Intra-cavity mode control in a Nd:YAG laser by optimizing the single-mode power factor with a spatial light modulator

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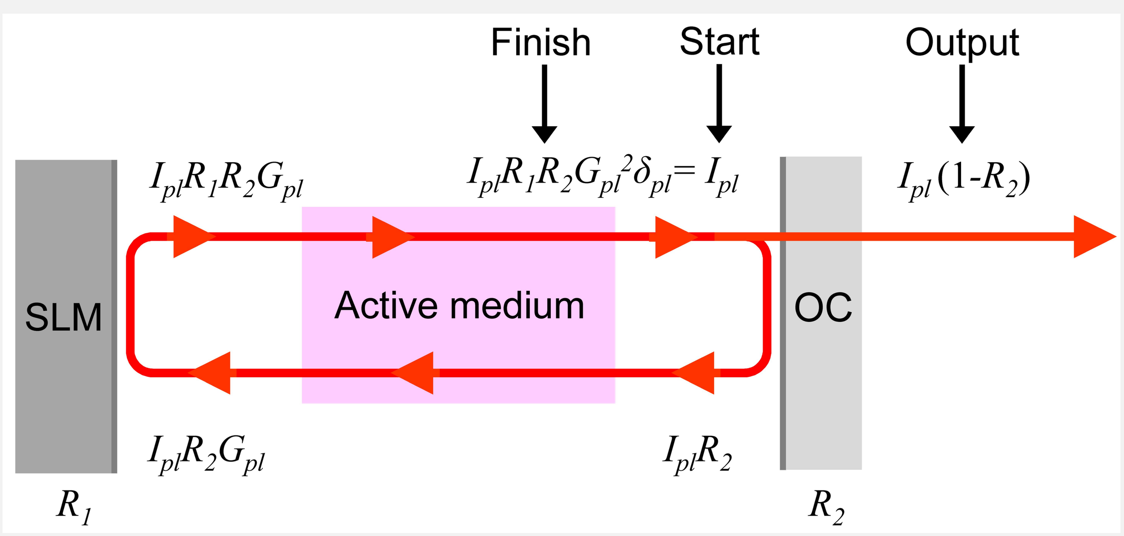
Abstract

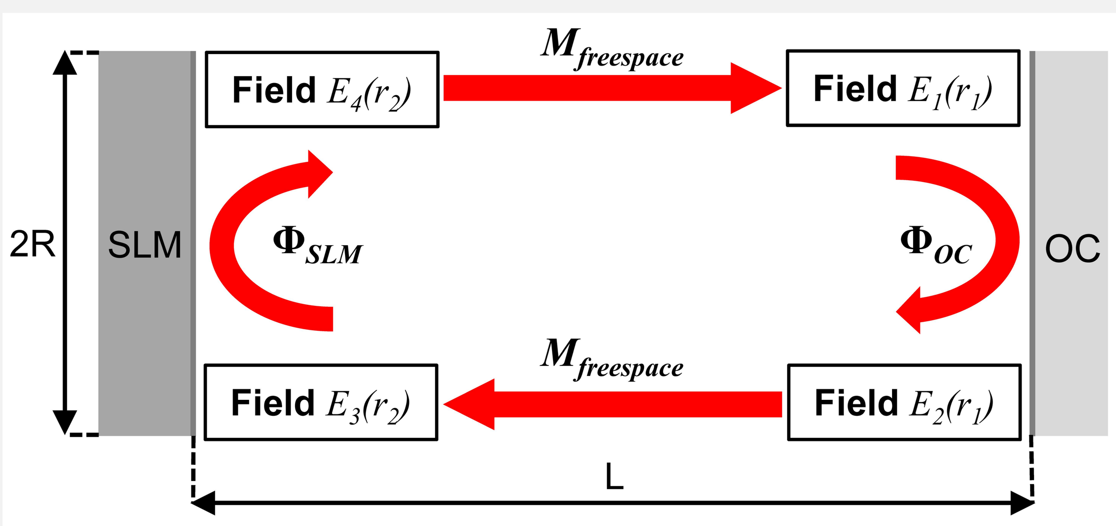
By utilizing customized intra-cavity optical elements including graded-phase mirrors, variable reflectivity mirrors, aspherical mirrors, diffractive optical elements and spatial light modulators, the mode discrimination of the cavity is enhanced and a pre-determined transverse mode, usually flat-top beams such as super-Gaussian beams or flattened-Gaussian beams, can be generated in the cavity. The design of such laser cavities oscillating in a predetermined transverse mode is commonly based on the concept of phase conjugation, whereby the desired phase profile of optical element is obtained by reversely propagating the predetermined transverse mode and creating a conjugate field to propagate back. However, this procedure is only accurate under the assumption that the mirror size is infinite and the propagation process is in a lossless manner. Moreover, the parameters of the pre-determined mode, such as beam size and amplitude distribution, must be carefully chosen or else non-negligible errors would occur due to finite-size apertures and associated truncation. Here, we report on a simple and effective approach for intra-cavity mode control based on optimizing the single-mode power factor, which represents the total power extracted by a single mode from the active medium. By optimizing the single-mode power factor of the desired mode, the cavity can be designed to operate in mono-mode, increasing the mode purity significantly. Our method is verified on a digital laser with a spatial light modulator as the rear mirror and the loaded phase profile is acquired by a simulated annealing algorithm. As a result, when the single-mode power factor of TEM_{00} mode is optimized, the resonator operates in a single fundamental mode. When the single-mode power factor of the vortex mode with a topological charge of 1 is optimized, the output mode purity is close to 100%.

Theoretical model

Intensity amplification in solid-state laser cavity:



Field propagation process in a roundtrip:

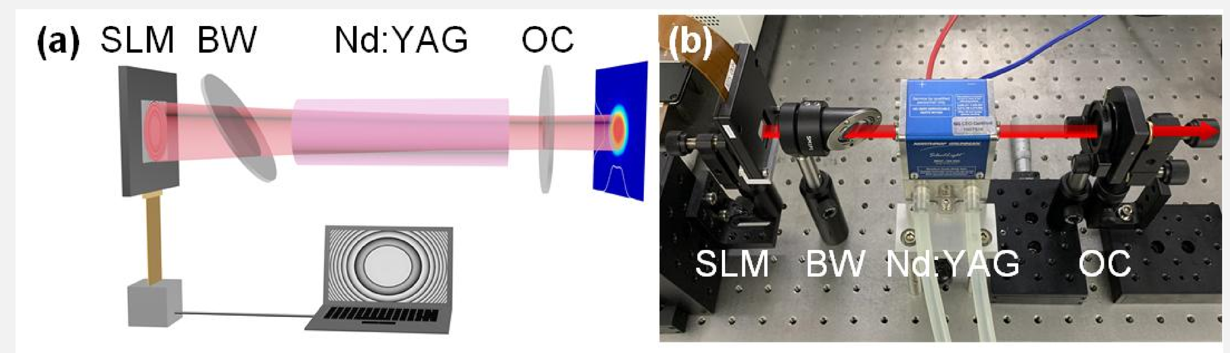


Definition of single mode power factor (SMPF):

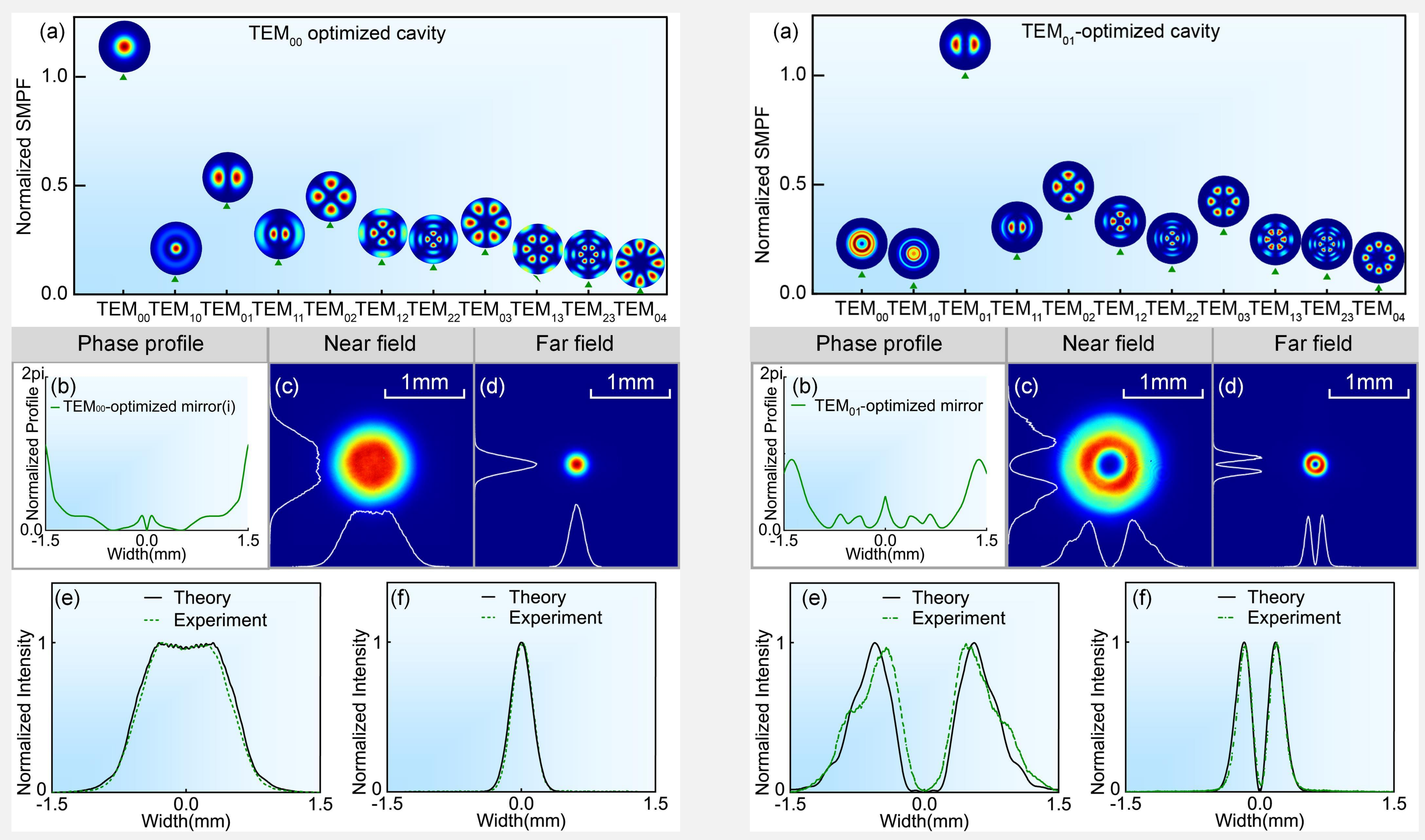
$$SMPF_{pl} = A_{pl} I_{pl}(1-R_2) = A_{pl} I_s (1-R_2)\left[\left(\frac{g_0 l}{|\ln(\sqrt{R_1 R_2 \delta_{pl}})|}\right)^{\frac{1}{x}} - 1\right]$$

Optimization and experiment

Schematic configuration of "digital" Nd:YAG laser:



Experiment results of the output beam from TEM_{00}-optimized and TEM_{01}-optimized optimized laser cavities.



Conclusion

1. A parameter, SMPF, to describe the mode discrimination ability of a resonator.
2. A general approach for the intra-cavity mode control with high power and high brightness is proposed.

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