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：2025.04.22】

課題データ / Project Data

課題番号 Project Issue Number	24UT1032
利用課題名 Title	クヌッセン力計測のための表面微細構造の作製
利用した実施機関 Support Institute	東京大学 / Tokyo 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	革新的なエネルギー変換を可能とするマテリアル/Materials enabling innovative energy conversion 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	光学顕微鏡/ Optical microscope,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,流路デバイス/ Fluidec Device,ナノ構造表面、クヌードゥセン力、触針段差計,電子線リソグラフィ/ EB lithography,ダイシング/ Dicing,MEMS/NEMSデバイス/ MEMS/NEMS device,膜加工・エッチング/ Film processing/etching

利用者と利用形態 / User and Support Type

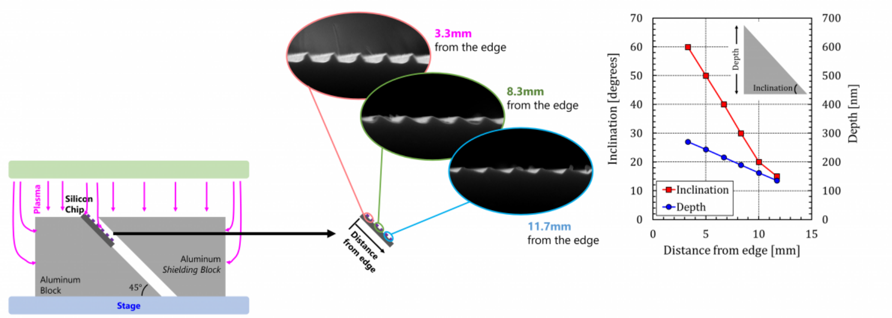
利用者名（課題申請者） User Name (Project Applicant)	杵淵 郁也
所属名 Affiliation	東京大学工学系研究科機械工学専攻
共同利用者氏名 Names of Collaborators Excluding Supporters in the Hub and Spoke Institutes	Clint John Otic
ARIM実施機関支援担当者 Names of Supporters in the Hub and Spoke Institutes	
利用形態 Support Type	機器利用/Equipment Utilization

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

利用した主な設備 Equipment ID & Name	UT-606：汎用平行平板RIE装置 UT-906：ブレードダイサー UT-500：高速大面積電子線描画装置 UT-850：形状・膜厚・電気特性評価装置群 UT-800：クリーンドラフト潤沢超純水付

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 investigates Knudsen forces, which arise due to rarefied gas effects around micro- and nanoscale structures [1]. These forces hold promise for energy conversion systems and microelectromechanical systems (MEMS), where momentum exchange at the gas-surface interface can be utilized for directed motion. In this study, we aim to experimentally validate this phenomenon by fabricating asymmetric microstructures designed to enhance Knudsen forces. Using electron beam lithography and reactive ion etching (RIE), we created periodic ratchet-like structures on silicon substrates, and the resulting geometries were analyzed using scanning electron microscopy (SEM).
実験 Experimental	To fabricate the asymmetric micro/nano-scale surface structures, silicon (Si) wafer samples were first diced into 20 mm × 20 mm pieces. Electron beam lithography was then used to create parallel line patterns on the surface, followed by dry etching using reactive ion etching (RIE) with the SAMCO RIE-10NR system. The fabrication process aimed to create a ratchet-type microstructure, which was identified as optimal for inducing Knudsen forces. Achieving the required asymmetric geometry during etching necessitated tilting the sample and implementing a shielding structure to control ion incidence angles [2]. In our setup, the Si sample was placed on an aluminum wedge block inclined at 45 degrees, while a second aluminum wedge block, also inclined at 45 degrees, served as the shielding structure (see Figure 1). The spacing between these blocks was carefully adjusted to optimize ion trajectories and ensure consistent anisotropic etching. Following several process refinements, the optimal etching conditions were determined as a methane (CH_4) flow rate of 50 sccm, a power of 100 W, a pressure of 5 Pa, and a duration of 10 minutes. The resulting microstructure, as observed in SEM images, exhibited a periodic ratchet-like pattern with a height of approximately 400 nm and a period of 800 nm.
結果と考察 Results and Discussion	The surface micro/nano-structures fabricated via reactive ion etching were examined using scanning electron microscopy (SEM) to evaluate their geometry and uniformity. Figure 1 presents SEM images of surface structures at different locations on the etched silicon sample, revealing variations in structural morphology depending on position. Near the upper edge of the silicon sample, the structures appear deeper while structures located further from the upper edge exhibit a shallower geometry, confirming the influence of the shielding setup. These observations indicate the need for further optimization of the fabrication process. Key parameters to be refined include the etching conditions, the geometry of the aluminum shielding block, and the thickness of the electron beam resist. Future modifications will focus on improving the uniformity of the tilted structures to enhance their effectiveness for Knudsen force applications.

図・表・数式 1 Figures, Tables and Equations 1	 Figure 1. Experimental set-up for reactive ion etching, and the resulting microstructures at various locations.
その他・特記事項（参考文献・謝辞等） Remarks(References and Acknowledgements)	[1] C. J. C.Otic and S.Yonemura, Micromachines13, 871 (2022). [2] S. Choi et al., IEICE Electronics Express 10, 1-8 (2013)

成果発表・成果利用 / Publication and Patents

DOI（論文・プロシーディング） DOI (Publication and Proceedings)	
口頭発表、ポスター発表および、その他の論文[1] Oral Presentations etc.	Otic, C.J.C., Kinefuchi, I., Yamaguchi, H., and Yonemura, S., "Asymmetric Surface Microstructures for Knudsen Force Application: From Fabrication to DSMC Simulation", 日本流体力学会年会2024, 2024年9月26日
特許出願件数 Number of Patent Applications	0件
特許登録件数 Number of Registered Patents	0件