マテリアル先端リサーチインフラ利用報告書
ARIM User's Report

【Release：2024.07.25】　【Update：2025.05.21】

課題データ / Project Data

課題番号 Project Issue Number	23WS0032
利用課題名 Title	Design and Experiment of Silicon Racetrack Loop Multi Mode Waveguide Structure for Compact Reservoir Computing Device
利用した実施機関 Support Institute	早稲田大学 / Waseda Univ.
機関外・機関内の利用 External or Internal Use	内部利用（ARIM事業参画者以外）/Internal Use (by non ARIM members)
ARIM半導体基盤PF 関連課題 Related to ARIM-SETI	指定なし / No Designation
横断技術領域 Cross-Technology Area	加工・デバイスプロセス/Nanofabrication 計測・分析/Advanced Characterization
重要技術領域 Important Technology Area	高度なデバイス機能の発現を可能とするマテリアル/Materials allowing high-level device functions to be performed
キーワード Keywords	蒸着・成膜/ Vapor deposition/film formation,CVD,スパッタリング/ Sputtering,リソグラフィ/ Lithography,電子線リソグラフィ/ EB lithography,膜加工・エッチング/ Film processing/etching,ダイシング/ Dicing,電子顕微鏡/ Electronic microscope,光学顕微鏡/ Optical microscope,高品質プロセス材料/技術/ High quality process materials/technique,光導波路/ Optical waveguide,MEMS/NEMSデバイス/ MEMS/NEMS device,光デバイス/ Optical Device

利用者と利用形態 / User and Support Type

利用者名（課題申請者） User Name (Project Applicant)	HEINSALU Siim
所属名 Affiliation	早稲田大学 基幹理工学部 電子物理システム学科
共同利用者氏名 Names of Collaborators Excluding Supporters in the Hub and Spoke Institutes	Takashi Kan; KDDI Research, inc.,Hideaki Tanaka; KDDI Research, inc.,Masatoshi Suzuki; KDDI Research, inc.
ARIM実施機関支援担当者 Names of Supporters in the Hub and Spoke Institutes	
利用形態 Support Type	機器利用/Equipment Utilization,技術相談/Technical Consultation

利用した主な設備 / Equipment Used in This Project

利用した主な設備 Equipment ID & Name	WS-015：電子ビーム描画装置 WS-007：ICP-RIE装置 WS-003：電子ビーム蒸着装置 WS-027：ダイシングソー WS-016：レーザー直接描画装置

報告書データ / Report

概要（目的・用途・実施内容） Abstract (Aim, Use Applications and Contents)	Photonic reservoir computing (RC) is gaining attention as a high-speed, low-power AI accelerator, addressing electronic device bottlenecks with a simple configuration. Several photonic RC architectures have been explored. Initial designs used many combiners and splitters, increasing cost and footprint. Two alternative approaches have emerged, namely those using multimode loop structures for higher memory effect and spiral multimode waveguides (MM WG) for speckle-like response. A compact "snake-crawling" structure has the advantage of reducing footprint. In this work, we combine both approaches, consisting of a racetrack-loop MM WG on the SOI platform. We also incorporate bends for improved mode mixing.
実験 Experimental	The samples underwent fabrication on silicon-on-insulator (SOI) substrates through a series of processes, namely electron beam lithography (EBL), inductively coupled plasma reactive ion etching (ICP-RIE), plasma chemical vapor deposition (Plasma-CVD), ultraviolet lithography (UVL), electron beam vapor deposition (EBVD), and wafer dicing. For detailed fabrication steps please contact: siim.heinsalu@fuji.waseda.jp
結果と考察 Results and Discussion	A silicon loop-type MM WG structure was studied as a compact RC device. The device would aim to enhance both spatial and temporal node counts through its loop-like configuration and the use of multimode waveguides. The experimental validations included observing speckle patterns, analyzing transmission spectra, and measuring pulse responses. With the final design featuring total node count as high as 845. A 3.25x improvement over initial work by Sunada et al. (10.1364/OPTICA.434918). Despite a 6.6x footprint increase, it can be mitigated using a spiral-like waveguide configuration for the loop, as used in the same reference. Additionally, parameter tendencies displayed scalability, indicating the potential for achieving higher node counts in future work with a similar configuration.
図・表・数式 Figures, Tables and Equations	
その他・特記事項（参考文献・謝辞等） Remarks(References and Acknowledgements)	The authors express their gratitude to Advanced Research Infrastructure for Materials and Nanotechnology in Japan (ARIM) of MEXT for granting permission to utilize the cleanroom facilities and equipment essential for fabricating the samples within the scope of this study.

成果発表・成果利用 / Publication and Patents

DOI（論文・プロシーディング）[1] DOI (Publication and Proceedings)	Siim Heinsalu, Design and Experiment of Silicon Racetrack-Loop Multi-Mode Waveguide Structure with Low-Loss and Adjustable Couplings for Compact Reservoir Computing Device, *2023 International Conference on Photonics in Switching and Computing (PSC)*, , 1-3(2023). DOI: 10.1109/PSC57974.2023.10297150

DOI（論文・プロシーディング）[2] DOI (Publication and Proceedings)	Siim Heinsalu, Silicon Loop-Type Multimode Waveguide Structure With Fan-Out Output for Photonic Reservoir Computing, *Journal of Lightwave Technology*, **42**, 7321-7329(2024). DOI: 10.1109/JLT.2024.3421522
口頭発表、ポスター発表および、その他の論文[1] Oral Presentations etc.	Improvement of pulse storage in MM racetrack loop for reservoir computing, 84th JSAP autumn meeting, 20p-A201-2, 9/20/2023
口頭発表、ポスター発表および、その他の論文[2] Oral Presentations etc.	Design and Experiment of silicon racetrack-Loop Multi-Mode Waveguide Structure for Compact reservoir Computing Device, ISPEC2023, P-28, 11/1/2023
特許出願件数 Number of Patent Applications	0件
特許登録件数 Number of Registered Patents	0件