ADVANCES IN PUPIL FILTERS FOR MICROSCOPY APPLICATIONS

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1. INTRODUCTION

There has been continuing interest in the use of pupil filters or masks, placed in the back focal plane of a lens to alter the imaging properties of the lens. Filters can be either superresolving or apodizing in both the transverse and longitudinal directions [1]. Use of a liquid crystal phase modulator is a convenient and flexible way to implement filters [2]. Filters can be of phase only, modulus only or mixed types. Although it is often stated that phase only filters are preferable because of their lower loss, this may not be true for many applications. Although amplitude filters have a lower Strehl ratio, the loss results in weaker side-lobes. Filters can be used in confocal systems [3] or in multiphoton microscopy [4], and in both cases the side-lobe levels can be reduced.

2. FILTER PERFORMANCE PARAMETERS

Simple performance parameters have been introduced that can be calculated from the pupil without it being necessary to calculate the focused field [1]. Although it is not often realized to be possible, these have been generalized to the non-paraxial, high aperture case, including vectorial cases for different polarization distributions including plane polarized illumination, the electric dipole field distribution and radially polarized illumination. They have also been applied to 4Pi microscopy. For phase filters, an axial shift in the diffraction focus may result [5]. Improved expressions for the parameters for a small axial shift have been developed. A simple filter consisting of two rings has been investigated in depth, and is found to exhibit a complicated range of different effects. For the case when the axial shift cannot be assumed small, an alternative approach of calculating the parameters relative to the diffraction focus has been used [6].

3. APPLICATIONS

We investigate two different applications of phase filters. In the first, a phase mask is used to improve the focused spot in second harmonic microscopy with radial polarization. A liquid crystal modulator is used both for generating the radially-polarized light and as a phase mask. In the second, a phase mask is used to increase the depth of focus in optical coherence tomography (OCT).

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