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：2025.06.10】　【Update：2025.04.08】

課題データ / Project Data

課題番号 Project Issue Number	24TU0004
利用課題名 Title	メタマテリアルデバイスの作製/Fabrication of Mtamaterial Dvices
利用した実施機関 Support Institute	東北大学 / Tohoku Univ.
機関外・機関内の利用 External or Internal Use	外部利用/External Use
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
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	フォトニクスデバイス/ Nanophotonics device,メタマテリアル/ Metamaterial,光リソグラフィ/ Photolithgraphy,膜加工・エッチング/ Film processing/etching

利用者と利用形態 / User and Support Type

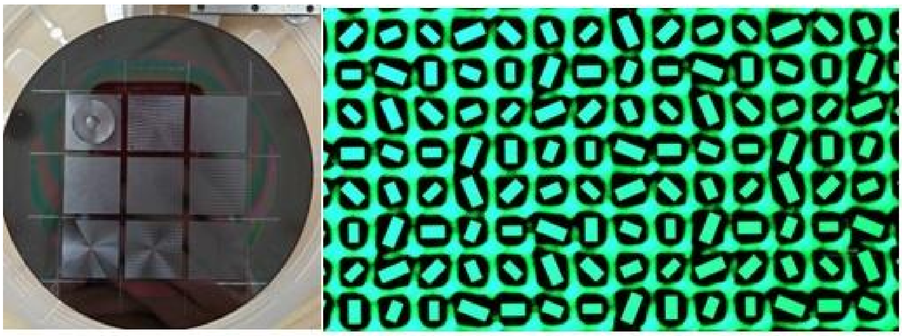
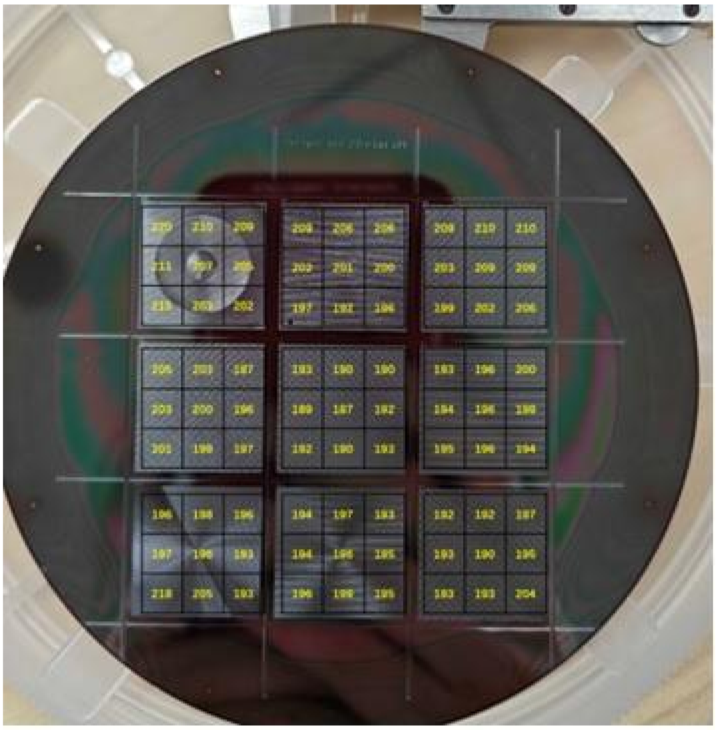
利用者名（課題申請者） User Name (Project Applicant)	佐々木 玲子
所属名 Affiliation	理化学研究所
共同利用者氏名 Names of Collaborators Excluding Supporters in the Hub and Spoke Institutes	
ARIM実施機関支援担当者 Names of Supporters in the Hub and Spoke Institutes	
利用形態 Support Type	機器利用/Equipment Utilization

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

利用した主な設備 Equipment ID & Name	TU-201：DeepRIE装置#1 TU-307：金属顕微鏡 TU-310：レーザ／白色共焦点顕微鏡 TU-058：マスクレスアライナ TU-060：現像ドラフト

報告書データ / Report

概要（目的・用途・実施内容） Abstract (Aim, Use Applications and Contents)	This study proposes a silicon pillar-based terahertz metasurface for polarization space-division multiplexing. By optimizing pillar geometry and spatial arrangement, it enables multi-polarization generation, modulation, and analysis. The M-4D device converts a linearly polarized wave into four beams with distinct polarization angles, while M-2B and M-4B generate vector Bessel beams. Fabricated on a high-resistivity silicon substrate using photolithography and deep silicon etching, the design is validated through simulations and experiments. This approach advances metasurface-based polarization control with potential applications in imaging, sensing, communication, and beyond.
実験 Experimental	(1) Mask Fabrication: First, the mask pattern was exposed onto a Cr-coated quartz substrate coated with AZ1350 positive photoresist using the Maskless Aligner TU-058. Development was carried out in the Draft Chamber for Development TU-060, followed by Cr pattern transfer using a Cr etchant. The remaining photoresist was removed in the Draft Chamber TU-001 using a H_2SO_4:H_2O_2 = 5:1 solution, yielding the final mask. This mask can be used in subsequent traditional photolithography processes, as shown in the figure 1 Photos and Microscopic Images of the Mask. (2) Photolithography Process: A high-resistivity silicon substrate (1 mm thick) was used. An adhesion promoter (OPA) was spin-coated using the Mikasa Spin Coater TU-051 and baked on the Hot Plate TU-054. PR800-200cp positive photoresist was then spin-coated using the Spin Coater TU-052 and baked on the Hot Plate TU-054. The mask was mounted on the Double-Side Aligner TU-056 for exposure. After exposure, development was performed in the Draft Chamber for Development TU-060, resulting in a patterned photoresist on the silicon substrate （Figure 2). (3)Deep Silicon Etching Process: Deep silicon etching was conducted using DeepRIE #1 TU-201, with etching depth monitored and measured using the Laser/White Light Confocal Microscope TU-310. After processing, the final sample was inspected using the Microscope TU-307. The final results are shown in the figure Photos and Microscopic Images of the Etched Sample.
結果と考察 Results and Discussion	The required etching depth is 200 μm. The actual etching depths measured at different positions using the Laser/White Light Confocal Microscope TU-310 are shown in the picture below （Figure 3). The results indicate that the central region has a shallower etching depth compared to the edges, exhibiting a certain degree of non-uniformity. Optimization may be achieved by adjusting etching parameters such as etching time, passivation time, and gas pressure.

図・表・数式 1 Figures, Tables and Equations 1	 Figure 1. Photos and Microscopic Images of the Mask
図・表・数式 2 Figures, Tables and Equations 2	 Figure 2. Photos and Microscopic Images of the Etched Sample
図・表・数式 3 Figures, Tables and Equations 3	 Figure 3. Etching Depth Measurement Results

その他・特記事項（参考文献・謝辞等） Remarks(References and Acknowledgements)	Reference: Yuehong Xu, Yuma Takida, Tetsu Suzuki, Hiroaki Minamide, Terahertz-Wave Polarization Space-Division Multiplexing Meta-Devices based on Spin-Decoupled Phase Control. *Advanced Science.* 2025, 12, 2412688. https://doi.org/10.1002/advs.202412688 Acknowledgements: This work was supported (in part) by RIKEN Incentive Research Project and (in part) by Innovative Science and Technology Initiative for Security Grant Number JPJ004596, ATLA, Japan. We thank Prof. Hiroaki Minamida in RIKEN, Prof. Hiromasa ITO in RIKEN and Tohoku University, Prof. Masahiro Henmi and Masaaki Moriyama in Tohoku University, previous and present researchers in RIKEN RAP, and researchers in collaboration works for effective support and discussion.

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)	Yuehong Xu, Terahertz-Wave Polarization Space-Division Multiplexing Meta-Devices based on Spin-Decoupled Phase Control, *Advanced Science*, **12**, (2024). DOI: https://doi.org/10.1002/advs.202412688
口頭発表、ポスター発表および、その他の論文[1] Oral Presentations etc.	Yuehong Xu, Yuma Takida, Tetsu Suzuki, Hiroaki Minamide, “Enhanced control of multi-beam THz-wave polarization using spin-decoupled phase engineering in metasurfaces,” the 45th Annual Meeting of the Laser Society of Japan, Hiroshima, Japan (Jan. 21-23, 2025)
特許出願件数 Number of Patent Applications	0件
特許登録件数 Number of Registered Patents	0件