Optica Applicata, Vol. XXVIII, No. 3, 1998

Letters to the Editor

Imaging of the clear slit in a two-photon coherent fluorescent microscope equipped with a pupil filter of $1-x^2, x^2$, and Lanczos types

ANNA MAGIERA

Institute of Physics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50–370 Wrocław, Poland.

In this paper, the imaging of the clear slit in a coherent two-photon fluorescence microscope (C2P) with a circular pupil and the pupil filters of $1-x^2$ and x^2 types as well as the circular ($\varepsilon = 0$) and annular ($\varepsilon = 0.5, 0.8$) pupils and Lanczos pupil filter outside the point of inflexion is demonstrated.

In paper [1] the authors showed the light intensity distribution in the clear slit image in a scanning microscope (CSM) equipped with a circular apodized Lanczos filter and determined the values of the point of inflexion for a constant value of parameter controlling the Lanczos filter transmittance β and the annular obstruction ε. In paper [2], the intensity distribution in the image of a clear slit in a nonapodized C2P with a pupil of circular ($\varepsilon = 0$) and annular ($\varepsilon = 0.5, 0.8$) shapes has been shown and the values of the point of inflexion for nonapodized C2P with annular pupil ($\varepsilon = 0$, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8) have been determined and the clear slit image at the point of inflexion has been determined.

In this paper, the imaging of the clear slit in a two-photon C2P with a circular pupil and the pupil filters $1-x^2$, x^2, as well as circular ($\varepsilon = 0$) and annular ($\varepsilon = 0.5$, 0.8) pupils and the Lanczos filter outside the point of inflexion is shown.

The intensity distribution in a CSM is described by the relation

$$I_{\mathrm{CSM}} = |A \otimes (h_{\mathrm{obj}} h_{\mathrm{coll}})|^2$$

where: A – the amplitude transmission of the object, h_{obj} and h_{coll} – the amplitude spread function in the objective and collector, respectively, while $\otimes$ means convolution.

In the two-photon C2P the intensity distribution is described by the dependence [3]

$$I_{\mathrm{C2P}} = I^2\left(\frac{u}{2}, \frac{v}{2}\right) I(u,v)$$

where: $I(u,v)$ – point source intensity, (u,v) – axial and radial normed optical coordinates:

$$u = 4kz\sin^2(\alpha/2), \quad v = kr\sin\alpha, \quad k = \frac{2\pi}{\lambda}.$$

For an object in the form of a slit of halfwidth u_0 and the amplitude transmittance

$$A(u,v) = \begin{cases} 1 \text{ for } |u| \leqslant u_0, \\ 0 \text{ for } |u| > u_0, \end{cases}$$

the light intensity in the slit image in C2P apodized with a annular pupil ε is described by the dependence [2]

$$I(z) = \left[\left(4u_0\int_{\varepsilon}^{1}\frac{\sin(2\pi u_0 x)}{(2\pi u_0 x)}A^*\cos\left(z\frac{x}{2}\right)dx\right)^2\right]^2\left[4u_0\int_{\varepsilon}^{1}\frac{\sin(2\pi u_0 x)}{(2\pi u_0 x)}A^*\cos(zx)dx\right]^2$$

where: A^* takes respectively the forms:

$$A^* = 1-x^2,\ x^2,\ \frac{\sin(\beta\pi x)}{(\beta\pi x)}\text{(Lanczos)}.$$

In Figure 1, the intensity distribution is shown for C2P with a circular pupil ($\varepsilon = 0$) and the pupil filter of $1-x^2$ type for a slit width: $u_0 = 0.5$ (Fig. 1**a**), $u_0 = 1.0$ (Fig. 1**b**), $u_0 = 1.5$ (Fig. 1**c** and Fig. 1**c**′, where **c**′ shows an enlarged fragment of Fig. 1**c**)*, $u_0 = 2.0$ (Fig. 1**d**) and $u_0 = 2.5$ (Fig. 1**e**). In Figure 2 the light intensity is shown for C2P with a circular pupil ($\varepsilon = 0$) and with a filter of x^2 type for the slit width: $u_0 = 0.5$ (Fig. 2**a**), $u_0 = 1$ (Fig. 2**b**), $u_0 = 1.5$ (Fig. 2**c**), $u_0 = 2.0$ (Fig. 2**d**), $u_0 = 2.5$ (Fig. 2**e**). The light intensity distribution for C2P with a circular pupil ($\varepsilon = 0$) and a Lanczos filter ($\beta = 0.5$) are presented in Fig. 3 for the width: $u_0 = 0.5$ (Fig. 3**a**), $u_0 = 1.0$ (Fig. 3**b**), $u_0 = 1.5$ (Fig. 3**c**), $u_0 = 2.0$ (Fig. 3**d**), $u_0 = 2.5$ (Fig. 3**e**). In Figure 4 the light intensity distribution for C2P with the annular pupil ($\varepsilon = 0.5$) and Lanczos filter ($\beta = 0.5$) for slit width: $u_0 = 0.5$ (Fig. 4**a**), $u_0 = 1.0$ (Fig. 4**b**), $u_0 = 1.5$ (Fig. 4**c**), $u_0 = 2.0$ (Fig. 4**d**), $u_0 = 2.5$ (Fig. 4**e**) is shown, and in Fig. 5, the light intensity distribution is presented for C2P with an annular pupil ($\varepsilon = 0.8$) and the Lanczos filter ($\beta = 0.5$) for the slit width: $u_0 = 0.5$ (Fig. 5**a**), $u_0 = 1.0$ (Fig. 5**b**), $u_0 = 1.5$ (Fig. 5**c**), $u_0 = 2.0$ (Fig. 5**d**), $u_0 = 2.5$ (Fig. 5**e**).

In the C2P an improvement of the fringe structure in the intensity distribution in the slit image (Fig. 1) occurs as compared to that which takes place in a CSM. Moreover, it is true both for nonapodized C2P [2] and apodized one by a $1-x^2$ filter. The latter filter, as it was shown in work [4] is an apodized filter in the transverse and axial directions. The Lanczos filter for $\varepsilon = 0$ shows a similarity to the filter $1-x^2$ (Figs. 1, 3). The filter x^2 is superresolving in the transverse direction and apodizing in the axial direction which was shown in the paper [4]. Some change in the intensity ratio in the maxima is observed for $\mu_0 \geqslant 1.5$ (Figs. 2**c**,**d**,**e**) in C2P with

* Also below the figures marked with primed letters show some enlarged fragments of respective unprimed figures.

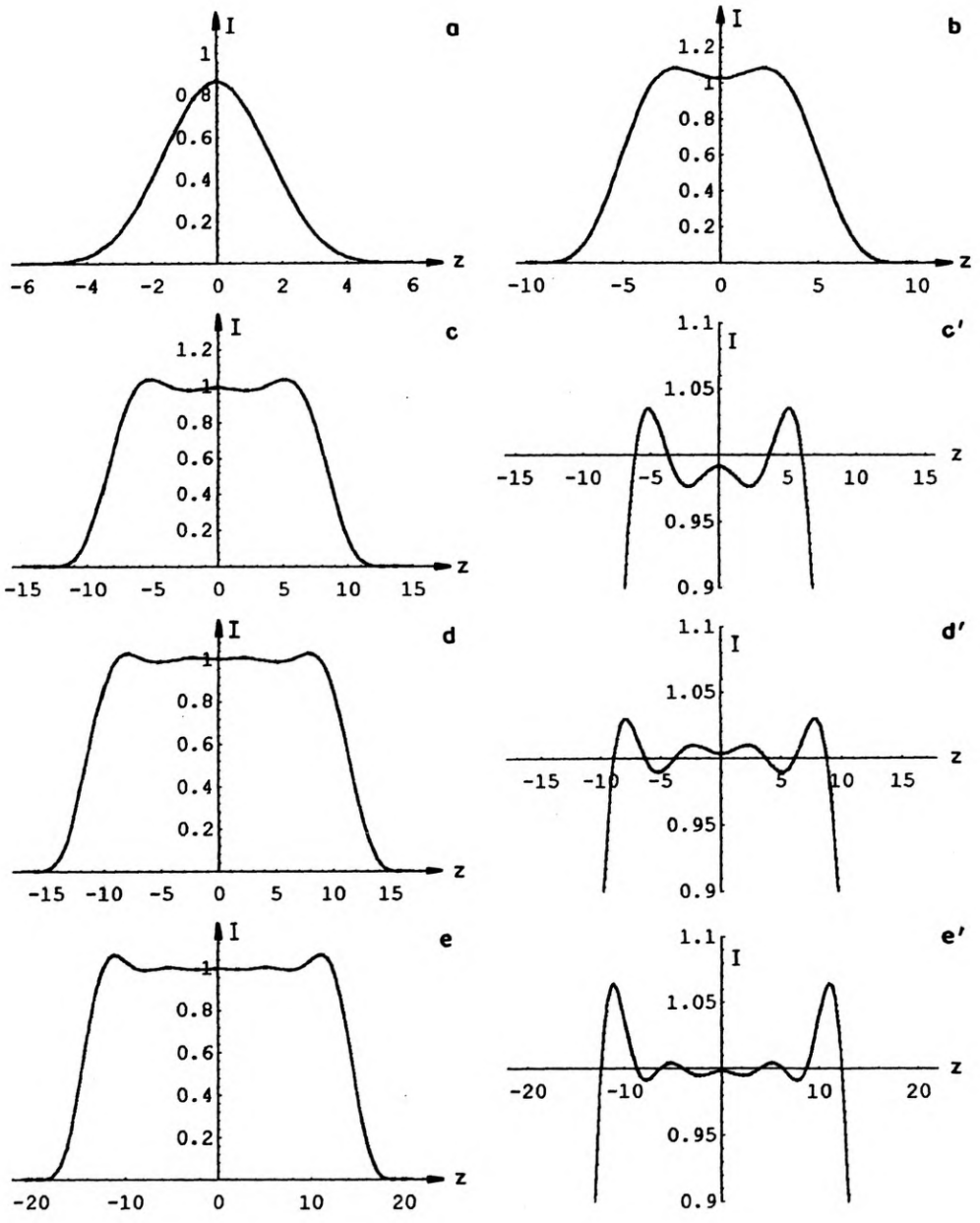

Fig. 1. Light intensity distribution in the clear slit image in C2P with a circular ($\varepsilon = 0$) pupil and a pupil filter $1-x^2$ for slit widths specified in the text

the pupil filter x^2 as well as for $u_0 = 1.5$ $\varepsilon = 0.5$ (Fig. 4c) and $u_0 = 2.5$, $\varepsilon = 0.5$ (Fig. 4e) in C2P with the Lanczos filter. The most faithful image of the slit is obtained at the point of inflexion [2].

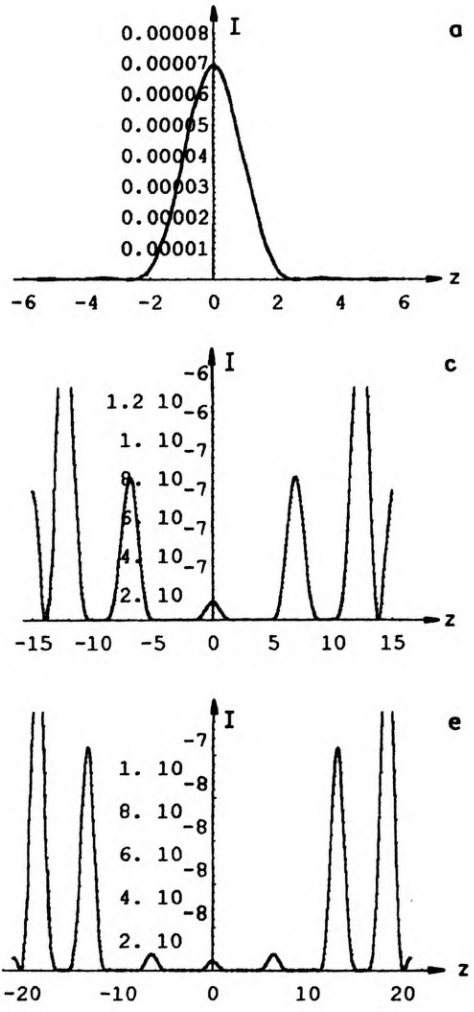

Fig. 2. Light intensity distribution in the clear slit image in C2P with a circualr aperture ($\varepsilon = 0$) and a pupil filter x^2 for the slit widths specified in the text

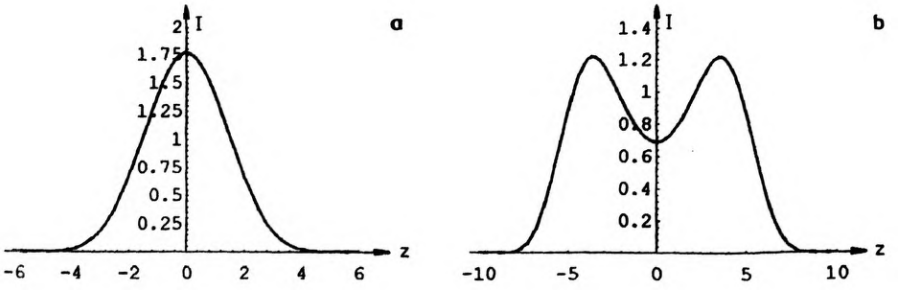

Fig. 3a,b

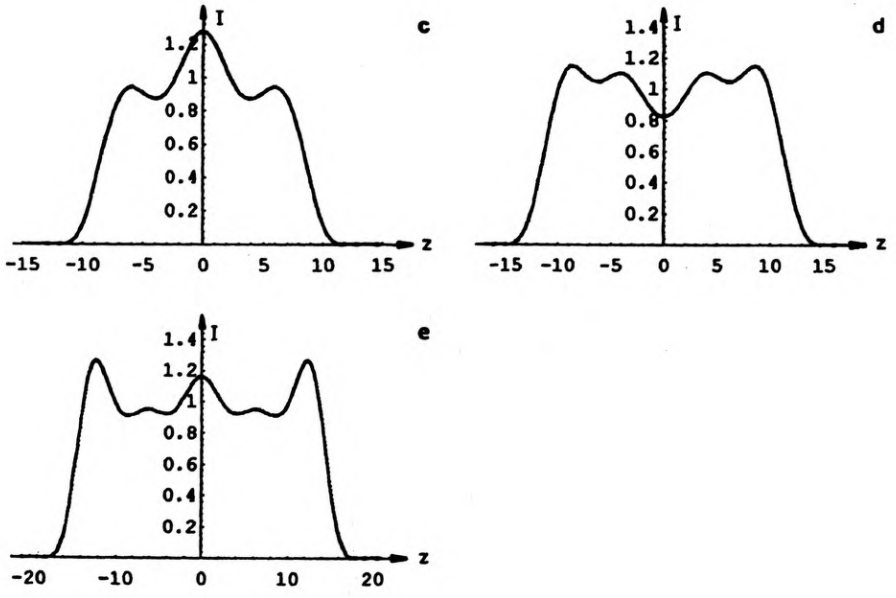

Fig. 3. Light intensity distribution in the clear slit image in C2P with an annular pupil ($\varepsilon = 0$) and a Lanczos filter ($\beta = 0.5$) for slit widths specified in the text

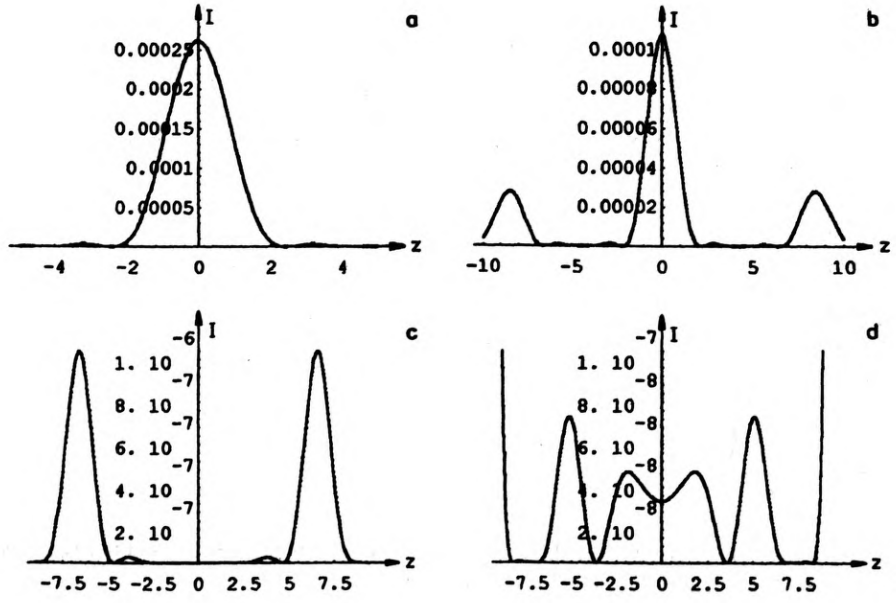

Fig. 4a, b, c, d

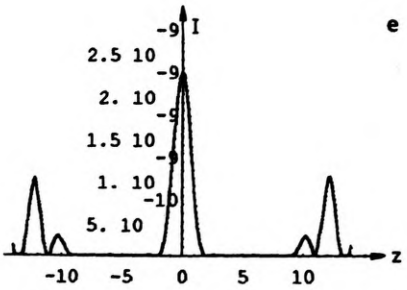

Fig. 4. Light intensity distribution in the clear slit image in C2P with an annular pupil ($\varepsilon = 0.5$) and a Lanczos filter ($\beta = 0.5$) for the slit widths specified in the text

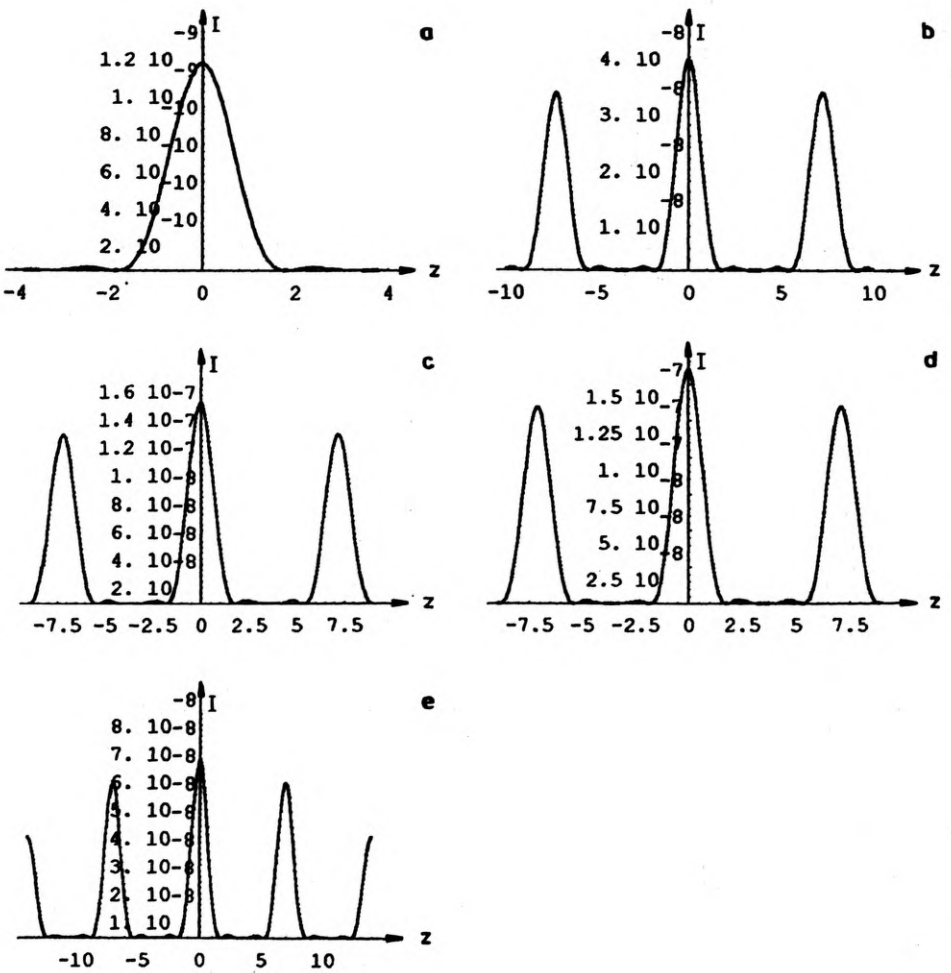

Fig. 5. Light intensity distribution in the clear slit image with an annular pupil ($\varepsilon = 0.8$) and the Lanczos filter ($\beta = 0.5$) in C2P ($\beta = 0.5$) for slit widths specified in the text

References

[1] SURENDAR K., GOUD S. L., DATTA G., MONDAL P. K., Atti Fondaz. Giorgio Ronchi **48** (1993), 693.
[2] MAGIERA A., Opt. Appl. **27** (1997), 291.
[3] SHEPPARD C. J. R., GU M., Optik **68** (1990), 104.
[4] SHEPPARD C. J. R., HEGEDUS Z. S., J. Opt. Soc. Am. A **5** (1988), 643.

Received May 9, 1998