Applying Simulated Annealing Method to Optimization Problems in Silicon Photonics

AIST, °Guangwei Cong, Noritsugu Yamamoto, Takashi Inoue, Makoto Okano, Yuriko Maegami, Morifumi Ohno, Koji Yamada
E-mail: gw-cong@aist.go.jp

[Introduction] The simulated annealing (SA) algorithm offers efficient global optimization in a large multivariate space for large-scale complex nonlinear systems where we have no knowledge of the problem structure and solution cannot be explicitly described or achieved by exhaustive traversal. Due to its robustness of global optimum, the SA algorithm has been applied to training artificial neural network for machine learning towards automatic driving [1] and many tough engineering fields such as VLSI design [2]. Photonic devices and systems face similar optimization problems because many determinative variables in both design and control consist of an N-dimension solution space that is impossible be explored analytically. We propose to apply the SA algorithm to deal with the optimization problems in photonics including automatic design, calibration, and intelligent control towards functionality reconfiguration, all of which are becoming important with integration being scaled up. According to the desired applications, achieving adaptive functionality reconfiguration without changing photonic devices can offer great system flexibility and decrease the cost. In this study, we utilize the SA algorithm to globally optimize the five control parameters (5-dimension solution space) of a single silicon Mach-Zehnder modulator (MZM) to realize an arbitrary 4-level optical waveform generation from an arbitrary initial state. We report this 5-multivariates 4-objectives optimization as an application example of SA algorithm for function reconfiguration of single MZM. We developed the SA algorithm with adaptively adjusting the random step selection according to the algorithm progress and achieved fast global convergence.

[Result] The top inset of Fig. 1(a) shows the schematic of the proposed SA optimization. The two arms of MZM are the conventional horizontal *pn* phase shifters and the bias dependent properties (*n, k*) of the *pn* phase shifter are shown in the bottom inset of Fig. 1(a), which were simulated by Lumerical simulators [3]. $X=\{V_{b1}, V_{b2}, V_{pp1}, V_{pp2}, \Delta\Phi\}$ is the solution space where V_{b1} and V_{b2} are biases, V_{pp1} and V_{pp2} peak-to-peak driving voltages, $\Delta\Phi$ phase difference. Y denotes the objective waveform with pre-defined 4 levels. Both driving signals were binary bit sequences and the frequency of V_{pp1} was double that of V_{pp2}. We implemented the SA algorithm to search the solution of X to achieve a target Y. The searching range of X was {-3~0, -3~0, -3~3, -3~3, -π~π}. For example, X was initially set to {0.5, 0.5, 0.5, 0.5, 0.5π} which corresponds to the start waveform in Fig. 2(b), from which we performed optimization to achieve four target waveforms of Y={0,0.333,0.666,1}, Y={1,0.666,0.333,0}, Y={0,0.25,0.75,1}, and Y={1,0.25,0.75,0}, respectively. As shown in Fig. 2(b), the finally approached waveforms marked as (1-4) were achieved by the optimization process of about 5000 times. The evolutions of maximum errors for each waveform are shown in Fig. 1(c). The final maximum errors are within 0.003 ~ 0.02, indicating effective convergences. We cannot display the random walk of the solution in 5-dimension space, but its projection to any two parameters can be extracted. For example, Fig. 1(d) shows the projection of solution in the optimization process to the 2-dimension space (V_{b1}, V_{b2}) for Y={0,0.333,0.666,1}. In this study, the SA algorithm was applied for arbitrary waveform generation in time domain for a one-input-one-output device; actually, it can also be applied in space domain optimization for multi-ports devices.

Acknowledgment: This work was partly supported by JST CREST Grant Number JPMJCR15N4, Japan.

[1] S. Ledesma, *et al.*, Simulated Annealing Evolution, IntechOpen, Aug. 2012.
[2] D.F. Wong, *et al.*, Simulated Annealing for VLSI design, Kluwer Academic Publishers, Norwell, 1988.
[3] https://www.lumerical.com/ tcad-products/device/, and /mode/.

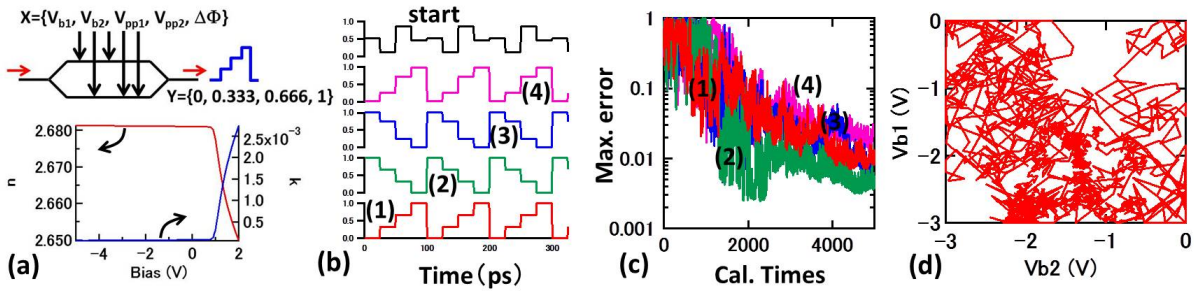

Fig. 1. (a) Schematic for simulated annealing optimization (top) and bias dependences of (*n, k*) of *pn* phase shifter. (b) Start waveform and four optimized waveforms (1-4). (c) Maximum error evolution. (d) Path projection of random walk trajectory in 5-dimension space to 2-dimension space of biases (V_{b1}, V_{b2}).