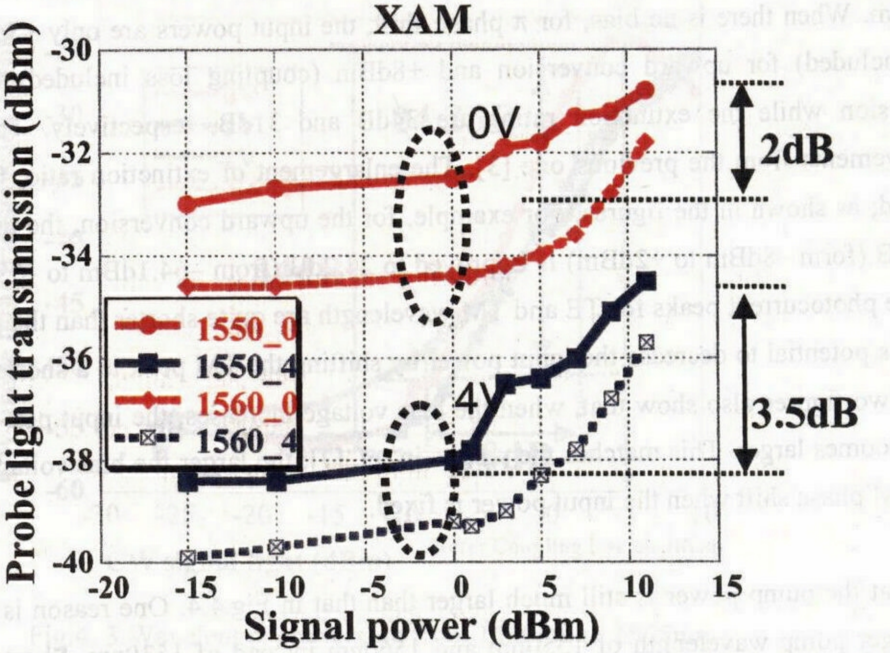


Fig.4. 8 XAM characteristics for InGaAlAs MQW-EA under different bias voltages. The solid lines are for 1550nm light, and the dotted lines are for 1560nm mode.

4.5 Dynamic wavelength conversion

4.5.1 Experiment

The dynamic measurement setup is shown in Fig.4.9. The pump pulse with 1553nm wavelength and 18 dBm average input power at 10GHz repetition rate with 20ps pulse width is generated by a mode-locked fiber ring laser (MLFL), pseudo-random encoding with the pattern length of 2^{31} -1 by a lithium niobate (LN) modulator. The co-propagating CW probe was set at 1563nm/1543 with 8dBm average power. Note that the input powers for both CW light and the pulse are 1dBm and 11dBm under the condition that every EAM facet has 7dB coupling loss. The polarization of the probe light is adjusted by a Babinet-Soleil polarization controller (BSPC) and the pulse is fixed in TE mode. The EAM is cooled at 20 °C.

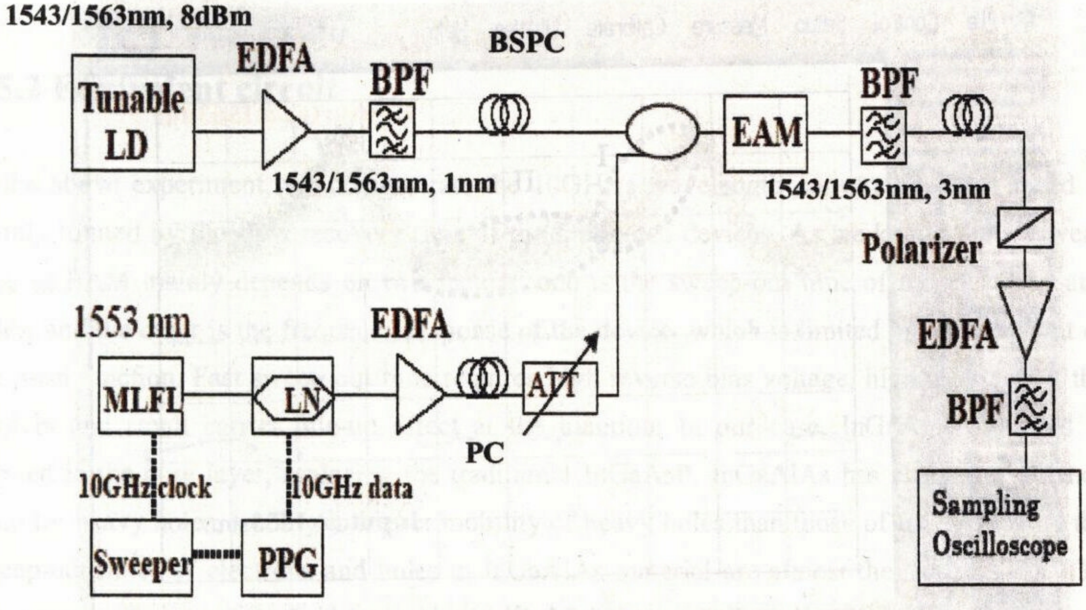
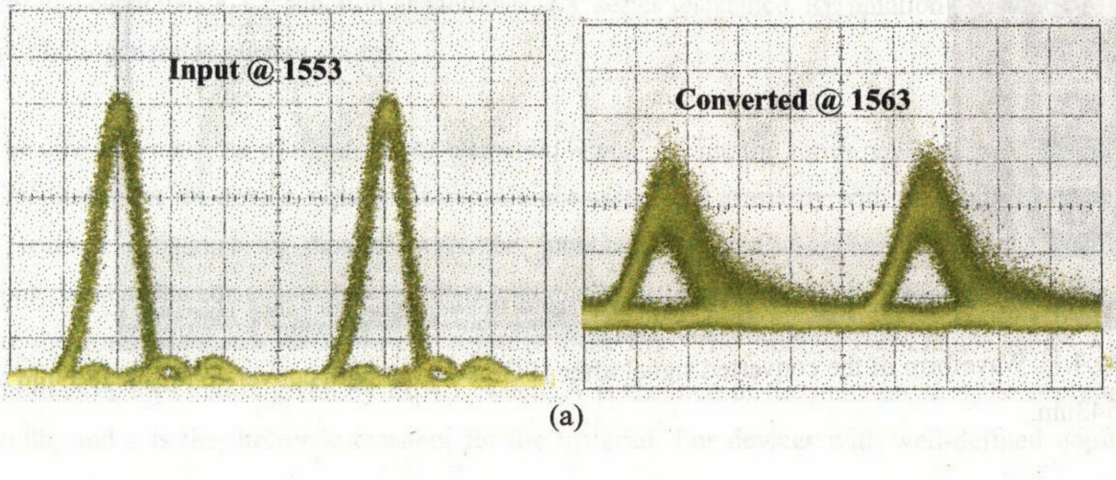


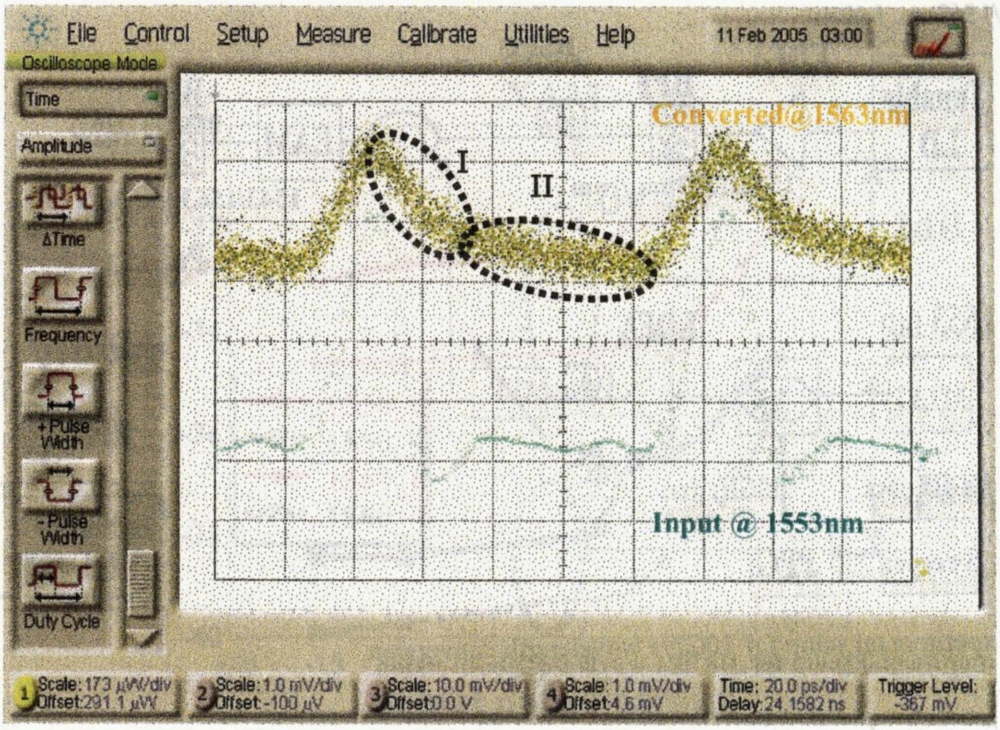
Fig.4.9. Experimental setup for 10Gb/s wavelength conversion.

Fig.4.10 illustrates the eye diagram of 10Gb/s wavelength conversion from 1553nm to 1563nm, captured by a 30GHz digital sampling oscilloscope at a reverse bias of 2.74 volts. In the figure exits the apparent broadening falling edge, which maybe results from the slow extraction of photo-generated carrier from the device by the probe, which will be discussed in the following subsection.

Fig.4.11 illustrates the eye diagram of 10Gb/s wavelength conversion from 1553nm to 1543nm. The EAM is reversely biased at 3.28V. Compared to Fig.10, we see that the light at 1543nm is more sensitive to XPM than that of 1563nm. This matches well with the simulation that for the same carrier density, light with the short wavelength has larger refractive index change than the light with longer wavelength.



(a)



(b)

Fig.4.10 10G/s wavelength conversion from 1553nm to 1563nm. (a) Eye diagram (b) waveform

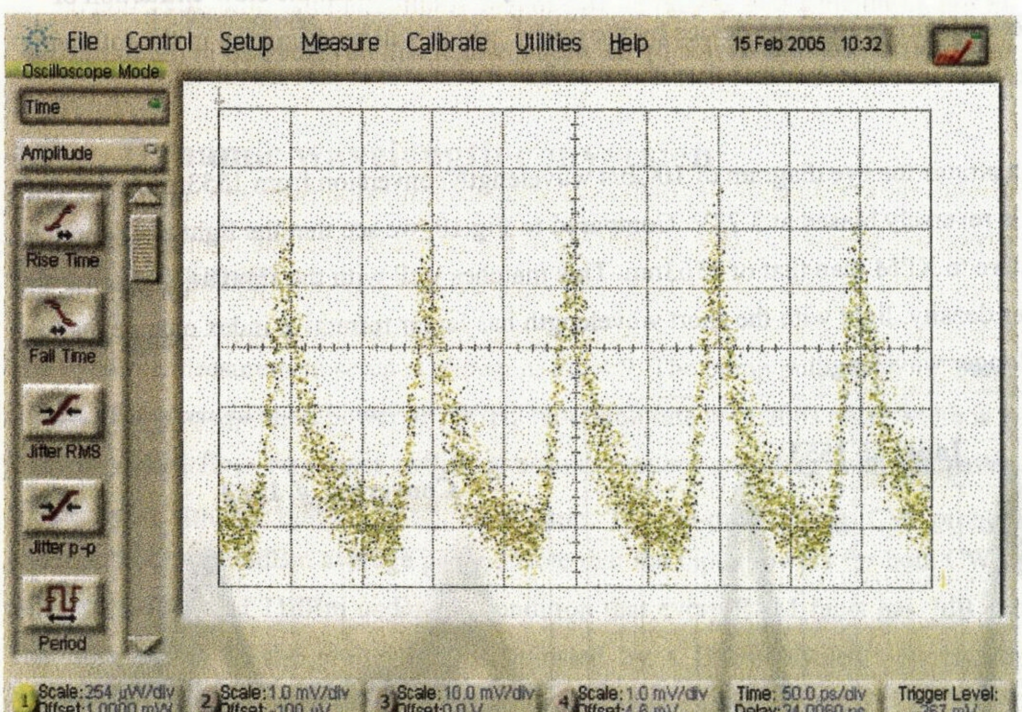
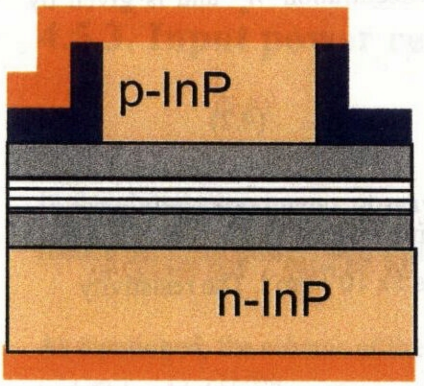


Fig.4.11 Waveform of the converted signal after 10Gb/s wavelength conversion from 1553nm to 1543nm.

4.5.2 Equivalent circuit

In the above experiment, we demonstrate the 10GHz/s wavelength conversion. This speed is mainly limited by the slow recovery time of the fabricated devices. As we know, the recovery time of EAM mainly depends on two factors: one is the sweep-out time of the electrons and holes, and the other is the frequency response of the device, which is limited by RC constant of the p-i-n junction. Fast sweep-out time requires high reverse bias voltage, high mobility of the carriers and small carrier pile-up effect at the junction. In our case, InGaAlAs material is applied in the core layer, replacing the traditional InGaAsP. InGaAlAs has shallower valence band for heavy holes, leading to higher mobility of heavy holes than those of InGaAsP, and the sweep-out times of electrons and holes in InGaAlAs material are almost the same as [7]. The frequency response of the EAM can be clarified by the equivalent circuit, which is shown in Fig.4.12.



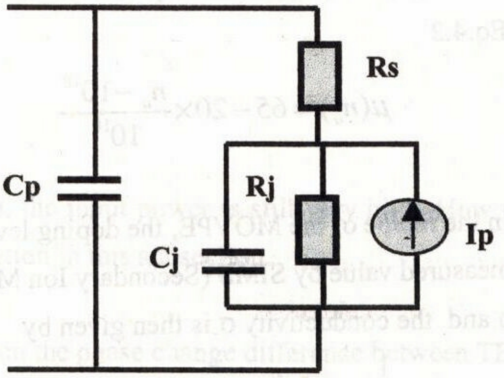


Fig. 4.12. Equivalent circuit of the EAM. (a) EAM layer stack. (b) equivalent circuit.
Cp: Pad capacitance, Cj: junction capacitance, Rs: series resistance, Rj: junction resistance
Ip: photo-generated current source.

The circuit is made up of a number of elements, which include the series resistance and junction capacitance for the device, a parasitic capacitance associated primarily with the contact pad, and a leakage resistance in parallel with the junction. The photo-generated carriers can be considered as the current source. In this model, the series resistance and the junction capacitance are the dominant elements so we can consider these first. The junction capacitance scales with the devices area and is given by Eq.4.1, where A is the area of the junction, d is the depletion width, and ε is the dielectric constant for the material. For devices with well-defined doping profiles, d is approximately equal to the thickness of the intrinsic layer. In our case, the waveguide width is 2um and the depletion region is 0.33um.

$$C_j = \frac{\varepsilon A}{d} \tag{4.1}$$

The series resistance is composed of several different components, which include the contact resistance for the n and p contacts, the series resistance of the p layer, and the series resistance of the n layer. In InP the mobility for holes is approximately 30 times lower than the mobility for electrons, also the specific constant resistance for the p contact is typically 10 times larger than for the n contact. Our devices are fabricated on n-type InP substrates, so the n contacts are very large covering the entire back side of the wafer, while the p-contact area is limited to the area of the waveguide. Because the resistance is in reverse proportion to the area, the p-type contact and p-semiconductor layer resistances dominate the series resistance. The specific contact resistance for an EA modulator is generally between 1 x e^{-5} and 1 x e^{-6} ($\Omega\,cm^2$). The mobility μ in p-type InP depends on the acceptor doping concentration n_a and is given by Eq.4.2

$$\mu(n_a) = 65 - 20\times\frac{n_a - 10^{18}}{10^{18}} \tag{4.2}$$

In the recipe of the MOVPE, the doping level for the InP cladding layer is 1x 10^{18} cm^{-3}, and the measured value by SIMS (Secondary Ion Mass Spectrometry) is 5x 10^{17} cm^{-3}. The resistivity ρ and the conductivity σ is then given by

$$\frac{1}{\rho} = \sigma = qn_a\mu \tag{4.3}$$

The total series resistance for the device can be calculated using Eq.4.4, where w is the width of the devices (2um), l is the length (300um), and t is the thickness o f the p cladding layer (1um).

$$R_s = \rho(\frac{t}{wl}) + \frac{r_c}{wl} \tag{4.4}$$

The resistance and capacitance per unit length for our EAM now can be calculated: they are 5.32 Ω·mm and 665 pF/mm respectively. The resistance value matches quite well with the result obtained from the I-V curve.

According to the 3dB bandwidth equation in (4.5)