All-fiber switch based on plasmonic FP cavity

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***Abstract*—In this paper, an all-fiber plasmonic switch is realized by embedding Au nanoparticles embedded in the FP cavity formed by two optical fiber ends coated with partially reflective films.**

Keywords—All-fiber switch, Plasmon, Au nanoparticles

I. INTRODUCTION

Optical switch is a kind of optical path conversion device, which generally has one or more optional transmission ports, acting on the physical switching or logical operation of optical signals in optical transmission lines or integrated optical paths. About 85% of the communication services in the world have been achieved in optical fiber transmission, where optical switches are widely used.

Optical switches can be divided into two categories: mechanical and non-mechanical. The mechanical optical switch changes the optical path by moving the optical fiber or optical element[1]. It has the advantages of low insertion loss, high isolation, and is not affected by polarization or wavelength. Mechanical optical switch has been widely used in recent years, but with the continuous expansion of the scale of optical network. This kind of switch is difficult to meet the needs of the future development of high-speed and high-capacity optical transport network.

Non-mechanical optical switch relies on electro-optic effect, magneto-optic effect, acousto-optic effect, thermo-optic effect and plasmonic effect to change the refractive index of the waveguide and the optical path[2-5]. It is a very hot research topic in recent years. The advantage of this kind of switch is that the switching time is short and it is convenient for optical integration or optoelectronic integration. Plasmonic devices, based on surface plasmon-polaritons (SPPs) propagation at metal-dielectric interfaces, have shown great potential to manipulate light by metallic nano-structure with strong optical filed enhancement.

In this paper, an all-fiber plasmonic switch based on metallic nanoparticle LSPR (localized surface plasmon resonance) absorption is introduced in this paper. The device is made by embedding Au nano-particles into the optical glue in the FP cavity formed by the end facets of two optical fibers coated with partial reflection films. The plasmonic effect of Au particles is excited by 980nm near-infrared light through the evanescent field of this structure, which leads to the change of the effective refractive index (RI) and the shift of the absorption spectrum. The proposed all-fiber switch is compatible with the current all-fiber system, so it has a great potential in all-optical communication.

II. EXPERIMENTAL CONFIGURE

The experimental device schematic diagram is shown in Fig. 1. The FP cavity is made of two optical fibers with 30% partial reflective film on the end facet. The solution of gold nano-bipyramids was mixed with thermally conductive adhesive and then injected into the fiber FP cavity. The structure is shown in the dotted frame of the Fig.1. The role of the thermally conductive adhesive is used to help the gold nanobipyramids solution adhere in the cavity.

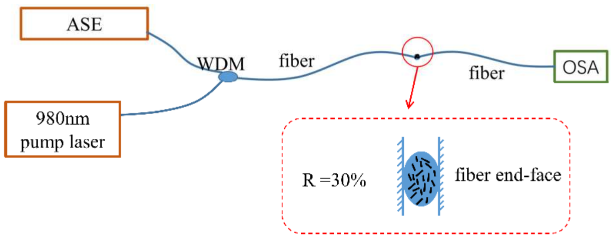

Fig. 1 Schematic diagram of all-fiber switch.

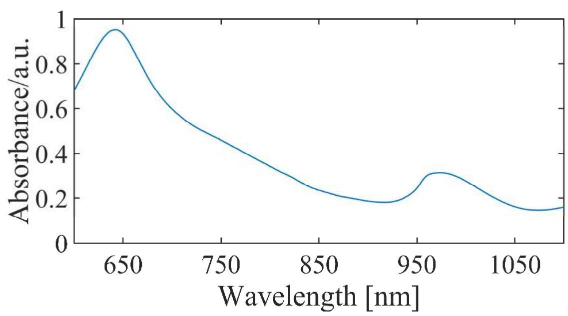

Fig. 2 The absorption spectrum of gold nanobipyramids.

We used gold nanobipyramids (GNBs) solution for fabricating all-fiber switch. The GNBs are stably dispersed in

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the solution, resulting in a bluish-green color of the solution. The length and the width of the GNBs are 50nm and 20nm respectively. Because the absorption wavelength of localized surface plasmon resonance (LSPR) of the nanoparticles is related to the peaks of their absorption spectrum[6], we measured the absorption spectrum of GNBs.

As shown in the Fig. 2, the result shows that there are two main absorption peaks of GNBs, located near 650 nm and 980 nm, respectively. In order to couple the pump light into the optical fiber conveniently and to improve the pumping efficiency, we use the 980nm pump laser which is more easily coupled into the optical fiber to excite the LSPR of GNBs.

As shown in Fig. 1, the amplified spontaneous emission (ASE) source and 980 nm pump laser are connected to the fiber FP cavity via a wavelength division multiplexer (WDM). The other side of the fiber FP cavity is connected to an optical spectrum analyzer. In the fiber FP cavity, multiple reflections of the light back and forth between the fiber ends cause interference. In the fiber FP cavity, interference caused by reflections of the light back and forth between the fiber end facets. And the normal incidence sequentially reflected beams have an optical path difference of $2nl$, here l represents the distance between two parallel fiber end facets, and n represents the refractive index inside the cavity.

When round trip path is equal to an integer multiple of the wavelength λ of light, interference occurs. Interference pattern was obtained by slowly adjusting the cavity length l, a typical spectrum is shown in the blue curve of Fig. 3. The free spectral range (FSR) of the interference spectrum was approximately 3.2 nm. Interference spectrum is correlated to three parameters: the intensity of light transmitted through the fiber end-facet for the first time, the intensity of light transmitted through the fiber end-facet after reflection in the cavity, and the phase difference between these two beams of light. Meanwhile, the optical path difference between the two beams of light determines the phase difference between the two beams. So, the optical path difference between the two beams of light determines the interference pattern of the FP cavity.

The reflectivity of 30% in the FP cavity is to balance the bandwidth and isolation of this optical switch. Too low reflectivity will cause low fineness and poor isolation, while too high reflectivity will lead to low bandwidth.

III. Results And Discussion

When 980 nm pump light was incident in the FP cavity, the GNBs inside the cavity absorbed the pump light and generate LSPR. The excitation of LSPR in the gold nanoparticles releases heat, leading to an increase in the temperature of the surrounding medium [6]. The refractive index n inside the cavity changed with the increase in temperature, causing changes in the optical path difference and phase difference. When the output power of the pump light was gradually increased, the changes in the transmission spectrum of the fiber FP cavity were recorded on a spectrometer, as shown in the Fig.3. By slowly and precisely adjusting the state of the two fiber end facets, the extinction ratio of the transmission spectrum reaches 10 dB. We have also done a comparative experiment, when there are no GNBs in the glue of the FP cavity, the spectral shift will not occur.

As the power of the pumping light increased from 0mW to 20mW, the transmission spectrum of the FP cavity shifted to longer wavelengths. The larger the power of the pumping light, the longer the wavelength of the red shift in the transmission spectrum. The reason for this result is when the power of the pump light increases, the LSPR of the GNBs also becomes stronger. The stronger LSPR generates more heat, which raises the refractive index n inside the cavity and leads to an increase in the optical path difference ΔL. According to the preceding statement, the transmission spectrum I experiences a red shift as the optical path difference ΔL increases. It can be calculated that an increase of 10mW in the pump light will cause a phase shift of 0.5π in the transmission spectrum.

To verify the performance of FP cavity as an optical switch, the ASE light source in the optical path was replaced with a laser source. According to the Fig.3, the wavelength of the laser source was set at 1597.9 nm. The position of the laser in the interference pattern is illustrated in Fig.3. The laser intensity was recorded as the pump power was increased from 0mW to 20mW, as shown in the Fig. 4. The laser intensity decreased as the pump power increased.

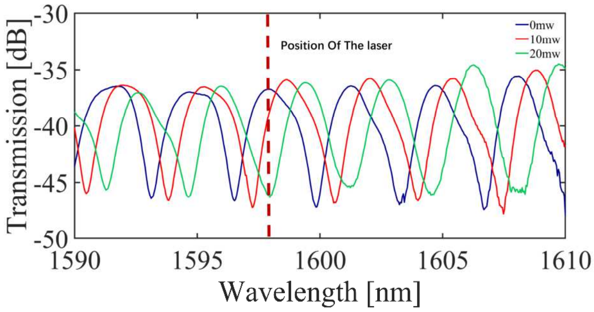

Fig. 3. Interference spectrum shifts with the increase of the pump light intensity. The dotted line shows the position of the laser in the interference patterns.

According to the extinction ratio of the transmission[6]: $E_x = [(I_0 - I_p)/(I_{peak} - I_{valley})] \times 100\%$, here I_0 and I_p represent the laser intensity when the pump power is 0 mW and p mW, respectively; I_{peak} and I_{valley} represent the peak and valley intensities of the transmission spectrum.

So, when the pump power increased from 0mW to 20mW, the interference spectrum moved from the peak to the valley, corresponding to the extinction ratio of the transmission is 81.4%. So the optical switch function of the fiber FP cavity was verified.

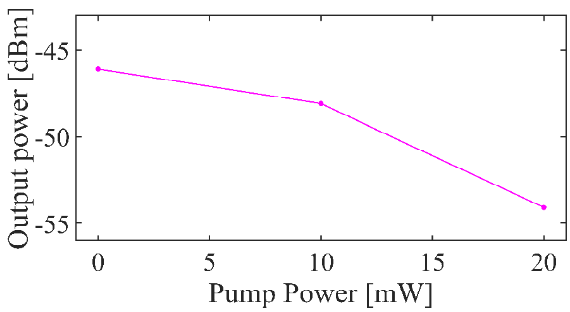

Fig. 4. Output light intensity changes with the pump light intensity.

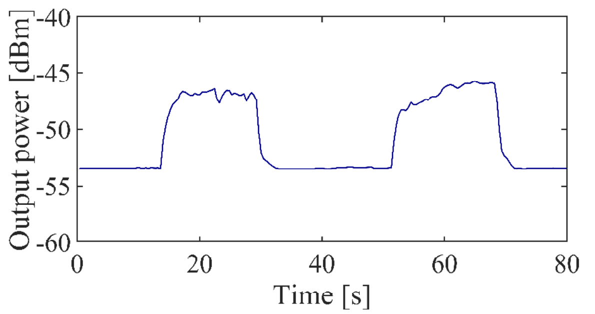

Fig. 5 Power variations of the laser within 80 seconds.

To measure the time response of the optical switch, the OSA in Fig.1 was replaced by an optical filter and an optical power meter. An L-band single-wavelength laser and a 980 nm pump laser were connected to the fiber FP cavity via a WDM, which was then linked to the filter and power meter. The filter was utilized to eliminate residual pump light passing through the FP cavity. The power meter can record the power fluctuations over a specific period of time. The pump light source was set to switch between 0 mW and 20 mW at specific intervals, and the single-wavelength laser was turned on. The power meter recorded the power variations of the laser within 80 seconds, as shown in the Fig. 5. The laser power exhibited periodic fluctuations with the power of the pump light, which demonstrated the excellent repeatability of the optical switch presented in this paper.

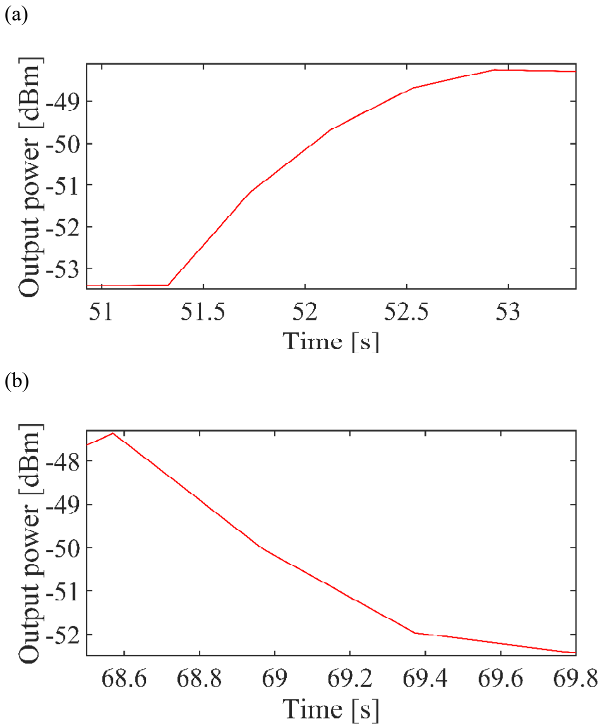

Fig. 6 (a) Rising time and (b) falling time in one switching cycle.

Fig. 6 (a-b) show the rising edge time and falling edge time of the optical switch respectively, with the rising edge time being 1.6s and the falling edge time being 0.75s. The edge time is dependent on the plasmonic resonance of GNBs and thermal conductivity inside the cavity [6].

The temporal response of the photothermal modulation of surface plasmon is in the order of ten μs [4]. The measured response time is limited by the low recording time of the power meter, which will improved by optimized the data access interface in the near future.

IV. CONCLUSION

We demonstrated an all-optical switch based on a fiber FP cavity with plasmonic GNBs. The pump light excited the GNBs to generate heat under the LSPR absorption effect and changed the optical path of the FP cavity. The change of optical path difference causes a phase shift in the interference spectrum of the FP cavity. The ability of the FP cavity to act as an optical switch was demonstrated when the phase shift reaches π. Our proposed all-fiber plasmonic switch has a simple fabrication process, shows great repeatability and reversibility. Moreover, it is intrinsically compatible with current all-fiber systems. This demonstration of all all-fiber plasmonic switch is not necessarily restricted to fiber, but can be extended to other photonic systems.

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