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Article

Unraveling the Nature of Lasing Emission from Hybrid Silicon Nitride and Colloidal Nanocrystal Photonic Crystals with Low Refractive Index Contrast

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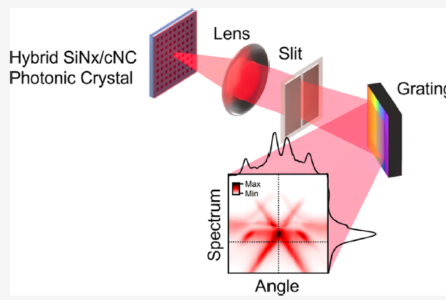
ABSTRACT: Silicon nitride is used for its low optical loss and high thermal stability, making it a suitable platform for visible-light applications in integrated photonic devices. However, its application has been limited due to inefficient light emission, a problem addressed by integrating various types of light emitters onto the platform. In particular, the integration of solution-processable colloidal nanocrystals (NCs) as optical gain materials onto the silicon nitride platform is a promising route but requires a more solid theoretical footing. By leveraging 2D surface-emitting photonic crystal structures combined with NCs, we effectively confine and manipulate light to achieve lasing from green to red. Building on this, we model the light−matter interactions of the low index contrast NC/nitride platform, validated by extensive experimental validations through Fourier imaging techniques, revealing the full photonic band structure and showing clear mode congestion. These comprehensive studies confirm the potential of hybrid NC-based structures for fully integrated on-chip laser applications and indicate routes for further improvement.



KEYWORDS: *photonic crystal, colloidal nanocrystal, laser, BIC lasing, silicon nitride, integrated photonics*

INTRODUCTION

The drive toward miniaturization in photonics implicates a need for compact, efficient, on-chip lasers capable of precise wavelength selectivity and directional emission. These devices are crucial across a variety of applications, including microdisplays, tunable light sources, and advanced sensing/imaging systems.[1,2] The need for integrating multiple laser sources on a single chip without compromising performance poses significant challenges in terms of possible device architectures and commensurate compatibility of the active materials.

Silicon photonics has emerged as a robust platform for addressing these challenges, particularly through the use of silicon nitride (SiNx), which offers excellent properties for visible-light applications due to its low optical loss in this part of the spectrum and a high thermal stability. By now, losses as low as 1 dB/m are achievable, allowing for quality factors (Q) above 1 million.[3] SiNx's compatibility with standard CMOS fabrication processes further enhances its appeal for integrated photonic devices.[4,5] However, despite its potential as a passive platform, the lack of efficient light emission from SiNx limits its wider application.

To address this, various heterogeneous integration methods have been developed to pair the low-loss SiNx platform with active semiconductor materials. These methods include bonding[6] and transfer printing,[7] which facilitate applications on the SiNx platform such as on-chip lasing with III−V semiconductors,[8] high-speed modulators, and efficient second-harmonic generation with lithium niobate.[9,10] However, these integration methods face clear limitations. For example, every additional bonding step requires complex processing, making it difficult to combine multiple gain materials on a single chip. Furthermore, both methods still require the use of two separate foundries to create both wafers, leading to a costly and complex manufacturing process.[2]

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