Progress in Biophysics and Molecular Biology 112 (2013) 118–123

Contents lists available at SciVerse ScienceDirect

Progress in Biophysics and Molecular Biology

journal homepage: www.elsevier.com/locate/pbiomolbio

Review

Copper ion-exchanged channel waveguides optimization for optical trapping

A.H. Reshak [a,b,*], K.N. Khor [c], M.M. Shahimin [c], S.A.Z. Murad [c]

[a] *Institute of Complex Systems, FFPW, CENAKVA, University of South Bohemia CB, Nove Hrady 37333, Czech Republic*
[b] *Center of Excellence Geopolymer and Green Technology, School of Material Engineering, University Malaysia Perlis, 01007 Kangar, Perlis, Malaysia*
[c] *School of Microelectronic Engineering, Universiti Malaysia Perlis (UniMAP), P.O Box 77, d/a Pejabat Pos Besar, 01000 Kangar, Perlis, Malaysia*

ARTICLE INFO

Article history:
Available online 30 May 2013

Keywords:
Optical manipulation
Channel waveguide
Beam propagation method

ABSTRACT

Optical trapping of particles has become a powerful non-mechanical and non-destructive technique for precise particle positioning. The manipulation of particles in the evanescent field of a channel waveguide potentially allows for sorting and trapping of several particles and cells simultaneously. Channel waveguide designs can be further optimized to increase evanescent field prior to the fabrication process. This is crucial in order to make sure that the surface intensity is sufficient for optical trapping. Simulation configurations are explained in detail with specific simulation flow. Discussion on parameters optimization; physical geometry, optical polarization and wavelength is included in this paper. The effect of physical, optical parameters and beam spot size on evanescent field has been thoroughly discussed. These studies will continue toward the development of a novel copper ion-exchanged waveguide as a method of particle sorting, with biological cell propulsion studies presently underway.

Contents

1. Introduction

Optical manipulation has been demonstrated by using evanescent field; a field of waveguide mode that penetrate through core-cover interface of waveguide (Shahimin et al., 2011; Ng et al., 2002; Grujic et al., 2004). This method has become popular due to its advantage of non-invasive characteristic, reducing sample size,

* Corresponding author. Institute of Complex Systems, FFPW, CENAKVA, University of South Bohemia CB, Nove Hrady 37333, Czech Republic.
E-mail address: maalidph@yahoo.co.uk (A.H. Reshak).

0079-6107/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.pbiomolbio.2013.05.003

sterile and high positional accuracy when dealing with living cells (Grujic, 2004) compared to conventional methods. By using waveguide, optical manipulation system can be integrated with other micro-systems to achieve lab-on-a-chip devices where functions including particle/cell preparation, sorting and post-processing can be achieved (Ahluwalia et al., 2010; West and Honkanen, 2005). In order to increase and maximize the efficiency of the channel waveguide in the context of optical manipulation, evanescent field which exerted optical force on particle in the region must be optimized. In addition, intensity of the evanescent field has been proved to be the main factor that will influence optical forces (Ng et al., 2000), both normal gradient force and forward scattering force as shown in Fig. 1.

The ion-exchanged channel waveguide used have a gradient index profile; where the refractive index changes gradually in the transverse direction. Apart from optical forces, there are also non-optical forces that are acting on the particle/cell. Thus a strong normal gradient force is needed to attract the particle to the surface and subsequently strong forward force for the particle/cell propulsion. This paper is aimed to demonstrate the optimization of channel waveguide design through a series of simulation by using beam propagation method (BPM) software. BPM algorithm has been the fastest yet precise method of simulating propagating field in the channel waveguide. Hence, field results of varied parameters can be immediately obtained. Ng in (Ng et al., 2002; Ng et al., 2000) has demonstrated theoretically and experimentally the optimization of evanescent field. It had been shown that optimum thickness and width is critical in forming stronger evanescent field, and hence stronger propulsion. In this paper, not only physical geometry of the channel waveguide is optimized, optical properties of channel waveguide, wavelength and polarization of light are also investigated as these parameters influenced the mode formation. Simulation configuration is clearly stated in all presented simulation results.

2. Experimental procedures

2.1. Simulation configurations

In this simulation, ion-exchanged channel waveguide is selected due to its flexibility to be tailored into various applications. Ion-exchanged channel waveguide has been widely used because of its process simplicity and economic value (Shahimin et al., 2011; Ng et al., 2002; Grujic et al., 2004; West and Honkanen, 2005; Villegas-Vicencio et al., 2001). Ion-exchanged channel waveguide has a gradient index profile due to index increment as ion diffuse further into the glass substrate to form waveguide (Li et al., 2006). Specifically in copper ion-exchanged waveguide, the index profile based on pre-annealing fabrication characterization on (Lei et al., 2007) closely follow a Fermi function, as indicated by Neuman et al. (1979). Thus, this can be approximated using a step index profile in the simulation. Simulation parameters are tabulated in Table 1. A three-dimensional (3-D) full-vectorial finite-difference (FD)-based beam-propagation method (BPM) is used in the simulation with mesh point resolution of 2 pts/μm (horizontal) and 6.7 pts/μm (vertical). The mesh point resolution of horizontal and vertical axis mainly depends on the dimension of the waveguide and must be smaller than width step and thickness step used in the simulation iteration.

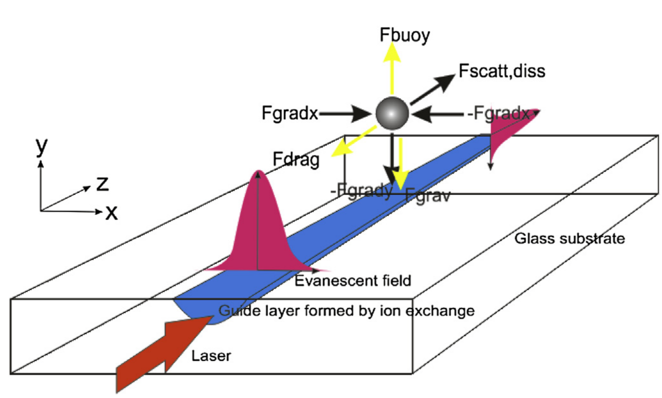

Fig. 1. Optical force and non-optical force exerted on particle on channel waveguide.

Table 1
Configuration for the simulation.

Parameter	Values
Waveguide type	Surface channel waveguide
Refractive index of cover layer, n_c	1.33
Refractive index of substrate layer, n_s	1.55
Refractive index of guide layer, n_g	1.6
Wavelength	1 μm
Input field	Gaussian optical field
Spot size	Feed exactly the input waveguide.

The waveguide structure simulated consists of 3 layers; cover, guide and substrate layer, where guide layer has higher refractive index compared to cover and substrate layer. Substrate layer used is soda lime glass (Corning 2947) with refractive index of 1.55 while cover layer is water with refractive index of 1.33. Guide layer is formed in the glass substrate through ion-exchanged process and the index increment is significantly influenced by the density and type of index increasing ion. In this case, copper ion is used and thus the refractive index increment is ~0.05. Both the refractive index of guide layer and glass substrate is taken from a fabricated ion exchanged waveguide presented in (Villegas-Vicencio et al., 2001). The input field is Gaussian optical field of 1 μm wavelength and the spot size is manipulated to feed the channel waveguide fully to reduce the coupling loss. The chosen parameter values are aimed to duplicate the actual ion-exchanged channel waveguide to reduce the deviation in simulation results.

2.2. Simulation flow

There are 5 simulations with different parameters to be optimized which are shown in Table 2. In the first simulation, propagated field of the channel waveguide is simulated with a range of channel waveguide width and thickness. Simulation result of TE (transverse electric) and TM (transverse magnetic) polarization is compared in the second simulation. The wavelength used is critical manipulating living cells (Stevenson et al., 2010) and hence the channel waveguide is simulated with a range of wavelengths so that evanescent field can be optimized yet viability of living cell is not compromised.

Refractive index of cover layer (n_c), guide layer (n_g) and substrate layer (n_s) are varied in the fourth simulation to study the influence of different configuration of refractive index on evanescent field.

Table 2
Simulation and the regarding parameter to be optimized.

Simulation	Parameter to be optimized
1	Physical geometry of channel waveguide
2	Polarization of field
3	Wavelength of field
4	Optical properties of channel waveguide
5	Spot size of Gaussian beam