論文 / 著書情報
Article / Book Information

題目(和文)	比色型バイオセンサーの応用のための大面積プラズモニックメタ表面の作製と評価
Title(English)	
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Plasmonic metasurfaces have gained significant attention due to their ability to generate vivid, tunable colors through localized surface plasmon resonances (LSPRs). These surfaces are highly sensitive to changes in the refractive index of the surrounding medium, making them useful for biosensors. Although conventional plasmonic biosensors typically require specialized optical equipment, which limits their practical use, the use of plasmonic metasurfaces can simplify optical setups, reducing the need for complex instrumentation while maintaining high sensitivity. In this context, the establishment of a fabrication method for large-area plasmonic metasurfaces using low-cost techniques has become crucial. The objective of this study is to fabricate scalable, reproducible, and cost-effective plasmonic metasurfaces for application in colorimetric plasmonic biosensors. To accomplish this, two types of plasmonic nanostructures were investigated: silver nanodome arrays and silver nanopillar arrays fabricated using moth-eye films.

Silver nanodome arrays, fabricated using a bottom-up approach, were initially examined for their ability to adjust plasmonic colors by the surface coverage. This study demonstrated that differences in the two-dimensional aggregation states of silver nanodome structures significantly influenced plasmonic coloration. In particular, it was found that plasmonic color variation was most pronounced when the surface coverage ranged between 50% and 70%. These results indicate that the surface coverage of silver nanodome structures can serve as a key parameter for controlling coloration. However, as a substrate for colorimetric plasmonic sensors, achieving improved uniformity and reproducibility necessitates the use of alternative metal nanostructure arrangements.

To address these limitations, silver nanopillar structures were fabricated using a nanoimprinting technique applied to moth-eye films, allowing for large-scale, cost-effective production with high reproducibility. Unlike nanodomes, nanopillar arrays exhibited color development governed primarily by variations in the thickness of the deposited silver film. Furthermore the silver nanopillar structures exhibited significantly greater color uniformity. Spectroscopic analysis, combined with cross-sectional electron microscopy observations and numerical simulations, was used to investigate the mechanism of plasmonic color changes depending on the thickness of the metallic film. The results indicated that thinner silver films allowed electric fields to be distributed across multiple regions of the nanopillars, generating multiple absorption peaks. As the film thickness increased, multiple plasmonic modes merged, resulting in strong electric field enhancement between the nanopillars and a blue shift in absorption peaks. These findings demonstrate that the fabrication method using moth-eye films exhibits high reproducibility and is well-suited for large-area production.

To evaluate the performance of these structures as sensor substrates for colorimetric plasmonic biosensors, spectroscopic measurements and colorimetric analysis were conducted. Bulk refractive index sensitivity measurements using solutions with different refractive indices demonstrated superior sensitivity and resolution compared to conventional metal nanodome structures. The refractive index sensitivity of the silver nanopillar array was measured at 730 [deg/RIU] by the colorimetric measurement using Hue as an indicator, achieved through the optimization of the silver film thickness. On the other hand, in a model immunoassay experiment targeting rabbit IgG, the sensor signal was reduced, and the superiority of the metal nanopillars was not evident. Numerical simulations were conducted to model these results, clarifying future challenges for further optimization.

This study successfully demonstrated the fabrication of large-area plasmonic metasurfaces using low-cost methods and established silver nanopillars as a superior alternative to nanodomes for achieving tunable plasmonic colors. Their high reproducibility, uniform coloration, and minimal angular dependence make them well-suited for integration into large-area optical devices. By leveraging scalable nanoimprinting techniques, these plasmonic metasurfaces have the potential to enable rapid and cost-effective fabrication for various optical applications. Furthermore, the ability to manufacture nanopillar structures using a nanoimprinting process suggests a pathway for mass production, making them viable for large-scale deployment in commercial plasmonic devices. The findings of this study contribute to the advancement of plasmonic metasurface technology, providing a practical approach to developing highly tunable and widely applicable optical platforms. The primary application of these metasurfaces is in colorimetric plasmonic biosensors, which detect biomolecular interactions based on refractive index changes. The integration of these metasurfaces into biosensing platforms could enable highly sensitive and rapid detection techniques for medical diagnostics and environmental monitoring. By offering a scalable and efficient solution for plasmonic color engineering, silver nanopillar-based metasurfaces represent a promising direction for the future of tunable plasmonic materials, addressing critical challenges in large-area fabrication and reproducibility.