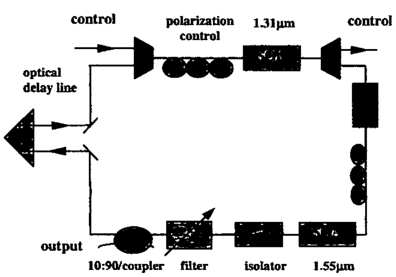
the fiber and semiconductor has obtained widely interests.[1–5] In this paper, a novel actively mode-locking ring laser which is based on the 1.55 μm-SOA as a gain medium and 1.31 μm-SOA as a novel and simple purely phase modulator is proposed and preliminarily discussed. The total cavity length of the ring laser can be considerably shortened to minimize the impact of an environmental perturbation and the gain fluctuations can be also removed. What's more, the new scheme is operated in all-optical domain that can be hoped to produce ultra-short optical pulses at high repetitive rates and to extract the all-optical clock signals if it is driven by optical data signals as well.

Experimental Set-Ups

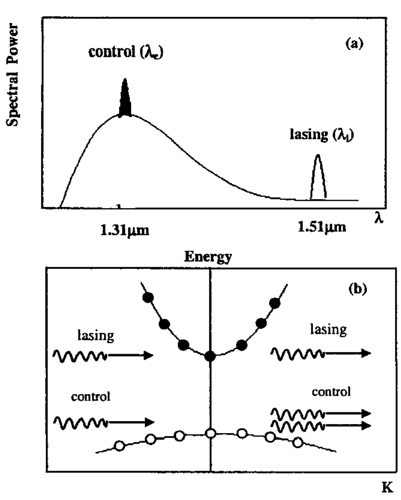
The experimental set-up is shown in Fig. 1. It includes two polarization-independent isolators, two polarization controllers, one 10:90 coupler, an optical delay line and a couple of 1.31/1.55 μm Wavelength-Division Multiplexer(WDM). The 1.55 μm-SOA provides the gain of the semiconductor-fiber ring laser. A 1.31 μm-SOA that has gain in the 1.31 μm regions but is gain-transparent to the lasing wavelength at 1.55 μm regions inside the ring cavity is used as an all-optical purely phase PM modulator.

Experimental Principles

Fig. 2 illustrated the principles of the gain-transparent SOA FM all-optical modulator. A control signal (1.31 μm) was coupled into and out of the ring cavity through low-loss 1.31/1.55 μm WDM-couplers. Because the wavelengths of the control light and lasing light are in the 1.31 μm and 1.55 μm regions respectively, we have $E_{control} \square hc/\lambda_{control} \square E_g$ and $E_{lasing} \square hc/\lambda_{ring} \square E_g$. Where $E_{control}$ and E_{lasing} are the energy of the control light and lasing light respectively, $\lambda_{control}$ and λ_{lasing} are the wavelengths of the control light and lasing light respectively, 'h' is the plank constant, 'c' is light velocity in vacuum, and E_g is the gap from the top of value band to the bottom of the conductor band. When the 1.31 μm optical pulses were injected into the 1.31 μm-SOA, they surely deplete the carriers in the SOA and cause a change of refractive index through the change of the carrier density. But the gain of the 1.31 μm-SOA is essentially unchanged to 1.55 μm light. Therefore, when intensity-modulated 1.31 μm control light is launched into the 1.31 μm SOA, it will modulate the carrier density and so surely produce a phase modulation on the 1.55 μm lasing light. When the modulation frequency matches the roundtrip frequency or its multiple, the ring laser will be actively mode locked.



CThR4 Fig. 1. The experimental set-up of the mode-locked ring laser.



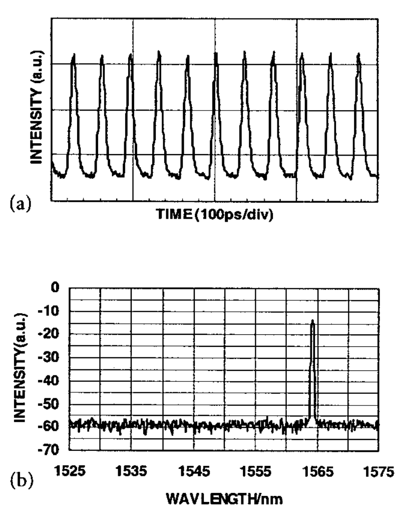
CThR4 Fig. 2. Principles of the gain-transparent modulation. (a) optical spectrum, (b) E-K diagram.

Experimental Results

The control signal was launched into and out of the ring cavity through the 1.31/1.55 μm WDM. The tunable filter in the cavity decided the lasing wavelength of the ring cavity. By carefully tuning the modulation frequency of the control signal and the length of the optical delay line in the cavity, the actively mode-locked pulses were obtained. Fig. 3a shows the pulse train when the laser was modulated at about 5.7 GHz harmonic frequency. Fig. 3b shows the optical spectrum of the emission. The central wavelength was 1564.2 nm and the 3 dB spectral width was about 0.4 nm. The pulse width indicated in the sampling scope measurements was about 41 ps.

Conclusions

In conclusion, a novel actively mode-locked ring laser scheme was proposed in this paper. The principle of this scheme was discussed and analyzed detailed. Primarily experimental results have also been obtained. And the more detail theories and experiments will be discussed in following work.



CThR4 Fig. 3. Mode-locked output pulses with a repetition rate of 5.7 GHz. (a) pulse waveform, (b) spectrum.

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CThR5 **3:30 pm**

Study of a Dispersion-tuned, Harmonically Mode-locked Fiber Ring Laser with a SOA

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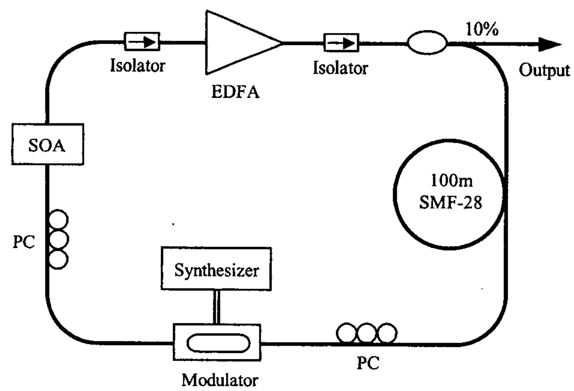
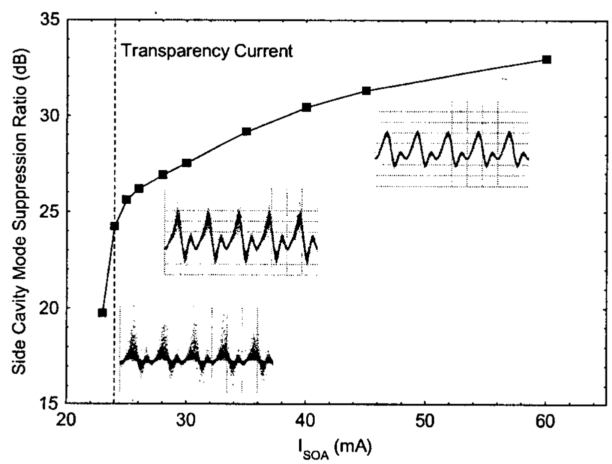
Dispersion-tuned, harmonically mode locked fiber ring lasers (DTHMLFRLs) are able to generate high-speed, picosecond optical pulses with smooth wavelength tuning.[1,2] However, large supermode noise (SMN) associated with harmonic mode locking significantly limits their applications.[3] While several methods have been proposed to suppress the SMN in mode-locked fiber ring lasers,[3–6] they cannot be used in a DTHMLFRL because the addition of filters prevents smooth wavelength tuning. We have reported a simple scheme to suppress the SMN in a DTHMLFRL by introducing a semiconductor optical amplifier (SOA) into the ring cavity.[7] Biased at its low-gain regime, the SOA suppressed the SMN by 13 dB. Smooth wavelength tuning was achieved within 10 nm by varying the modulation frequency 0.25 MHz. 5.3-ps pulses were obtained at a repetition rate of 10 GHz. In this paper, we report the experimental study of this system at different driving currents of the SOA and compare some of the experimental data with result from numerical simulations.

Fig. 1 is a schematic of the experiment setup. The unidirectional ring cavity consists of an EDFA, a SOA, an electro-optic modulator, 100 meters of SMF-28 fiber, two Faraday optical isolators and a pair of polarization controllers (PCs). The total length of the loop was about 150 m. The EDFA provided the majority of the total gain to keep the SOA biased in its low-gain regime. The modulation frequency was 10 GHz.

The effects of the SOA in the dispersive fiber ring cavity was investigated by changing the driving current I_{SOA}, while keeping the average optical power inside the cavity the same by adjusting the pump power of the EDFA accordingly. Fig. 2 shows the relation of the side cavity mode suppression ratio (modulation peak/highest side mode) versus I_{SOA}. I_{SOA} was varied from 23 mA, which was slightly below the transparency current (24 mA), to 60 mA, which was much lower than the maximum current 250 mA. The sampling scope traces at 23 mA, 26 mA and 45 mA are shown in the insets. It is evident from Fig. 2 that SMN suppression improves as the gain increases.



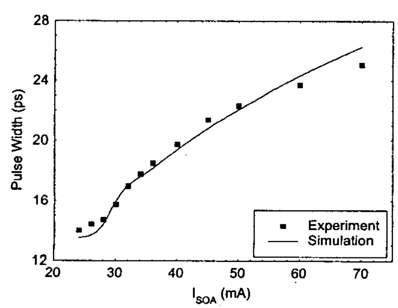
CThR5 Fig. 1. Experimental Setup.



CThR5 Fig. 2. Side cavity mode suppression ratio increases with the driving current of the SOA.

Moreover, SMN is significantly suppressed when the SOA switches from absorption to gain. These results provide information about the mechanism of SMN suppression by SOAs, which is under further investigation.

The width of the uncompressed output pulses was also measured at different I_{SOA}. As shown in Fig. 3, the pulse width increases with I_{SOA}. This behavior was studied with a simple numerical model, which followed the Kuizenga-Siegman approach.[8] The pulse duration was assumed much shorter than the carrier lifetime in the SOA so that the time-dependent gain can be expressed analytically.[9] The small signal gain was determined by experiment and the saturation energy was considered proportional to I_{SOA}. The linewidth enhancement factor was assumed to be 3.5. Other parameters were the same as in the experiment. The gain of the EDFA was adjusted to keep the average power a constant. The agreement between the simulation result and the experimental data demonstrates the validity of the model. Work is in progress to establish a more complete model to study the effects of the SOA on both SMN and pulse properties.



CThR5 Fig. 3. The uncompressed output pulse width varies with the driving current of the SOA.

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CThR6 **3:45 pm**

Q-switched 980 nm Yb-doped Fiber Laser

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Double-clad rare-earth doped fiber lasers pumped by high brightness laser diodes are very efficient and compact sources of cw and pulsed radiation. Ytterbium-doped fiber lasers (YDFLs) have been demonstrated at around 1100 nm in cw configurations with output powers of 110 W[1] and in Q-switched operation with pulse energies approaching 10 mJ.[2] Ytterbium can also emit at around 980 nm, with output power of around 1 W demonstrated in cw operation.[3] Here, we present a Q-switched 980 nm cladding-pumped YDFL with 1.2 μJ of energy and 60 W of peak power in pulses shorter than 20 ns at repetition rates of up to ~0.2 MHz and 250 mW of average output power for repetition rates between 0.2 and 0.65 MHz. A pulsed 980 nm source with high peak power and good beam quality is attractive for frequency conversion, e.g., frequency quadrupling to 245 nm.

A Q-switched cladding-pumped 980 nm YDFL presents two challenges: Its pronounced three-level nature leads to a high threshold and potential problems with strong amplified spontaneous emission (ASE) at 1030 nm.[4] Because of this, a high pump intensity and low cladding-to-core area ratio is needed for efficient operation. We used a jacketed air-clad fiber[5] that provided a tight pump confinement in a 28 μm diameter inner cladding with a high NA (up to 0.5)[5]. See inset in Fig. 1. Furthermore, the small inner cladding results in a high pump absorption and thus short device lengths, which promotes high