Optics & Laser Technology 68 (2015) 79–83

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Preparation and spectral characteristics of silver nano-sphere doped quartz micro-fiber

Jin Li [a,*], Hanyang Li [b], Haifeng Hu [a], Yong Zhao [a,c], Qi Wang [a]

[a] College of Information Science and Engineering, Northeastern University, No. 11, Lane 3, Wenhua Road, Heping District, Shenyang 110819, China
[b] National Key Laboratory of Tunable Laser Technology, Institute of Opto-Electronics, Harbin Institute of Technology, Harbin 150080, China
[c] State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang 110819, China

ARTICLE INFO

Article history:
Received 8 June 2014
Received in revised form
14 October 2014
Accepted 3 November 2014
Available online 5 December 2014

Keywords:
Fiber optics
Integrated optics devices
Surface plasmon

ABSTRACT

We have proposed a micron quartz fiber doped with metal particles and experimentally studied its spectral characteristics. The corresponding simulated spectra meet very well the experimental results. In this configuration, the silver spheres with the diameters of 300–500 nm are fixed in the quartz fiber and embraced by two air cavities. We measured the transmission spectra by micro-manipulating the signal and probe fiber taper simultaneously. The resonance wavelength transformed from 1544 nm to 1557 nm when we moved the probe fiber taper along the micron fiber. The simulated calculation indicates that the spectra characteristics depend on the geometry parameters of the fiber configuration.

1. Introduction

Surface plasmon resonance (SPR) is the resonance wave generated by the interaction between photons and the free electrons at metal–dielectric interface [1]. In recent years, SPR has caught the researchers' attention, because it is sensitive to the fluctuation of light field [2] and can realize the photoelectric conversion on a chip [3]. Metal nano-particles therefore are applied for biochemical sensing and optical signal processing [4–7]. It is well known that the small changes (derived from arrangement, configuration and sizes of the metal nano-particles) will transform the phase or amplitude of light signal [8,9]. The regular arrangement is very difficult to realize for the metal nano-particles [10,11]. A simple and effective controlling technology is destined to become a hot topic at the moment and in future [12–15]. Using metal nano-particles doped polymers, one can control the distribution of the particles effectively, and produce doped films or fibers [16–18]. Relative to quartz fiber, the polymer's melting point is low; the transmission range and rate are limited; the corrosion resistance is poor, which limited its applications. In this work, we further experimentally and numerically studied the spectra characteristics of silver nano-sphere doped quartz micro-fiber, which was proposed in our previous work [19]. We also compared the simulated and experimental results, and analyzed the reason for the slight distinction. Furthermore, we studied the intensity and the location of the resonance wavelength for the configurations with different geometry parameters (including the diameter of the silver nano-sphere and the length of the air cavity). The proposed micofiber may be used as real-time chemical and biological sensors to sense the concentration, as well as the species of the liquid, gas, DNA, and virocyte with a high sensitivity. The optical response of this configuration depends on its geometry parameters, which include the size and the assembly of the silver nano-sphere, as well as the heating temperature and stretching force during the production of the microfiber. All the factors mentioned above should be considered carefully and studied in detail to design the desired optical response.

2. Experiment

2.1. Experiment sample preparation

The quartz capillary we used in the experiment was produced by Polymicro Company, has a polyimide coating layer with the thickness of 12 μm, and the air-core and the external diameters of 100 μm and 170 μm, respectively. The diameter of the silver nano-sphere (from 300 nm to 500 nm) and the experimental limitations finally determine the size of the micro-fiber configuration in the experiment (about 1 μm in diameter).

In order to obtain the novel fiber configuration, firstly, we prepared the quartz capillary with a length of 20 mm. Its polyimide coating was moved away in the flame of a Bunsen burner (with the maximum temperature of 1300 °C). In the process, one should carefully control the temperature and heating time of the

* Corresponding author. Tel./fax: +86 24 83687266.
E-mail address: lijin@ise.neu.edu.cn (J. Li).

http://dx.doi.org/10.1016/j.optlastec.2014.11.005
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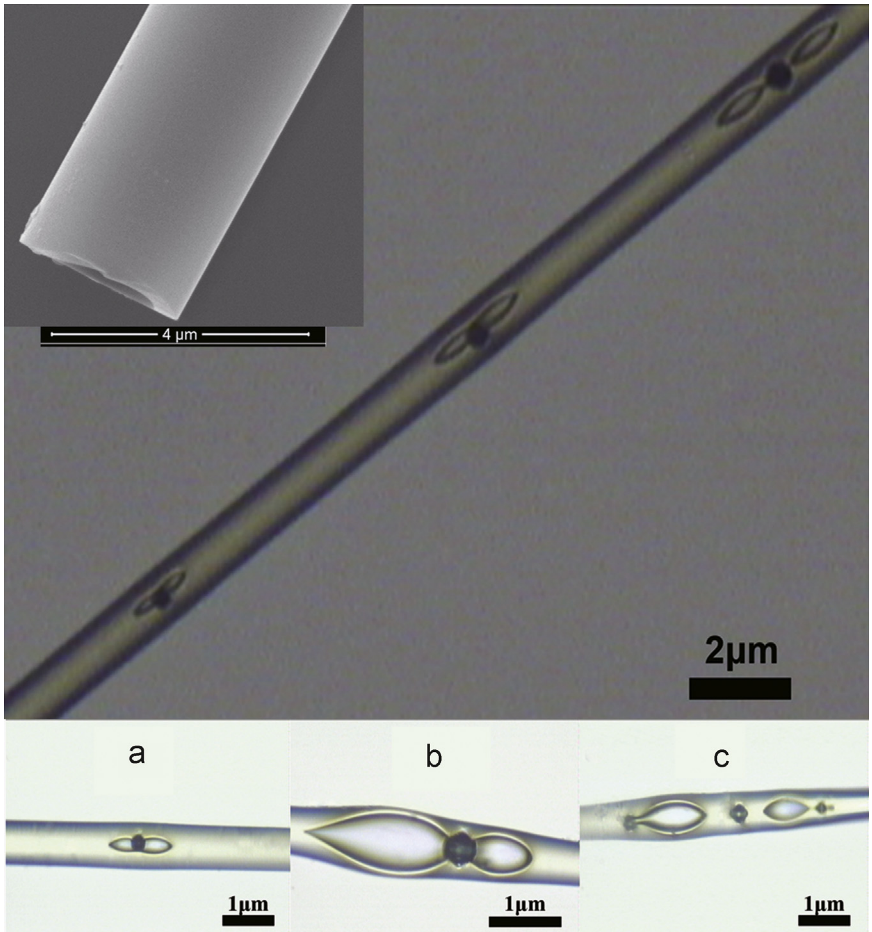

Fig. 1. Image of a quartz fiber with three configurations; the inset shows a SEM image of fine quartz capillary with the diameter of 2.4 μm; microscopic images of three hourglass configurations, including an ideal configuration (a) and the other two configurations with defects (b, c).

quartz capillary to avoid deformation. Secondly, we filled the quartz capillary with the silver nano-sphere with the diameter of 300–500 nm by an ultrasound oscillation method. In this way, we obtained the silver nano-sphere filled quartz capillary. Thirdly, the quartz capillary is melted and drawn quickly in the flame to get the required fiber configuration.

By drawing the doped capillary in the high temperature flame, one could get the micro-fiber with the silver nano-spheres and the air cavities. Because of the uneven force distribution, one may get some undesired micro-fiber configurations, as shown in Fig. 1 (the scale bar is 2 μm). Fig. 1(a) indicates one cut of fine quartz fiber with three hourglass configurations in which, each silver nano-sphere is embraced by two spindle-shaped air cavities. The diameter of the fine fiber is about 1 μm. The diameters of the three silver nano-spheres are 300 nm, 340 nm and 480 nm from left to right. The distance between two hourglass configurations is about 7.7 μm. The plasmon resonance phenomenon can be excited using monochromatic light. Furthermore, the shape of air cavity is related with the uniform stretching force, heating temperature, as well as the diameter and geometry of silver nano-spheres. In Fig. 1(b) and (c), the two air cavities are different, and even disappear.

2.2. Experiment setup

Fig. 2 shows the experimental setup we used to study the spectra characteristics of the micro-fiber configuration (including two air-cavities and one silver nano-sphere). To reduce the refractive index loss, we put the micro-fiber on a MgF_2 substrate with high transmittance and low refractive index from about 110 nm to 7.5 μm.

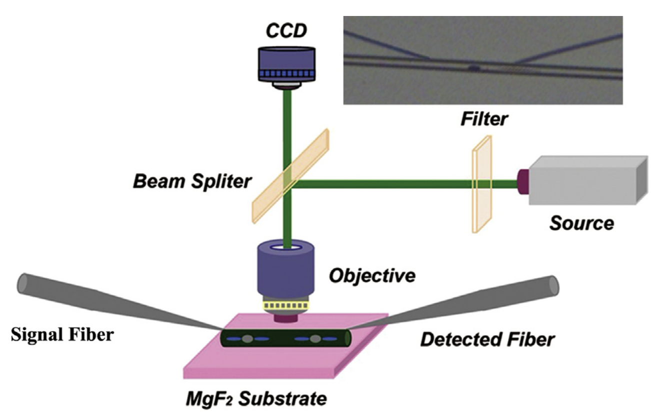

Fig. 2. Experimental schematic diagram; the inset is a microscope image of the coupling between fiber tapers and doped fiber.

We studied the spectra characteristics of the silver nano-sphere doped micro-fiber configuration by the micro-manipulation method, in which we used two fiber tapers as the signal and probe fiber, respectively. We equiped the two fiber tapers with 3D fiber adjustments (with an adjustment precision of 0.1 μm) to precisely control their locations. Light (with a wide wavelength range from 1530 nm to 1560 nm) is launched into the signal fiber taper. A spectrometer (with a resolution of 20 pm) is used to measure the transmission spectra from the probe fiber taper.

In the experiment, the geometry of the doped micro-fiber configuration and the location of the two fiber tapers can be