OPTICAL BEAMS

White Light Takes Shape

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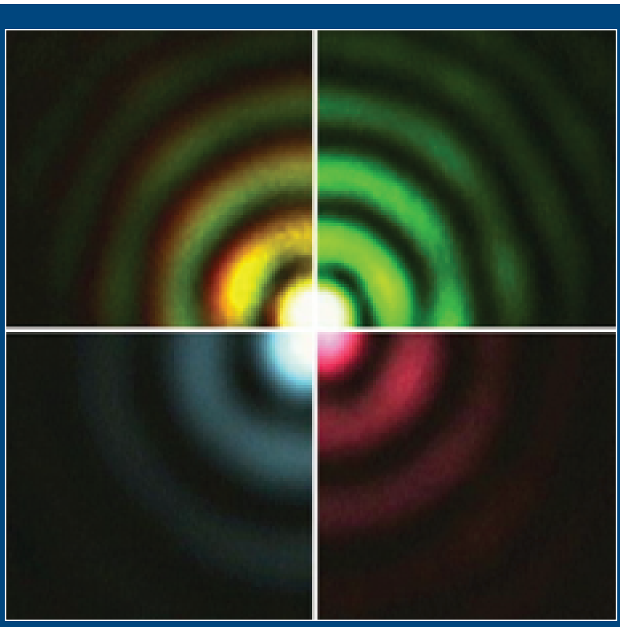
Coherence in both the temporal and spatial domains is central to understanding the rich and diverse range of phenomena involving light and matter interactions. Indeed, the ability to predict the relative phases between light beams, for instance, may lead to well-defined interference. With broadband light that has relatively poor phase coherence, interference is observed in the temporal domain only when the optical path lengths are matched, as exploited for optical sectioning using coherence tomography.

By contrast, lasers more typically exhibit outstanding spatial and temporal coherence properties. These sources normally operate with a Gaussian output beam profile but recently more specialized light patterns have enabled dramatic impacts to be made in many areas of physics. The Bessel beam is a primary example in this respect and represents an intriguing propagation invariant or pseudo "non-diffracting" light source. Durnin elucidated the zeroth-order Bessel beam solutions for the free-space scalar wave equation: The beam comprises a narrow central region surrounded by a series of concentric rings.[1]

So how may we interpret this Bessel beam? Any light beam can be thought of as a superposition of plane waves. As the waves propagate, they experience relative phase shifts. In most cases, each plane wave component suffers a distinctive phase shift such that the resultant beam—the interference pattern of the plane waves changes shape. There exist, however, particular light beams where the phase shift is the same for each plane wave component. These beams are invariant on propagation and therefore may be considered "diffraction-free."

An approximation to such a beam may be realized with a conical lens known as an axicon. This also leads one to ask the following question: If all of the component waves for such a beam traverse the same distance (and equivalent phase shift), could such a non-diffracting beam be made without having a temporally coherent source? In other words, would it be possible to sculpt or shape white light to form such a beam?



The white light Bessel beam and its spectral composition. The top left shows a quadrant of the white light Bessel beam. We observe the Bessel beam through various interference filters at 500 nm (top right), 700 nm (bottom right) and 850 nm (bottom left).

In recent work, we have explored the generation of such "non-diffracting" light fields using broadband and incoherent light sources.[2] We have made "white" Bessel light modes from laser diodes operating below threshold, supercontinuum light sources and even halogen bulbs. The main criterion we found was the need to ensure good spatial coherence in the light field. Remarkably, the superposition of the conical wave-vectors arising from passage through the axicon and the inherent absence of chromatic aberration results in a pure focal line of white light.

White light sources such as these are coming to prominence for a wide variety of applications, including imaging using optical coherence tomography[3] as well as fundamental studies of light propagation, angular momentum, depth penetration,[4] micro-manipulation[5] and quantum information. We anticipate that exploiting the coherence properties of light in combination with sculpting the wavefronts should lead to new and unexpected innovations in these fields in the future.

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