10 Gbps Optical Signal Transmission via Long-Range Surface Plasmon Polariton Waveguide

Jung Jin Ju, Min-su Kim, Suntak Park, Jin Tae Kim, Seung Koo Park, and Myung-Hyun Lee

ABSTRACT—We demonstrate 10 Gbps optical signal transmission via long-range surface plasmon polaritons (LR-SPPs) in a very thin metal strip-guided geometry. The LR-SPP waveguide was fabricated as a 14 nm thick, 2.5 μm wide, and 4 cm long gold strip embedded in a polymer and pigtailed with single-mode fibers. The total insertion loss of 16 dB was achieved at a wavelength of 1.55 μm as a carrier wave. In a 10 Gbps optical signal transmission experiment, the LR-SPP waveguide exhibits an excellent eye opening and a 2.2 dB power penalty at 10^{-12} bit error rate. We confirm, for the first time, that LR-SPPs can efficiently transfer data signals as well as the carrier light.

Keywords—Long-range surface plasmon polariton, 10 Gbps optical signal transmission, metal strip waveguide.

I. Introduction

Surface plasmons (SPs) are coherent longitudinal charge oscillations of conduction electrons coupled to the electromagnetic field at the interface between a metal and a dielectric material. Surface plasmon polaritons (SPPs) are waves that propagate along the metal-dielectric interface. These are essentially light waves which are trapped on the interface because of their interaction with the free electrons of the metal. The free electrons respond collectively by oscillating in resonance with the light waves. The resonant interaction between the surface charge oscillation and the electromagnetic field of the light constitute SPs [1]-[3]. The SPP field components decay exponentially at the interface. The SPP propagation loss is due mainly to internal damping in metal [4]. Therefore, SPPs inherently have a large propagation loss and are considered to be somewhat limited in their applications [5].

The SPP propagation loss can be significantly decreased by changing a metal-dielectric interface to a symmetrical structure and making the thickness of a metal film very thin. The SPPs with a symmetric mode can propagate a long distance with less loss in this symmetrical structure, so called long-range surface plasmon polariton (LR-SPP) [5]. The LR-SPP mode is a symmetric guided mode in a metal waveguide where a metal strip core is surrounded by a dielectric material. There have been several studies of the application of LR-SPP waveguides for integrated optical components [4]-[7]. Figures of merit for LR-SPP waveguides have been also studied [8]. However, these studies have all been focused on LR-SPP propagations as carrier frequencies, not as signal frequencies.

As a carrier, an SPP is a wave of longitudinal charge oscillations of the conduction electrons at the surface of a metal, but light is a transverse electromagnetic wave. The SPP is excited and propagated when the light wave couples in and the propagated SPP couples out as the light wave. The dispersion relation including the wave vector or momentum difference between the SPP and light waves is well explained in [2]. It is not certain whether the signals are well transferred or not, even if an SPP as a carrier is well excited and propagated by the light wave coupled in and out the SPP waveguide.

Transmissions of high-capacity digital information by means of an optical interconnection have been considered as a promising technology to solve the current transport limit

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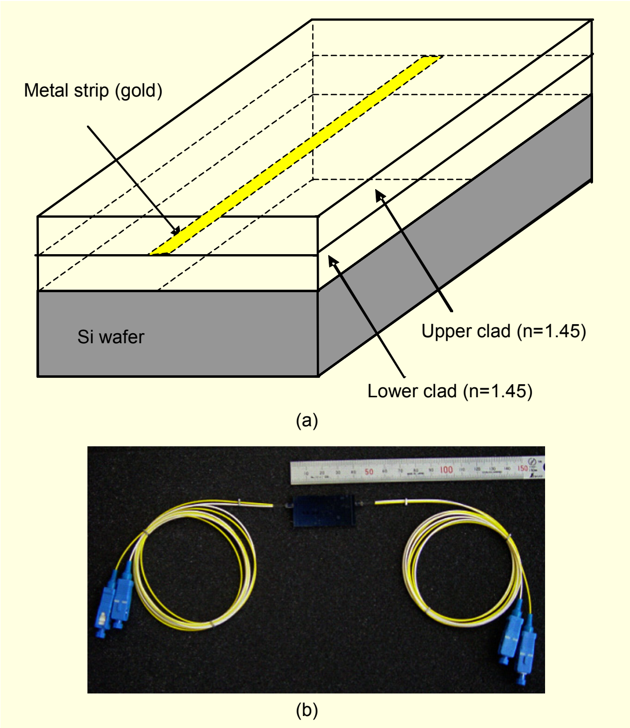

Fig. 1. Schematic diagram of a metal strip waveguide based on (a) LR-SPP and (b) pigtailed LR-SPP waveguides.

(2.5 Gbps per channel) of electrical copper lines in chip-to-chip or board-to-board interconnections. The LR-SPP technology is one of the emerging technologies for optical interconnection, particularly at nanoscale dimensions [3]. Moreover, a 10 Gbps optical signal process will soon be achieved.

In this letter, we present a 10 Gbps optical signal transmission experiment via LR-SPP and report the results for the first time.

II. Experiments

The fabricated LR-SPP waveguide consists of a Si substrate, a lower cladding layer, a thin metal strip, and an upper cladding layer as shown in Fig. 1(a). The lower cladding polymer was spin-coated on a Si-wafer and UV-cured with a thickness of 30 μm. Onto that, an Au layer was thermally evaporated with a thickness of 14 nm and patterned as a strip waveguide 4 cm long and 2.5 μm wide. Then, the upper cladding polymer was spin-coated and UV-cured with a thickness of 30 μm. The lower and upper cladding layers are the same polymer which is a UV-curable polymer, ZPU 450, supplied by ChemOptics, Inc., Korea [9]. The opto-chip was prepared by dicing and the opto-chip end faces were polished and then pig-tailed with V-groove arrayed single mode fibers using an epoxy welding technique as shown in Fig. 1(b).

The experimental set-up for 10 Gbps optical signal transmission via the LR-SPP waveguide is shown in Fig. 2. The above pig-tailed LR-SPP waveguide was used. A 10 Gbps pulse pattern generator (PPG), a digital communication analyzer (DCA) and bit error rate (BER) tester [10] were used. A polarization controller was used because an SPP is excited by a TM mode light. A 1.55 μm laser diode was used for the carrier wave.

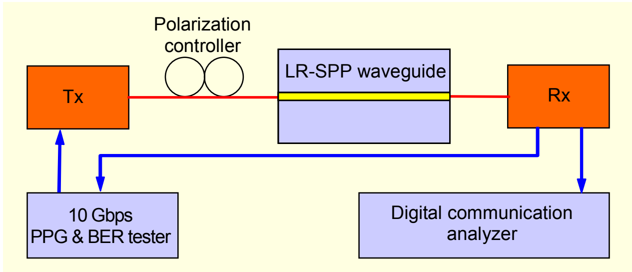

Fig. 2. Experimental set-up for measuring transmission properties of the LR-SPP waveguide at 10 Gbps optical signals.

III. Results and Discussion

We measured the propagation loss of our LR-SPP waveguides at the 1.55 μm wavelength with a cut-back method. The measured propagation loss was 3 dB/cm. The detailed results were reported in [11]. We also measured the total insertion loss with our pig-tailed LR-SPP waveguides. The measured total insertion loss was 16 dB/cm. We estimated a coupling loss of 2 dB at each facet with a standard single mode fiber.

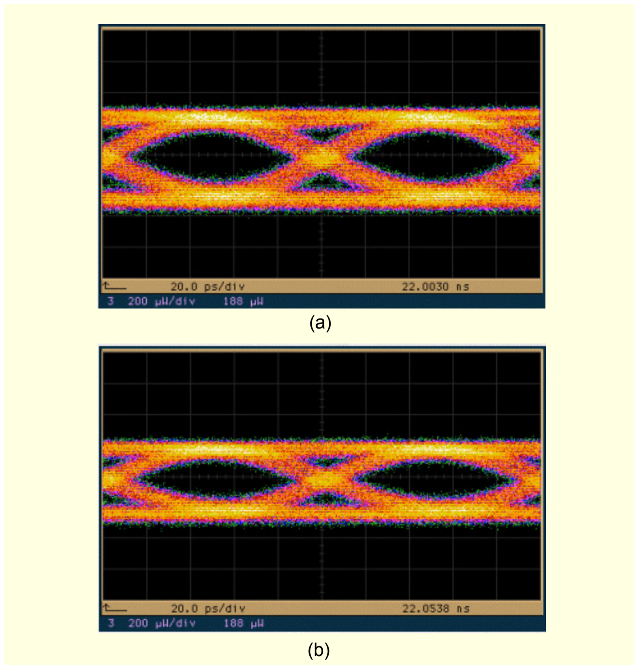

Fig. 3. Measured eye diagrams of (a) back-to-back and (b) after transmission of the LR-SPP waveguide.

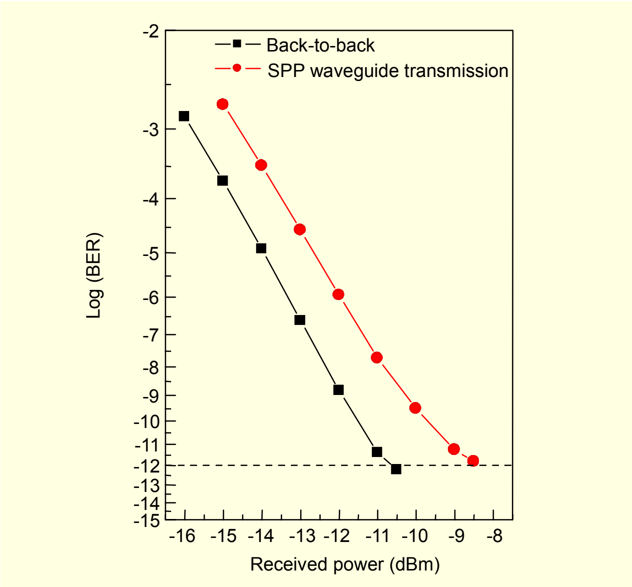

Fig. 4. Measured BER curves at 10 Gbps optical signals.

Figure 3 shows eye diagrams for 10 Gbps optical signal transmissions. Figure 3(a) shows the back-to-back eye diagram without the LR-SPP waveguide. Figure 3(b) shows the eye diagram measured after the LR-SPP waveguide. As shown in Fig. 3(b), the eye is well open but the intensity is reduced compared with the back-to-back eye diagram in Fig. 3(a). The reduced intensity resulted from the difference in the optical power delivered to the DCA due to the 16 dB total insertion loss of the LR-SPP waveguide. We tested the bit error rate at 10 Gbps. The LR-SPP waveguide transmitted optical signals with power penalties of 1.7 dB at 10^{-9} and 2.2 dB at 10^{-12} bit error rates as shown in Fig. 4. Thus, we confirmed for the first time that an LR-SPP transfers data signals as well as the carrier light even though there are many obstacles such as the longitudinal oscillations of the electrons, loss, the wave vector difference, dispersion, and so on. These results indicate that the LR-SPP waveguide is a potential transmission line for optical interconnections which can overcome current problems in electric interconnections.

IV. Conclusion

The LR-SPP waveguide was fabricated as a 14 nm thick, 2.5 µm wide, 4 cm long gold strip embedded in the UV-curable polymer and pigtailed with single mode fibers. The propagation loss was 3 dB/cm, and the total insertion loss was 16 dB at the 1.55 µm wavelength. In a 10 Gbps optical transmission experiment, The LR-SPP waveguide showed a clear eye opening and power penalties of 1.7 dB at a BER of 10^{-9} and 2.2 dB at a BER of 10^{-12}. The LR-SPP waveguide efficiently transferred the carrier light as well as the 10 Gbps data signals.

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