Towards Next-Generation Solid-State Masers Using Permanent Magnets

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Solid-state masers offer a promising platform to enhance medical imaging technologies and increase the sensitivity of qubit readout detection due to their capabilities in ultra-low-noise amplification. Current implementations of room-temperature solid-state masers are plagued by the use of unwieldy electromagnets, poor temperature management, or restrictions to pulsed operation. In this work, we investigate an alternative approach to the production of table-top diamond masers through the use of permanent magnet Halbach arrays coupled to shimming coils to optimise field homogeneity. The Halbach configuration obviates the need for bulky power supplies or water cooling to provide a pathway to the development of compact, ubiquitous maser systems. To correct the residual field inhomogeneities across the diamond sample, a set of current-controlled shimming coils are introduced. We present the design and numerical modelling of the combined Halbach-shim system including an analysis of the field strength, homogeneity, and resonator quality factor. Particular attention is given to enabling the use of tuneable resonators, temperature control of the sample, motorised sample orientation control to optimise spin-cavity coupling. Our results demonstrate that Halbach-generated bias fields, realised using industry standard neodymium magnets, can meet the field strength requirements for the Zeeman splitting necessary for maser operation, while maintaining sufficient homogeneity through active shimming. This approach serves as a crucial step towards the development of scalable solid- state masers for applications in quantum metrology, sensing, and low-noise amplification by reducing the complexity and footprint of current maser oscillators.

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[2] J. D. Breeze *et al.*, *Nature* **555**, 493 (2018).

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