A study on all-optical switching devices using active multimode interferometers

（能動多モード干渉計を用いた全光スイッチング素子に関する研究）

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In this study, we investigate a modified structure for the semiconductor optical amplifier (SOA) so as to make the SOA-based all-optical switches more cascadable and suitable for high-density integration. In the all-optical switch, we replace the single-mode SOA by a 2×2 multimode interferometer (MMI) with SOA epitaxial layers designed as a bar coupler. This replacement results in several direct benefits, e.g. separating the control signal without filtering and decreasing the all-optical switch size. Our research is divided between theoretical and experimental work. At first, we investigate by simulation the cross phase modulation (XPM) between two different CW optical signals inserted into the active MMI through separate ports. For 10 to 12 µm-wide active MMIs and specific material parameters, steady state results show that a phase shift amounting to several multiples of π could be induced in the data signal at low injected current densities (3.2 kA/cm^2) and for achievable control power values. Furthermore to investigate XPM between optical pulses, we develop a new modeling and simulation approach. In this approach, the carrier density distribution in the active MMI is modeled by few lateral profiles added to the average density. The coefficients of these profiles and average density are functions of time and longitudinal position. A separate update equation is derived for each of them from the carrier rate equation that takes into account carrier diffusion, detailed recombination and stimulated emission by optical signals. At the same time, following the approximation of first order perturbation an adapted wave equation is derived for each propagating modal phase and power. The resulting system of equations is solved by the FDTD method, after artificial interleaving in time and space for all variables. Dynamic XPM and carrier recovery are then examined by a simulation program.

Regarding the experimental part of our study, we managed to fabricate workable discrete active MMIs with passive ports and active-MMI-based all-optical switches using the monolithic integration technique of offset quantum well. To reach this end, some modifications have been added to a pre-developed fabrication process, e.g. we have enabled wider contact openings in the devices' active regions. We have also contributed to the reduction of optical propagation loss in waveguides etched by the inductive coupled plasma (ICP) machine. Cross-port cross gain modulation (XGM) has been measured in the fabricated discrete active MMIs. Moreover, all-optical switching has been demonstrated (by 10 dBs) in the fabricated all-optical switch for an input control power of 7 dBm and with a reduction in control power coupled to the data port by approx. 4 dBs. These results would clearly serve as a proof of concept, and we believe that further optimization would much enhance the new switch performance. Finally seeking to make the active MMI a more power-efficient device for all-optical switching, we briefly highlight some suggested alternatives.