PROPAGATING FIELDS

Improving the Beam Quality Of High-Order Laser Modes

A. Ishaaya, R. Oron, N. Davidson, E. Hasman, and A.A. Friesem

In recent years new methods for operating a laser with a single high-order transverse mode have been reported.[1] These methods, which have included the insertion of binary and spiral phase elements within various laser resonators, have resulted in higher output power due to the larger mode volume of high-order modes. But since the beam propagation factor (M^2) of high-order modes is larger then that of the fundamental mode, the beam quality of high-order modes is considered degraded compared to that of the fundamental mode.

Analysis of beam quality by means of entropy shows that the entropy of a single high-order mode is equal to that of a single Gaussian mode.[1] Thus it is allowed thermodynamically to transform without losses a high-order mode beam into a Gaussian beam. Recently we demonstrated a practical and efficient method of transforming a single high-order Laguerre-Gaussian helical mode into a nearly Gaussian mode, leading to a significant improvement of the M^2 parameter.[2] In our experiments, a high-order TEM_{01^*} helical mode beam was generated by using a spiral phase element and a cylindrical lens within the laser resonator[3] (Fig. 1). The external spiral phase element changes the phase of the beam so as to produce a uniform phase front yielding a high central lobe surrounded by a ring-shaped side lobe in the far field. The new M^2 is equal to the square root of the original M^2, thus allowing for considerable improvement in the beam quality. The spatial filter eliminates the ring-shaped side lobe, resulting in further improvement of the M^2 (M^2<1.1) with an insignificant decrease in power.

Using a more generalized approach, we have shown that in the case of a laser operating with several high-order modes, an improvement of the M^2 is also possible.[4] This can be achieved by examining the Wigner distribution function (WDF) of the laser beam. For lasers operating with the fundamental Gaussian mode or multimodes, the actual and envelope volumes of the WDF coincide, whereby the envelope is completely full. However, for lasers operating with either a single or a few high-order modes, the envelope volume of the WDF is significantly larger than the actual volume. Thus, according to the Wigner algebra, it may be possible to reduce the WDF envelope volume towards that of the actual volume, thereby obtaining a beam with lower M^2. We have demonstrated this using a laser operating with only two mutually incoherent transverse modes $TEM_{1,\pm1}$, whose M^2 value is 4. Using an annular binary phase plate and a spatial filter, we reduced the envelope volume of the WDF, obtaining improved beam quality (M^2~2) with an efficiency of 76%. A further improvement in the beam quality was obtained by combining modes of orthogonal polarization.[5]

In conclusion, the optimal beam quality depends on the initial *number* of modes, not necessarily on the *highest order* mode, as would be expected on the basis of the M^2 criterion.

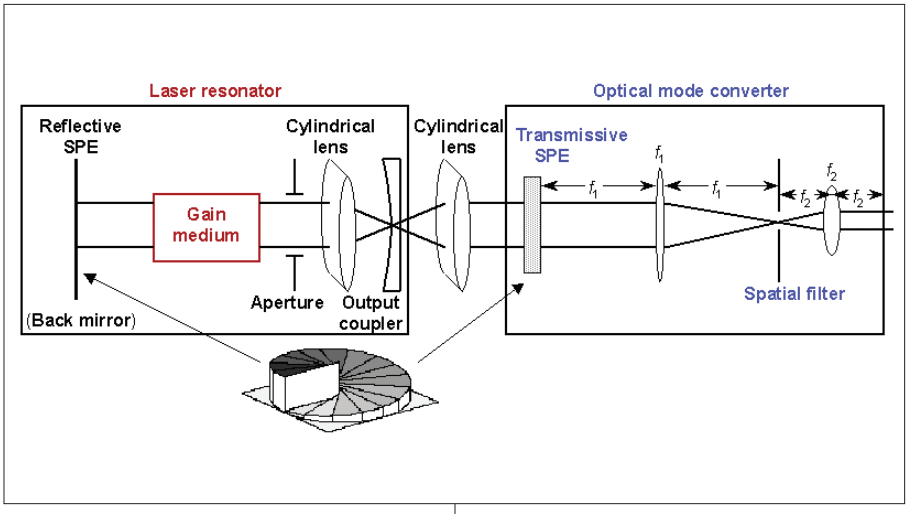

Figure 1. Basic laser resonator configuration for generating a high-order helical beam and an optical mode converter that yields a nearly Gaussian mode. The reflective SPE and the cylindrical lens inside the laser resonator generate the TEM_{01^*}, which is externally collimated by the additional cylindrical lens. The transmissive SPE and the spatial filter transform the beam into a nearly Gaussian beam.

References

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A. Ishaaya, R. Oron, N. Davidson, A. A. Friesem, Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot, Israel and E. Hasman, Optical Engineering Laboratory, Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa, Israel.