A Multi-tiered Memetic Multiobjective Evolutionary Algorithm for the Design of Quantum Cascade Lasers*

Mark P. Kleeman[1], Gary B. Lamont[1], Adam Cooney[2], and Thomas R. Nelson[3]

[1] Air Force Institute of Technology, Dept of Electrical and Computer Engineering, Graduate School of Engineering & Management, Wright-Patterson AFB (Dayton) OH, 45433, USA
[2] Air Force Research Laboratory, Materials and Manufacturing Directorate Wright-Patterson AFB (Dayton) OH, 45433, USA
[3] Air Force Research Laboratory, Sensors Directorate Wright-Patterson AFB (Dayton) OH, 45433, USA

Abstract. Recent advances in quantum cascade lasers (QCLs) have enabled their use as (tunable) emission sources for chemical and biological spectroscopy, as well as allowed their demonstration in applications in medical diagnostics and potential homeland security systems. Finding the optimal design solution can be challenging, especially for lasers that operate in the terahertz region. The production process is prohibitive, so an optimization algorithm is needed to find high quality QCL designs. Past research attempts using multiobjective evolutionary algorithms (MOEAs) have found good solutions, but lacked a local search element that could enable them to find more effective solutions. This research looks at two memetic MOEAs that use a neighborhood search. Our baseline memetic MOEA used a simple neighborhood search, which is similar to other MOEA neighborhood searches found in the literature. Alternatively, our innovative multi-tiered memetic MOEA uses problem domain knowledge to change the temporal focus of the neighborhood search based on the generation. It is empirically shown that the multi-tiered memetic MOEA is able to find solutions that dominate the baseline memetic algorithm. Additional experiments suggest that using local search on only non-dominated individuals improves the effectiveness and efficiency of the algorithm versus applying the local search to dominated individuals as well. This research validates the importance of using multi-objective problem (MOP) domain knowledge in order to obtain the best results for a real world solution. It also introduces a new multi-tiered local search procedure that is able to focus the local search on specific critical elements of the problem at different stages in the optimization process.

* The views expressed in this article are those of the authors and do not reflect the official policy of the United States Air Force, Department of Defense, or the United States Government.

S. Obayashi et al. (Eds.): EMO 2007, LNCS 4403, pp. 186–200, 2007.

1 Introduction

In 2000, Zhores Alferov and Herbert Kroemer received a share of the Nobel Prize in Physics for their work in developing a semiconductor laser using interband transitions in a double heterostructure. These types of lasers are now quite common, and can be found in everyday devices such as laser printers, compact disk players, and laser pointers. Unfortunately, these devices can only operate in a limited range of wavelengths, a fundamental limitation imposed by the bandgap of the constituent materials. For wavelengths greater than 2 microns, suitable semiconductor materials have yet to be developed that can enable interband lasing at room temperature [1].

Quantum cascade lasers (QCL) are semiconductor lasers that are not based on the heterostructure design, but on quantum mechanics. In these devices, lasing is based upon intersubband transitions with properties that are tailored through the careful epitaxial growth different semiconductor layers. Therefore, a QCL does not have the same limitations as the traditional double heterostructure laser. As such, QCLs are used in applications where the standard double heterostructure cannot be utilized [2].

This research focuses on developing good QCL designs in the terahertz frequency range. A terahertz QCL can have potential applications in spectroscopy, astronomy, medicine, free-space communication, near-space radar, and possibly chemical/biological detection [3]. Of particular interest is its potential use as a sensor for security purposes, particularly in the realm of homeland security.

Our previous QCL research [4,3] using multiobjective evolutionary algorithms (MOEAs) found valid designs, which had to be manually adjusted in order to find more stable designs. This is a tedious process that can be remedied by adding a local search technique. We initially implemented a neighborhood search into our MOEA, but this failed to provide us with the type of results we were looking for. We then implemented an innovative multi-tiered neighborhood search that utilizes problem domain knowledge. This new local search technique focuses its search on a specific region based on the stage of the algorithm. The results detailed below empirically show that our multi-tiered memetic MOEA is more effective than a memetic MOEA designed without domain knowledge.

This paper also compares the results of implementing the multi-tiered memetic MOEA on only the non-dominated solutions, the top 10 ranked solutions, and on all current population members. The results show that the multi-tiered memetic MOEA works best when the local search is applied to only the current non-dominated solutions.

Section 2 presents the basics of QCL design. Section 3 discusses generic memetic MOEAs and describes the ones created for the QCL problem. Section 4 describes the algorithm that was extended with local search. Section 5 presents an analysis of the results.