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A Photonic Modulator Based on a Semiconductor Soliton Device

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1. Introduction

All-optical switching and modulation devices are attractive for applications in signal processing and telecommunications [1-2]. A spatial soliton, in which a beam of light propagates without change in its transverse profile due to a positive light-induced change in the index of refraction which balances normal diffraction in the light propagation medium. Soliton are proved to be excited from electric-field-induced carrier drift in photorefractive media, such as quasisteady-state solitons, and screening solitons are interest because of the low light intensities required for solitons formation [3-5]. Particularly, soliton in photovoltaic–photorefractive media is more significant because external electric field is not required and the long lifetime of the charge-induced index perturbations permits its wave guiding last for minutes after stopping by soliton formation [6-8]. Here we demonstrated a photonic light intensity modulation based on a semiconductor soliton device witch which is able to achieve controlling the transmission of light propagation through the waveguide formed by the emission from a circular ring resonator.

2. Device fabrication

The soliton device is based on a sigma shape laser diode device consisted with a circular ring resonator and a linear Y-junction coupler section. The device is divided into three sections: an input coupling section, a soliton control device section, and an output coupling section. At the input coupling section, a input signal is guided through a proximity single mode optical fiber and is optically aligned with the end facet of the ridge waveguide Y-junction output coupler. The sigma shape laser diode is the key element of the device in which spatial soliton can be generated and propagating along non-waveguide region. The output coupling section has the same signal connection structure as used at the input terminal.

The device was fabricated on an MOCVD grown InGaAlP multiple quantum wells structure which is a photovoltaic–photorefractive media and is possible for soliton generation with low light power level and without the perturbation by the existence of an external electric field. The soliton device is a sigma shape laser diode with a circular ridge-waveguide resonator of 500 μm in diameter. The width of the ridge waveguide is 10 μm, and the Y-junction coupling branch is 500 μm long. The etching for defining the ridge-waveguide structure is crucial since that the uniformity of the etched side-walls depends on the anisotropic characteristics of the etching. UV laser assisted cryoetching had been developed to achieve anisotropic of the uniform circular ridge waveguide structure without damage to the etched side wall [9]. Etching was operating at 140 K of substrate temperature, with 10 mTorr of chlorine (99.95%), and by 150 mJ/cm^2 of 193nm ArF excimer laser at 10Hz repetition rate. Figure 1 shows the pictures of the fabricated device and its detailed waveguide structure. Confinement of the current injection area along the ring cavity is achieved by a patterned 0.2 μm silicate based spin on glass (SOG) (ACCUGLASS 204) to provide electrical isolation. Then a blanket thick Au layer was deposited on top of the device for electrode contact.

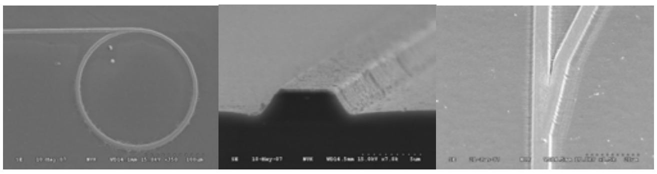

Fig.1. SEM pictures of the (a). soliton modulation device, (b). cross section of the ridge waveguide structure, and (c). detailed structure of the Y-junction coupling section.

3. Characterizations and discussions

The device was mounted on a probe-tested X/Y/Z precision piezoelectric controlled stage. The tested device was driven by a pulse mode current source (HP 8114A) at 10 kHz. Figure 2 shows the measurement of the output power at Y-junction terminal and at the soliton emission terminal on non-waveguide region. In general, the output power at the Y-junction terminal is higher than the power output at soliton emission terminal. The threshold current for the lasing of the sigma shape laser diode includes the Y-junction coupling section is about 200 mA. After the threshold of the lasing, emission through the non waveguide region increase exponentially and reaches lasing at correction injection about 450 mA. Figure 2 shows L-I characteristics and included photos of the tested device while emission at Y-junction terminal and at soliton emission terminal. It shows the confinement of the propagation of the emission at Y-junction and along the non waveguide region without external applied electric field perturbation and under very low excitation. Following the increase of the intensity of the soliton emission, the width of the confinement increases until the lasing condition of soliton emission was reached. As a result, control of the width of the waveguide is able to achieve by the emission of the soliton.

To test the signal modulation of the device, a laser diode lasing at 1560 nm was aligned to the Y-junction output terminal by proximity alignment with a single mode optical fiber. The transmission through the soliton waveguide is coupled out by a single mode fiber and monitored by a optical spectrometer (HP 4095B). Figure 3 shows the configuration for the measurement of transmission modulation of the soliton device. Figure 4 shows the correspondence of the transmission of the 1560 nm and the emission of the 650 nm at the soliton terminal. It clearly showed the 1560 nm input power was modulated by the 650 nm emission of the ring resonator within 10 dBm. The emission of 650 nm from the Y-junction is attenuated along the non waveguide region due to direct band absorption of the quantum wells structure.

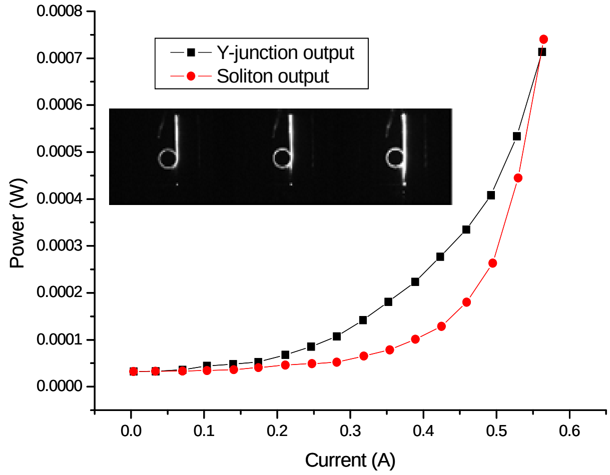

Fig.2. L-I characteristics of the emission at the terminal of the Y-junction and at the terminal of soliton emission, and inserted photos of the top view of the device operating with 200 mA, 300 mA, and 400 mA current injection.

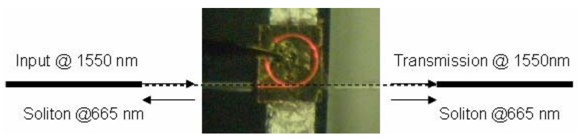

Fig.3. Configuration of the test of transmission modulation of a 1550 nm input signal.

The width of the confinement along the non waveguide region increases with the increasing of excitation from the ring resonator until the soliton device reaches lasing while the width of the light confinement at the soliton terminal approaches to the width of the ridge waveguide which is about 8 μ m.

4. Conclusions

We have demonstrated the modulation of a 1560 nm transmission through a soliton device which is photovoltaic photorefractive medium in which waveguide structures can be generated optically through nonlinear effect at lower power levels. The signal modulation depth is as high as 10 dBm. Detailed study of the soliton waveguide structure required for the all optical modulation will be presented in the future.

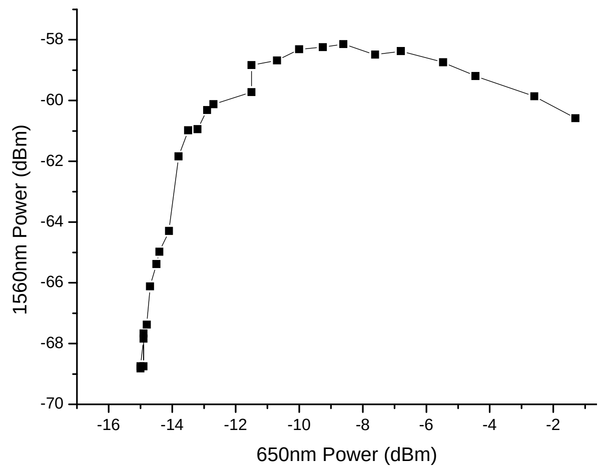

Fig.4. Dependence of the modulation of the transmission signal on the power level of the soliton device.

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