

High performance micro-flow cytometer based on optical fibres

S. Etcheverry^{1,2*}, A. Faridi,³ H. Ramachandraiah,³ T. Kumar³, W. Margulis,^{1,2} F. Laurell,¹ and A. Russom³

¹Department of Applied Physics, KTH Royal Institute of Technology, Stockholm, Sweden.

²Department of Fibre Optics, RISE Acreo AB, Stockholm, Sweden

³Division of Proteomics and Nanobiotechnology, Science for Life Laboratory, KTH Royal Institute of Technology, Solna, Sweden

Supplementary note 1: Theoretical background for excitation and collection of light

The laser beam diverging from the core of the double-clad fiber (DCF) has a Gaussian intensity profile $I(r,z)$ given by:

$$I(r, z) = \frac{2P}{\pi w(z)^2} \exp\left(\frac{-(2r)^2}{w(z)^2}\right) \quad (1)$$

where P is the total power and $w(z)$ is the half width of the beam, which depends on the laser wavelength λ , the refractive index of the medium n and the core diameter d_{core} ,

$$w(z) = \frac{d_{core}}{2} \sqrt{1 + \left(\frac{4\lambda z}{d_{core}^2 n}\right)^2} \quad (2)$$

When the laser beam excites a fluorescent particle, a portion of the fluorescence is collected by the inner cladding of the double-clad fiber and is subsequently measured. The particle can be considered as a point-source located at (r,z) which emits light in all directions. The fraction of the light that reaches the inner cladding is defined by the solid angle¹:

$$\Omega_f(r, z) = 2\pi \left(1 - \cos \left[\tan^{-1} \left(\frac{d_{clad}}{2z} \left(\cos \left(\tan^{-1} \left(\frac{r}{z} \right) \right) \right)^{\frac{3}{2}} \right) \right] \right) \quad (3)$$

where d_{clad} is the diameter of the DCF inner cladding. Additionally, the numerical aperture NA of an optical fiber defines an acceptance solid angle Ω_{NA} ,

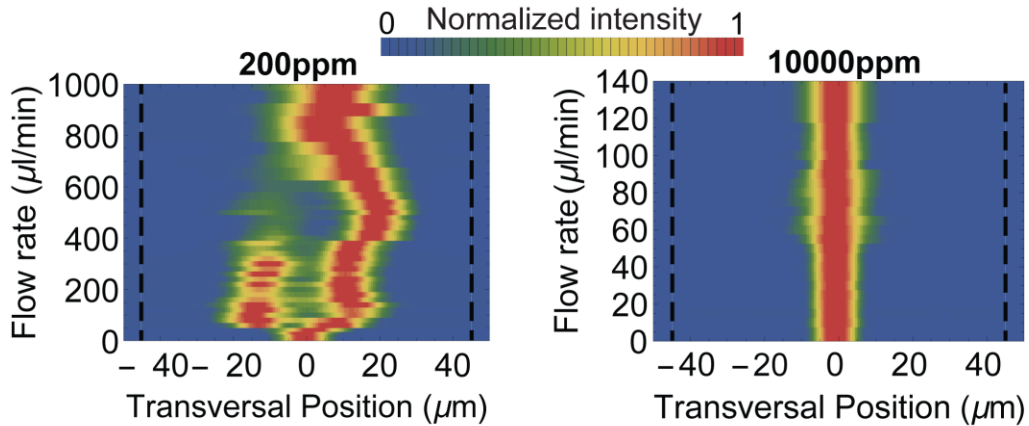
$$\Omega_{NA} = 2\pi \left(1 - \cos \left(\sin^{-1} \frac{NA}{n} \right) \right) \quad (4)$$

Light entering the fiber at angles larger than Ω_{NA} is not guided by total internal reflection and lost. The collection efficiency $\eta(r, z)$ normalized to 4π can be calculated as,

$$\eta(r, z) = \frac{\text{Min}(\Omega_f(r, z), \Omega_{NA}) A(r, z)}{4\pi} \quad (5)$$

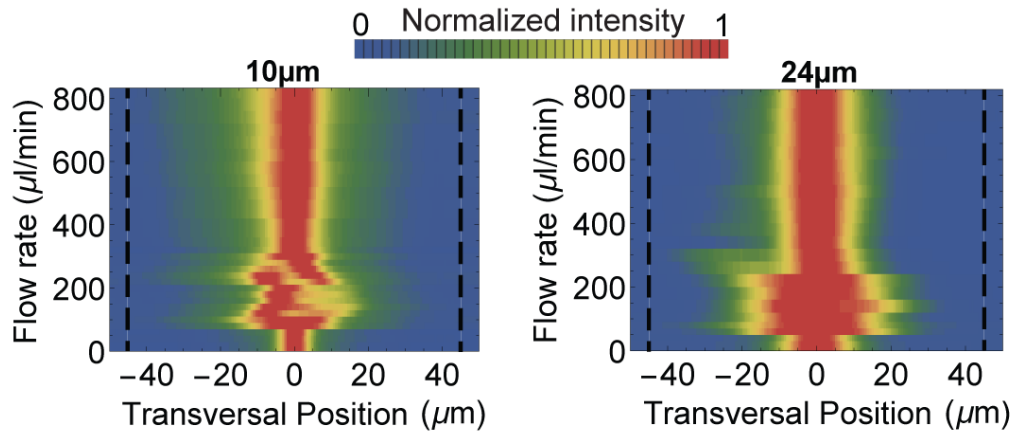
where $A(r, z)$ represents the fraction of the light encompassed by Ω_{NA} that overlaps the DCF inner cladding¹. The collection efficiency $\eta(r, z)$ is constant and maximum for $\Omega_{NA} > \Omega_f$ and decreases with z for $\Omega_f > \Omega_{NA}$.

Supplementary figure 1



Elasto-inertial focusing of 15-μm particles flowing in a 90-μm capillary at different flow rates for PEO concentrations of 200 ppm and 10000 ppm. Dashed black lines define the capillary walls.

Supplementary figure 2



Elasto-inertial focusing of 10- μm and 24- μm particles flowing in a 90- μm capillary at different flow rates/ for PEO concentration of 500 ppm . Dashed black lines define the capillary walls.

References

1. Engelbrecht, C. J., Göbel, W. & Helmchen, F. Enhanced fluorescence signal in nonlinear microscopy through supplementary fiber-optic light collection. *Opt. Express* **17**, 6421–35 (2009).