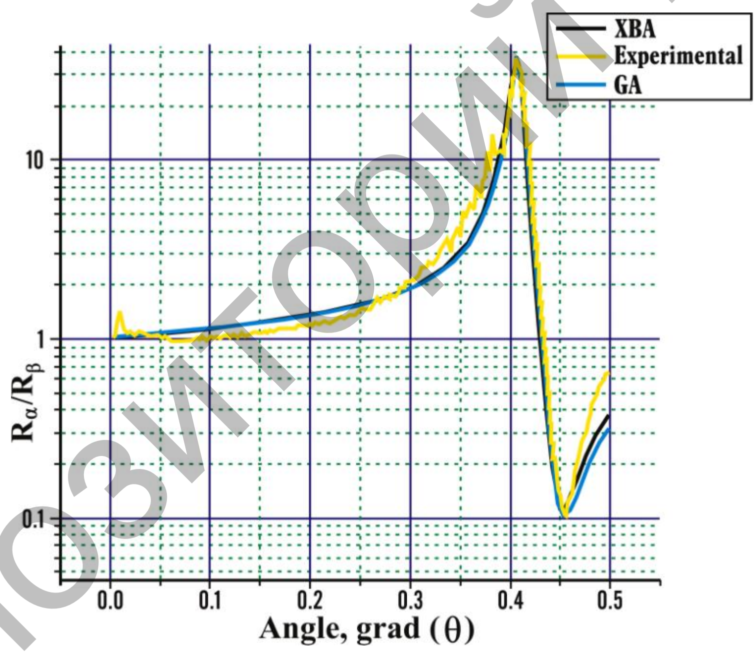

Fig. 6. 6.5 nm platinum layer upon silicon substrate experimental reflectogram compared to calculated reflectograms obtained with 2000 computation steps of XBA or GA.

2000 iteration was set and computation time for each calculation took about 10 minutes with 2.5 GHz Intel Core 2 Duo. Computation program of XBA used only about 1Mb RAM, while in case of GA and conventional BA the size of RAM used for computation was sufficiently greater.

Error functions decrease and reach saturation at about 1000 iteration runs as it is seen at Fig.3 and Fig.5. Based on these date we may consider 1000 iteration runs a consistent criterion for computation completion and it will take about 10 minutes of calculation.

Results Discussion

Let’s compare the graphs obtained. In Fig. 3 the advantage of the XBA algorithm is obvious as one compared with the first iterations of the GA staring form. However, the bees’ algorithm demonstrates the best results at first. The effectiveness of the genetic algorithm drops abruptly after 30 iterations (8 seconds of computation), the bees algorithm – after 100 iterations (30 seconds of computation), and an effective operation time of expanded bees algorithm much more – 200 iterations (1 minute), that makes it possible to decrease an error to 0.055. It is almost twice as less as that for GA (0.09) and 2.5 times as less as that for BA (0.11). However, after 500 iterations BA produces better result among reviewed algorithms (error about 0.04), but further it becomes ineffective as well. This achievement is not as essential as that of XBA, which allows getting practically the same error during shorter time, and is an evidence of its advantage over GA and BA. It should be noted as well that after 1200 iterations the error value, obtained with the help of XBA becomes the same as in case with BA.

In Fig. 5 GA algorithm compared with XBA appears more effective during first 100 iterations. From the graph one can see that an effectiveness of GA is dropping after 60 iterations (16 minutes of computation), but nevertheless during 60 iterations. An error that appears during GA operation is equal to 0.15 that is less than the error during operation of XBA in 1.2 times (0.18). At the number of iterations exceeding 100 (30 minutes of computation), XBA algorithm produces a less error (0.09), than GA one, but after that it also becomes ineffective. It should be noted that after 500 iterations the error value obtained with the help of GA becomes practically identical. The BA algorithm is not so good for that structure, because it does not give an error less than 0.22. This effect proves ambiguity of selection of an optimal algorithm for computation of actual structures, at a small number of iterations, but at the same time it demonstrates that in case of a great number of iterations the XBA algorithm appears to be the best one.

From analysis of graphs presented in Fig.4 and Fig.6 it is obviously seen that the theoretical and experimental curves coincide rather well when the algorithm XBA is used. Although in case of thicker film (65A) the curves fitting is less but it is still better than one in case of GA.

Summary

Analysis of the data shows some compelling advantages of XBA, compared with GA and BA due to the shorter calculation time. At similar conditions XBA demonstrates higher computation precision compared to GA and BA. It seems to be more attractive and suitable especially for the cases of high throughput metrology applications in high volume manufacturing environment.

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