Sensors and Actuators A 222 (2015) 212–219

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

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

Photonic studies on polymer-coated sapphire-spheres: A model system for biological ligands

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ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form
24 November 2014
Accepted 24 November 2014
Available online 11 December 2014

Keywords:
Label-free biosensor
Microcavity
Photonics
Polydopamine
Sapphire microsphere
Whispering gallery modes

ABSTRACT

In this study we show an optical biosensor concept, based on elastic light scattering from sapphire microspheres. Transmitted and elastic scattering intensity of the microspheres (radius 500 μm, refractive index 1.77) on an optical fiber half coupler is analyzed at 1510 nm. The 0.43 nm angular mode spacing of the resonances is comparable to the angular mode spacing value estimated using the optical size of the microsphere. The spectral linewidths of the resonances are in the order of 0.01 nm, which corresponds to quality factors of approximately 10^5. A polydopamine layer is used as a functionalizing agent on sapphire microspherical resonators in view of biosensor implementation. The varying layer thickness on the microsphere is determined as a function of the resonance wavelength shift. It is shown that polymer functionalization has a minor effect on the quality factor. This is a promising step toward the development of an optical biosensor.

1. Introduction

Development of biological, chemical and biochemical sensors is one of the current needs of the society. Label-free detection of DNA was studied by elastic measurements at the level of a single DNA molecule[1] via force-induced denaturation [2], electrochemistry [3,4], field-effect sensors [5,6], and by monitoring the denaturation dynamics in real-time using impedance spectroscopy [7] and the heat transfer method [8]. Label-free detection of protein–protein interaction was shown recently using nanowires [9], nanoparticle probes [10], biochips [11], and mechanical cantilevers [12]. Optical measurement techniques can provide high sensitivity, compactness, fast response and real-time measurements [13]. They are non-destructive to the sample, and the transduction processes generally take place on a surface and can be tailored to sense almost any kind of (bio)chemical molecules [14].

Optical sensing can be performed using plasmonic biosensors [15], ring resonators [16], confocal microscopy [7], prism couplers [17], and spherical cavities [18,19]. Optical microcavities such as spherical resonators, where optical rays are confined by total internal reflection, are promising optical label-free detection setups and play a prominent role in modern optics [20].

Recently, a silicon-on-insulator (SOI) microring resonator for sensitive label-free biosensing was fabricated [21]. Hereby, microring surface functionalization with biotin and a detection limit of 0.37 fg avidin mass (3260 molecules) was achieved [22,23]. In an optical microcavity, the target molecules can be sampled hundreds of times due to the recirculation of light within the microcavity by total internal reflection (TIR) [20]. The target molecule induces a change in the optical microcavity properties such as its size. As a result, a change in the whispering gallery mode (WGM) resonant wavelength is encountered [24]. In order to preserve the high quality of the transducer and the interaction with the sensing layer and

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http://dx.doi.org/10.1016/j.sna.2014.11.024
0924-4247/

the WGMs [14,24–26] a good control of surface functionalization of the transducer surface is a crucial step for producing reliable biosensors for the binding of the biological recognition element to it. The circumnavigating light within the microcavity will evanesce to the external medium and extends about 200 nm [24]. Hence, the functional layer has to be very thin, i.e. ≈10 to ≤200 nm, and homogeneous.

So far, silicon-on-insulator ring resonators [23] and glass microspheres [18] have been used as microcavity-based biosensors. However, silicon and glass are known to degrade easily in aqueous media, especially at longer time scale and in non-neutral pH circumstances [27,28]. Hence, the usibilty of these two materials as biosensors is somehow limited. To overcome the drawback of limited chemical stabiltiy, recently, diamond ring resonators [29] and nearly spherical diamond resonators were developed [30]. However, their fabrication is expensive and diamond surface modification with proteins or DNA still requires a good control of the functionalization steps [27,31].

In this article, an experimental study of an optical biosensor concept based on elastic light scattering from sapphire microspheres and the corresponding shift of WGMs, after an add-on polydopamine (PDA) layer to the sphere, is performed. Mussel-inspired polydopamine coating have been intensely studied in recent years [32–34]. Surface functionalization using this biopolymer is especially robust. By simply dipping any substrate into an aqueous solution of dopamine, a surface-adherent polydopamine thin film is first formed within hours through oxidative self-polymerization and subsequentially bounded to the sapphire surface via hydrogen bonds [32,35]. The thickness of the formed polymer can be tuned by varying the concentration of the dopamine used or by adapting the immersion time of the substrates. Using atomic force micrsocopy (AFM), Lee et al. found that the thickness of the polymers formed

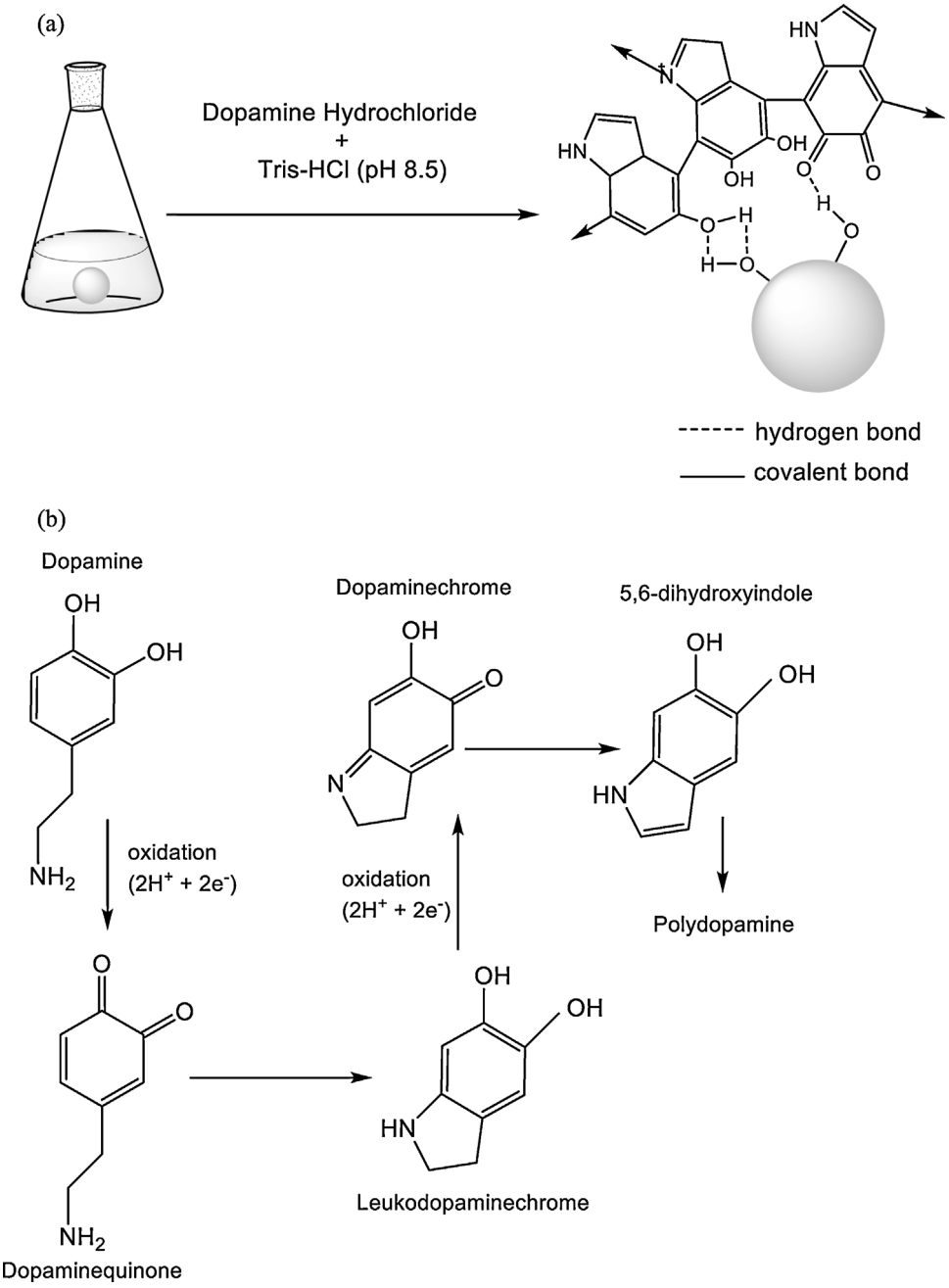

Fig. 1. (a) Sapphire surface functionalization with PDA. (b) Polymerization mechanisms of dopamine adapted from Lee et al.