Spatial Laser Beam Characterization and Propagation

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The talk is intended to gradually introduce the three levels to understand the spatial laser beam characterization and beam propagation: the elementary level, the current level, and the advanced level. At the elementary (textbook) level, the concept of idealized Gaussian beam (IGB) is introduced and its spatial parameters and propagation properties are discussed. The closest IGB physical realization is the rotationally symmetric beam from a low power TEM_{00} laser. Real beams are never IGB, and depart more or less from this idealized description. However, by using the moments of the beam irradiance (up to second-order) as an averaged description of the beam spatial parameters, a close similarity to the properties of the IGB is obtained. Because of this similarity and the corresponding advantages, the second-order moments is the current method used to characterize the laser beams, and it is also selected as the basis of several beam-related standards developed by the International Organization of Standardization (ISO). An important parameter in the current beam characterization is the so-called "beam propagation ratio" M^2 (or "beam quality parameter", "beam propagation parameter", etc), which is a beam-related invariant number, $M^2 \geq 1$, unchanged at the beam propagation through optical systems that are linear (aberration free), lossless, passive, and centered (called ABCD-type systems). The second part of the talk is dedicated to the current status of beam characterization and of the associated ISO standard. An important physical assumption in the current mathematical treatment is that the beams have independent properties along two orthogonal transverse directions, x and y (decoupled properties); these beams are called simple astigmatic (SA) beams, as opposed to the beams with identical properties in any transverse direction, named stigmatic (ST) beams, which have also rotationally symmetric properties. In the third part, the beams with coupling between the x and y coordinates, called general astigmatic (GA) beams are introduced and discussed. New and interesting features are specific to the GA beams, as, for example, the impossibility to use M^2 as a beam invariant, the existence of GA beams looking similar to the ST and the SA ones but containing a hidden general astigmatism (named pseudo-symmetrical beams), beams carrying optical orbital angular momentum, etc. The advanced level briefly discusses some important results as: finding the most general two independent invariants for any beam, including the GA beams (named the intrinsic astigmatism a and the effective beam propagation ratio M_{eff}^4, or alternatively the maximum intrinsic astigmatism a_M); beam classifications based on the intrinsic beam properties and also on their geometrical properties manifested in the matrix of second-order moments; methods for measuring any beam without prior knowledge of its character (GA, SA, or ST); solving the problem of beam transformation (GA→ SA→ST, or in the reverse order) by using their intrinsic equivalence; and the status of the ISO standard 11146 on characterizing and measuring GA beams. A brief experimental demo involving beam transformations by a VariSpot® optical system (developed by Astigmat) ends the presentation.