Jurnal
Teknologi

Full Paper

The Potential of Optical Tweezer (OT) For Viscoelastivity Measurement of Nanocellulose Solution

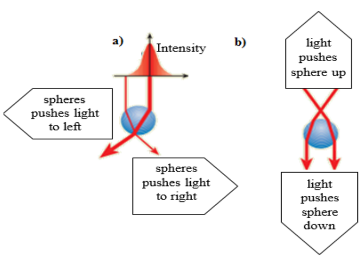
Wan Nor Suhaila Wan Aziz, Shahrul Kadri Ayop*, Sugeng Riyanto

Department of Physics, Faculty Science and Mathematics, Universiti Pendidikan Sultan Idris, Malaysia

Article history
Received
10 October 2014
Received in revised form
10 December 2014
Accepted
13 January 2015

*Corresponding author
shahrul.kadri@fsmt.upsi.edu.my

Graphical abstract



Abstract

In this paper, we review the recent applications of optical tweezer (OT) in studying the microrheology of variety of polymeric solution. Our aim is to expose optical tweezer research to the public and newcomer. This paper highlights and summarizes the advantages of optical tweezer as compared with the conventional method, introduces the benefit of nanocellulose and also presents an overview of the potential in the measurement of nanocellulose solution's viscoelasticity by using optical trapping method.

Keywords: Optical tweezer, nanocellulose, viscoelasticity, microrheology, optical trapping

Abstrak

Dalam kertas ini, kita mengkaji semula aplikasi terkini mencabut dengan penyepit optik (OT) dalam mengkaji microrheology daripada pelbagai penyelesaian polimer. Matlamat kami adalah untuk mendedahkan penyelidikan penyepit optik kepada orang ramai dan pendatang baru. Kajian ini mengetengahkan dan meringkaskan kelebihan mencabut dengan penyepit optik berbanding dengan kaedah konvensional, memperkenalkan manfaat nanoselulosa dan juga membentangkan gambaran keseluruhan potensi dalam pengukuran kenyal-likat penyelesaian nanoselulosa dengan menggunakan kaedah memerangkap optik.

Kata kunci: Penyepit optik, nanoselulosa, likat-kenyal, mikrorheologi, memerangkap optik

1.0 INTRODUCTION

Two major types of techniques have been developed as an experimental method for measuring probe dynamics of viscoelastic material: The first uses scattering method such as the diffusing wave spectroscopy (DWS), and dynamic light scattering (DLS). The other is real space methods such as particle tracking microscopy (PTM), laser deflection particle tracking and particle interferometric tracking (PIT) [1]. Optical tweezers have expanded recently as an essential tool to study the rheological properties of a material. Living cells and microorganism can be captured or trapped using optical tweezers as it is a tool that adopts principle of optical pressure to trap an object without mechanical contact which can damage delicated samples.

Optical trapping covers wide-ranging series of experiment from cooling and trapping of neutral atoms, live bacteria and viruses manipulation pioneered by Ashkin and co-workers [2][3]. Nowadays, exploration using optical traps method has been employed in both physics and biology.

Theoretical and experimental work for all related aspects of optical trapping is being actively implemented in parallel with the widespread utilization of optical trapping. For the purpose of this review, we will concentrate on the most recent applications of optical tweezer and its advantages. In addition to it, we will introduce the benefits of nanocellulose and presents the potential of using optical tweezer on nanocellulose solution's viscoelasticity measurement.

2.0 OPTICAL TWEEZER

Optical tweezers is applied to facilitate the process of micromanipulation a particle using light. It required laser light with high intensity values which is focused through a microscope objective lens. The momentum of photons is changing when it are absorbed, reflected, refracted by a transparent object which commensurate to the force acting on the photons.

Optical tweezers works when the pull of gravity balanced the laser beam in trapping process. The longitudinal force is necessary to be exert in the same direction with the laser beam while the transverse force on the right angle of the beam to trap a particle in three dimensions. The high intensity of laser at the centre of the beam will create the transverse force (Figure 2). According to the Figure 1(a), the particle will refract more light from the right to the left rather than from the left to the right if the particle is directed to the left from the centre of the laser beam. In this direction, the effect is to transfer momentum to the beam. So, the particle will undergo an similar or opposite force back towards the centre of the laser beam. In addition, based on the Figure 1(b), it is possible for the particla to experience a force which is push back direct to the laser beam if the beam is strictly focused [4].

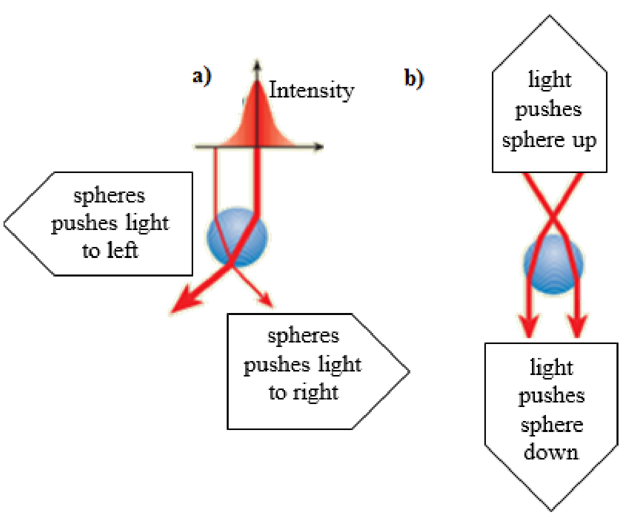


Figure 1 Rays pathway of the laser beam

2.1 Applications of Optical Tweezer

Optical tweezers or optical traps are practicably as the most flexible for single-particle molecule manipulation technique. They simultaneously measuring the three-dimensional displacement of the trapped particle with sub-nanometer accuracy and sub-millisecond time resolution and also they can exert forces exceeding 100 pN on particles ranging in microns to nanometer size. These attribute make them suitable for the measurement of motion and force [5]. The particles now can be trap, observe, orient and guide by the optical tweezers. Optical trapping could make an impact in bioengineering, for example in attempts to control the organization of cells during organ and tissue growth [6].

One of the examples of an optical tweezers application is exploring the linear stretching force to the red cell membrane and measuring the response to fast and slow induced distortions [7]. In that study, the measurement of elastic properties is approached using the principle of the optical-tweezers. The measurement of elastic properties have been done by attaching two adhesive beads to the cell at opposite ends of a diameter, and holding one in place with one trap, while moving the other with a second trap, to induce a tension (positive or negative) in the cell. By monitoring the movement of the first bead in response to the controlled displacement of the second bead, a force-extension profile can be generated [7]. Optical tweezers also have been applied to measure biological forces such as forces of cellular membrane and DNA folding force by obtaining the traceable trap stiffness.

2.2 Comparison with Other Methods

A basic magnetic tweezers contain of a pair of permanent magnets placed above the sample holder of an inverted microscope equipped with a charge coupled device (CCD) camera connected to a frame grabber [8], [9]. This tool are afford to exert forces exceed 1 nanonewton (nN) and it can be used to manipulate magnetic particles size range from 0.5–5 µm [5]. Magnetic tweezers are also has a unique characteristics that they capable passive, infinite bandwidth, force clamping over great displacements [5]. Nucleic acid enzymes and particularly DNA topoisomerases study are ideally suited according to these characteristics [10], [11]. Magnetic tweezers are not quite versatile as optical tweezers or the AFM despite their many unique attribute [5]. The manipulation ability of other techniques are lack for the steady permanent magnet configuration [5]. The large applied torque prevent the direct measure of rotation or torque generation even though, the ability to rotate magnetic beads has evidenced useful [5]. The direct measurement of very fast or very small displacements is prevented because the bandwidth and sensitivity are limited by the video based detection [5].

Electromagnetic tweezers allow full three-dimensional manipulation, however this need intricate feedback control in extension to advance custom machined pole pieces [5]. For some other force spectroscopy techniques also has not achieved yet the sensitivity. Moreover, it required high current electromagnets in producing the large magnetic field and field gradient that can produce significant heating, or small, closely spaced, pole pieces that no longer preserve the constant-force benefit of magnetic tweezers [5].

The atomic force microscopy (AFM) is a version of the scanning probe microscope. A proximal probe are used to investigated the properties of the surface [12], [13]. The mapping of the surface characteristics at sub-nanometer resolution is allowed using this technique. To overcome disadvantages and limitations of the scanning tunnelling microscope in imaging non-conductive samples are the reasons why the AFM was initially developed [14]. The large size and relatively high stiffness of the cantilevers, which impose a lower bound on the useful force range and a diminish bandwidth, particularly in aqueous conditions is the main drawbacks and limitations of the AFM stem [5]. It difficult to study with the AFM because the forces associated with many biological processes and structures [5]. In many AFM interesting experiments, specificity is a second major concern [5]. The interactions between the AFM tip with the molecule of interest from nonspecific interactions or inappropriate contacts with the molecule of interest, such as binding at an intermediate position rather than at one of the ends can be difficult to distinguish [5].

3.0 NANOCELLULOSE

Cellulose is the most abundant biomass material in nature. Extracted from natural fibers, its hierarchical and multi-level organization allows different kinds of nanoscaled cellulosic fillers [15]. Cellulose is considered to be the most abundant renewable polymer on Earth [15]. This structural material is naturally organized as microfibrils linked together to form cellulose fibers [15]. It is biosynthesized by a number of living organisms ranging from higher to lower plants, such as amoebae, sea animals, bacteria and fungi [16]. Cellulose nanoparticles have been extensively used in a wide variety of application in nanosized dimensions, e.g., packaging, adhesives and electronic display material [15]. The peculiarity of nanocellulose nanoparticles is that their dispersions have unusual rheological properties. Nanocellulose particles are capable of immobilizing a high amount of water into developed internal and external surfaces with the formation of highly viscous gel-like water systems [17]. It unique structural and physical aspects give them unique tensile, optical, electrical, and chemical properties [18].

3.1 How to Characterize Mechanical Properties of Nanocelullose

Viscoelastic response is often used as a probe in polymer science because of its sensitivity to chemical and microstructural properties of a material. One of the viscoelastic measurement techniques is by using optical tweezers. Optical trap oscillation control microsphere trapped at a certain frequency. Active response nanocelullose microspheres in solution can provide microrheological information. Power spectral density S (f) of the motion of the microsphere is used to estimate the shear modulus, G (f) of the nanocelullose solution,

$$G(f)=\frac{1}{6pa(f)} \qquad (1)$$

$$a(f)=\frac{p}{2k_BT}fS(f) \; ; \qquad (2)$$

where; kB Boltzmann constant, and T the temperature of the solution.

4.0 RESULTS AND DISCUSSION

We have successfully trap a single 3 micron diameter polystyrene bead in solution using optical tweezers. (Thorlabs, OTKB). We mix low centration of polystyrene bead with nanocellulose solution sample from Bio-based material UPSI (with courtesy of Dr. Rosazley), Figure 2 shows beads in nanocellulose solution. The fiber structure is bulk form of nanocellulose. The nanocellulose need to be separated so that it can dilute well in solution. Further work is carried out to treat the nanocellulose for the purpose of this study. One can also test the mechanical strength of the single nanocellulose using optical tweezers.

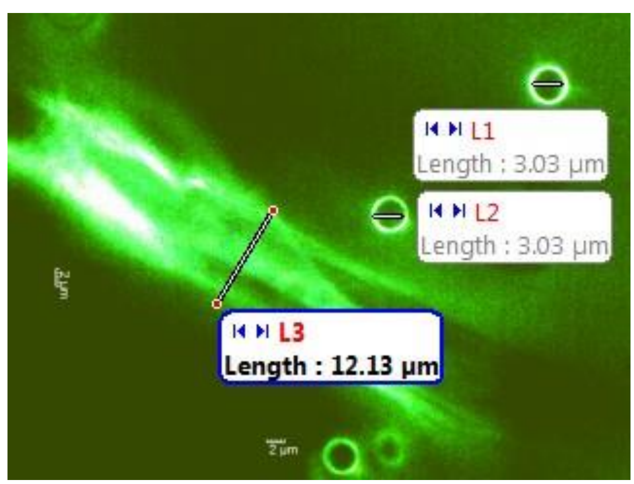


Figure 2 Polystyrene beads (circular shape) in nanocellulose solution, fibrous structure can be seen

5.0 CONCLUSION

Nanocellulose has been widely studied for its potential use in advanced material due to its flexibility and biodegradability. In addition, only small amount of sample (µL) is required for microrheological test using the optical tweezers**.** As the conclusion, this paper aims to give some review on optical trapping method, explore its potential to extract microrheological properties of nanocellulose solution in variation of chemical and physical environment.

Acknowledgement

The upcoming study relating to this research area is supported by Research Acculturation Grant Scheme (RAGS) of Malaysian Ministry of Education under UPSI code 2013-0003-102-72. Please direct your E-mail to shahrul.kadri@fsmt.upsi.edu.my regarding this paper.

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