Gradient-Index Optics for Laser Applications

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INTRODUCTION

Lasers are employed in many optical technologies owing to their high coherence and directionality. In most applications, the laser resonator is engineered to operate in the fundamental transverse mode. The phase profile, or wavefront, of such a mode is one of the factors that determines the influence of diffraction as the beam propagates. Since the fundamental mode has the highest intensity and lowest angular divergence of all cavity modes[1], the ability to select it from the laser cavity is paramount for good device performance. The purpose of our research is to design an optics which can retain the intensity of fundamental mode and increase loss of higher-order modes.

METHOD

We will perform mode selection using a wavefront distortion and compensation technique by introducing specialized optics into a laser cavity. As illustrated in Fig. 1, the wavefront of the beam will be distorted as it propagates to the left using a prototype gradient-refractive-index (GRIN) optic. The wavefront distortion applies to all cavity modes, including the fundamental. At the rear of the cavity is a spatial light modulator (SLM), which has replaced one of the cavity mirrors. This is an electronically-addressed optical device that can alter the phase profile of an incoming wave.

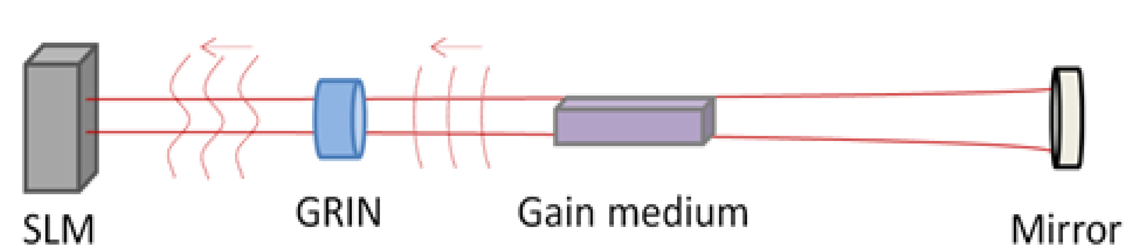

Figure 1: Laser cavity design. A spatial light modulator (SLM) and gradient-index (GRIN) optic perform conjugate wavefront distortion to improve mode selection.

PROCEDURE

In order to get the optimized GRIN index profile, we must to develop the algorithm to simulate the beam propagation in the resonator with GRIN and SLM. We first generated Gaussian Beam in the resonator without GRIN and SLM using MATLAB. We used Fourier Transform to simulate the beam propagation and got the intensity profile and index profile showed as Figure 2 and Figure 3. The GRIN we had has the index profile showed as Figure 4.

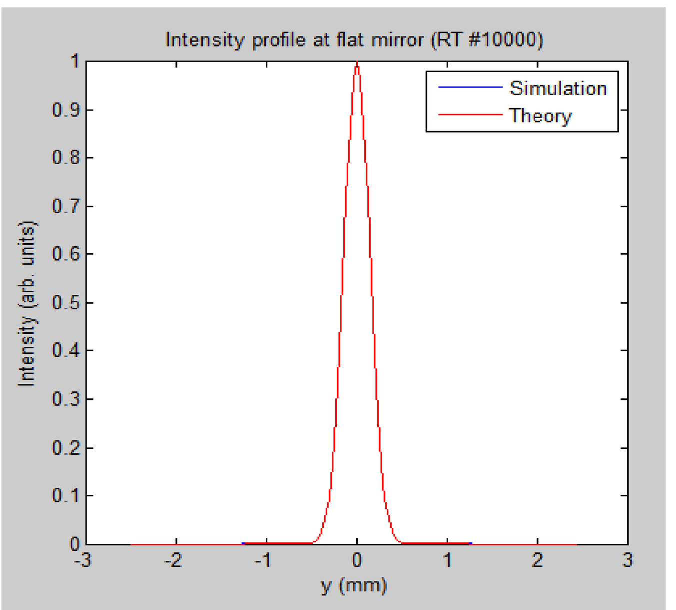

Figure 2: Intensity profile at flat mirror

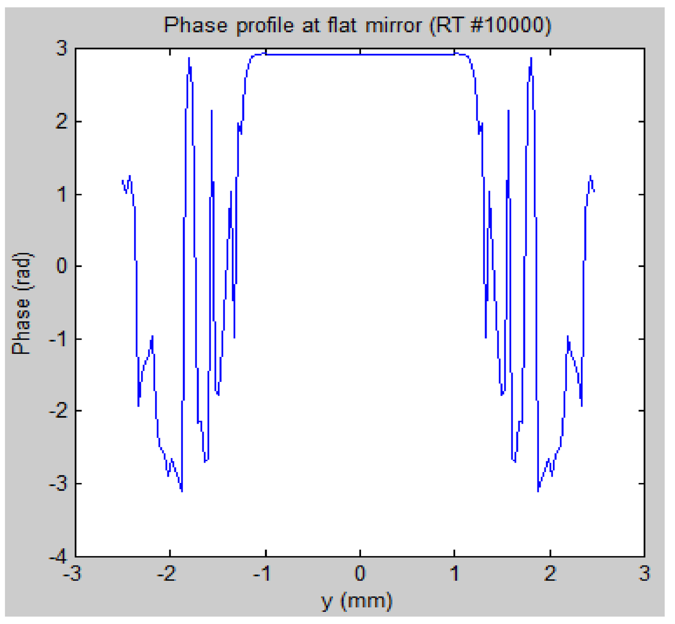

Figure 3: Phase profile at flat mirror

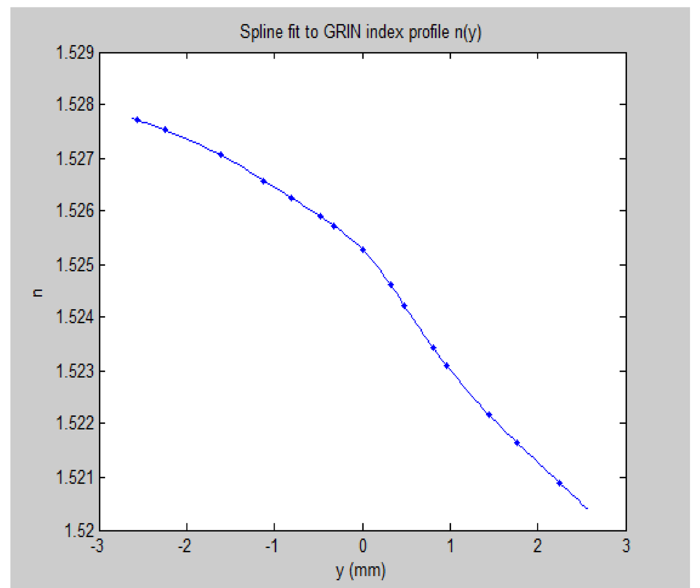

Figure 4: Actual GRIN index profile

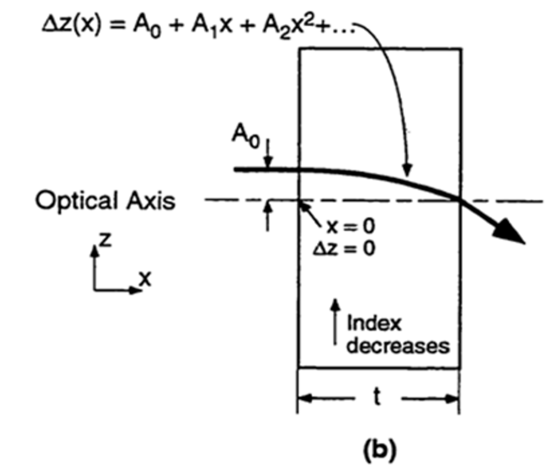

Figure 5: Diagrams for calculating Δn from the measured optical phase. (a) Thin phase object approximation for Δn calculation. (b) Diagram for the second-order correction term that accounts for the curved ray path within the sample.

The key point is to calculate the ray-position during the propagation in the GRIN. According to Southwell[2], we have the equation[2] $\frac{d}{ds}\left(n\frac{dr}{ds}\right) = \nabla n$, where r is the ray-position vector and n is the media index. It is hard to calculate the according to this difference equation because we cannot easily express the index as a function in order to calculate its gradient. Fortunately, we have a good approximation method to simulate the propagation in the GRIN: treat the beam pass as parabolic[3], which is showed as Figure 5.[3] With this approximation, we get the intensity and phase profile at the SLM as Figure 6.

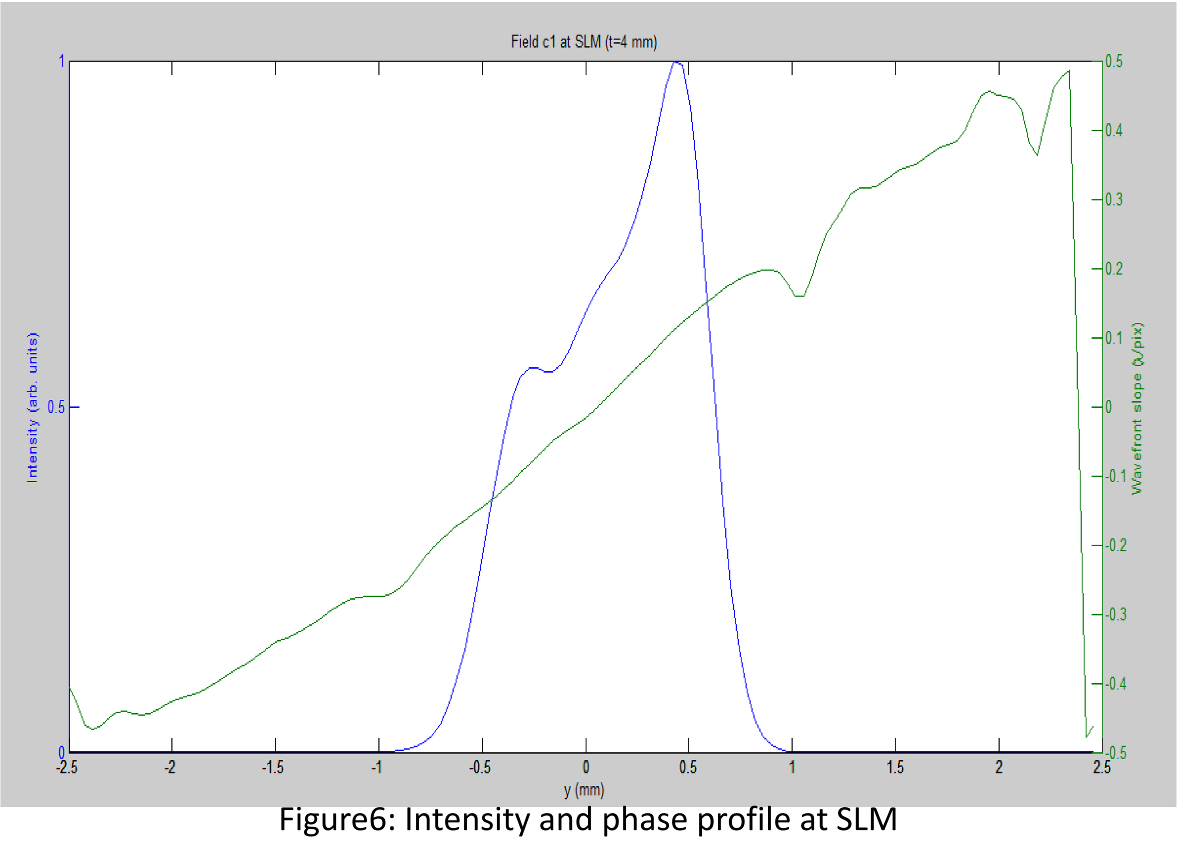

Figure6: Intensity and phase profile at SLM

After applying the same algorithm to the backwards propagation, we get the phase profile and intensity profile after GRIN, which showed as Figure 7. This phase and intensity profiles are what we expected.

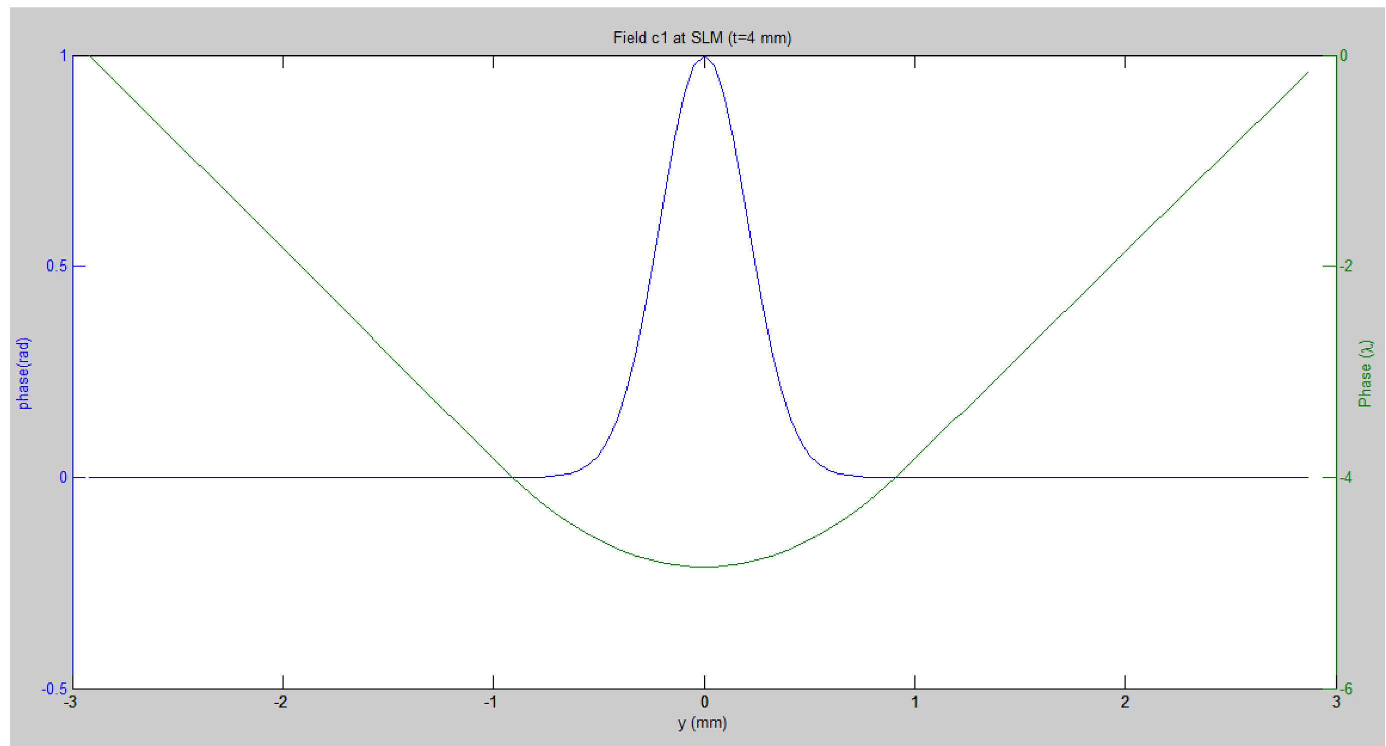

Figure 7: Intensity and Phase profile after GRIN

RESULT

Improvements to the modal discrimination can result in significant changes to laser dimensions and performance. Our design improves modal discrimination and reduce the cavity length. In summary, our laser design enables the production of small, highly efficient lasers using a GRIN optic in a conjugate-distortion cavity.

Due to some numerical approximation, we did not get the exactly conjugated phase for Gaussian beam. Therefore, the next stage is to revise the algorithm to reduce the uncertainty to make the Gaussian beam phase conjugate. After that, we can characterize the index profile of GRIN as a function of coordinate to calculate the mode discrimination in order to get the best GRIN index profile.

REFERENCE

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2. W.H. Southwell, "Ray tracing in gradient-index media," *The Journal of the Optical Society of America,* vol. 72, no. 7, p.908, July 1982.
3. C. E. Saxer. Interferometric characterization of the chromatic dispersion of gradient-index glasses. *ProQuest Dissertations and Theses p. 1998.*

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