High-Resolution Spatial and Spectral Characterization of Optical Fields

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Applications in areas including microscopy, lithography and data storage rely on the properties of optical fields structured at subwavelength scales. Recently, the exploitation of various subwavelength characteristics of the near field has also generated a considerable amount of interest.[1] In these experiments, significant challenges—usually out of reach of conventional techniques—must be overcome before the full spectral characterization of the field amplitude and phase can be achieved. First, evolving wave fields can have wave-front dislocations; these are points at which the field amplitude vanishes and the measurement requires high sensitivity over a large range of intensities. Second, the superposition of propagating waves can lead to superoscillations or spatial structures on scales smaller than the wavelength, a factor which imposes severe requirements on spatial resolution. Third, for light that is essentially polychromatic, sometimes measurements of steady-state fields need to be performed; in this case, interpretation of the concept of phase is not straightforward.[2,3]

We have developed a novel interferometric technique that permits high sensitivity measurements of the spectral properties of light over narrow spatial regions. The experiment is schematically illustrated in Fig. 1 and more details can be found in Ref. 4. The optical path lengths in the single-mode interferometer are such that the reference field is equivalent to the reflection from point P_1 in the origin of measurement plane. If the point-like mirror is translated at a different point P_2 situated at a small distance ρ from the origin, one can measure the cross-spectral density between light vibrations at P_1 and P_2. In Fig. 1, we illustrate the spectral and spatial resolution capabilities of our technique by presenting evidence for the remarkable spectral anomalies in the neighborhood of phase singularities of diffracted focused waves.[5] Note the π jump in the phase of the cross-spectral density corresponding to the phase dislocation in the Airy ring. To our knowledge, this was the first direct measurement of the complex field in the focal plane of a convergent lens.

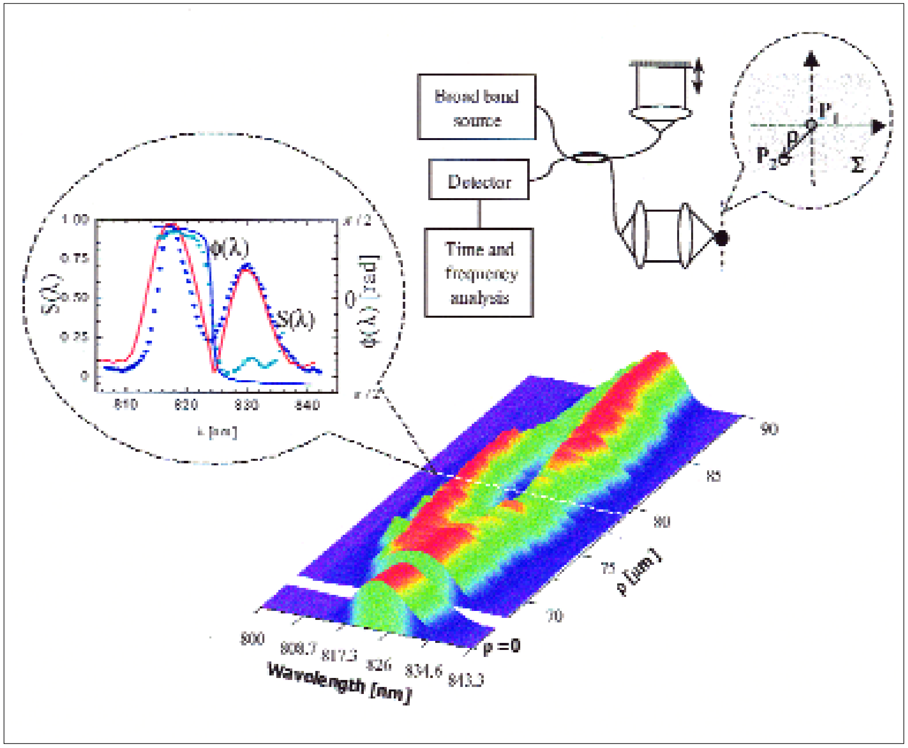

Figure 1. A single-mode interferometer is used to measure the cross-spectral density in the plane Σ, where a point-like mirror acts as a narrow band-pass filter for the spatial frequencies. Also shown is the anomalous behavior of the optical spectral density and the spectral phase in the neighborhood of an Airy ring produced by focusing a truncated Gaussian beam.

Interference is essential for producing phase singularities or dislocations. However, the presence of singular points is not limited to deterministic fields and we have found similar anomalous spectral behavior in random wave fields—speckle patterns—that result from the interaction between coherent or partially coherent waves and inhomogeneous media such as rough surfaces or multiple scattering volumes.[4]

Our results suggest that new possibilities exist for manipulating optical spectra and, because these spectral properties are specific to critical points of optical fields, there are fundamental consequences for field reorganization phenomena at subwavelength scales. Understanding the rich behavior of the optical phase should be of paramount interest in the practice of imaging and scattering techniques dealing with the interaction between light and heterogeneous matter.

References

1. M. Ohtsu and H. Hori, Near-Field Nano-Optics, Kluwer, (1999).
2. E. Wolf, Opt. Lett., (in press).
3. A. Dogariu and G. Popescu, Phys. Rev. Lett., (in press).
4. G. Popescu and A. Dogariu, Phys. Rev. Lett. **88**, 183902, (2002).
5. G. Gbur, T. D. Visser, and E. Wolf, Phys. Rev. Lett. **88**, 013901 (2002).

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