FABRICATION AND PERFORMANCE EVALUATION OF ACTIVE *Er:Ti:LiNbO₃* WAVEGUIDES

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ABSTRACT

The excellent performance of Erbium doped fiber amplifiers and lasers in the 1550 nm wavelength region has stimulated increased interest in Erbium doped integrated optic planar waveguide devices (particularly $LiNbO_3$)

This work describes the measurement techniques and the performance evaluation of Er-doped, X-cut and Z-cut Ti:$LiNbO_3$ waveguides. Waveguide losses have been measured in the 1300 nm and 1550 nm wavelength regions, in both TE and TM polarization states, using the low finesse Fabry-Perot technique [1]. The resonance phenomena has been obtained with two different methods, the thermal cavity tuning and the sweeping in wavelength using a tunable semiconductor laser. The results obtained in this second case are in good agreement with those obtained by the temperature tuning. The second method has also the advantage of avoiding the coupling stability problems inherent to the thermal tuning.

Absorption spectra have been evaluated using a white spectral lamp and a semiconductor LED;. spontaneous emission spectra have been evaluated pumping with semiconductor laser.

A strong absorption was observed around the value of 1530 nm for TE and TM polarization. Using the spectral lamp significant absorption around 980 nm was observed.

1.INTRODUCTION

Er-diffused Ti:$LiNbO_3$ waveguides have attracted much attention because they allow the fabrication of amplifier and laser [3] devices. The doping with Erbium allows the stimulated emission in the 1550 nm wavelength region which is the range of minimum losses of the optical fibres. This property, combined with the excellent electro-optical and acousto-optical properties of $LiNbO_3$, can be utilized to integrate on the same substrate modulation and

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amplification of the signal, for example in the realization of Mode-Locked [2] and Tunable laser sources.

In this contribution we report the results of losses, mode field diameter and spectral analysis characterization of X-cut and Z-cut Er:Ti:$LiNbO_3$ waveguides.

2.WAVEGUIDE FABRICATION TECHNOLOGY

Z-cut and X-cut 3 inch $LiNbO_3$ wafers were doped near the surface by diffusion of an evaporated Erbium layer. On the doped surface 8 groups of waveguides with variable width from 5.0 μm to 10 μm are photolithographically defined. Titanium stripes of about 100 nm were vacuum deposited and diffused to form (53 mm long) optical channel waveguides. Subsequently the wafers were cut in 8 samples and the end faces polished.

3.WAVEGUIDES CHARACTERIZATION

3.1.Loss measurement

The waveguide absorption and scattering losses were evaluated with the low finesse Fabry-Perot technique [3]: the Fabry-Perot cavity is formed by the waveguide and the two polished and faces. The interference contrast is produced by heating the sample to temperature tune the cavity or sweeping the wavelength of a semiconductor tunable laser.

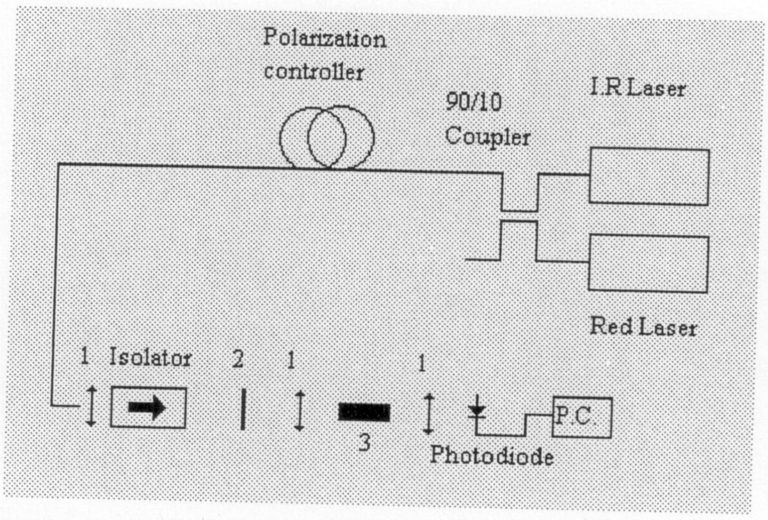

Fig.1: Experimental setup for attenuation measurement. 1) Microscope Objective. 2) Polarizer. 3) Sample mounted on a Peltier element.

The measurement setup is shown in Fig.1. In the first case the I. R. laser was working at a fixed wavelength and the temperature of the samples was changed using a Peltier element. The signal source used had a long coherence length compared with the waveguide length. In the second method the temperature of the sample was constant and the wavelength of the source was swept.

We measured the losses at 1300 nm with the heating technique, and at 1523 nm with both techniques. The data were acquired and elaborated with a personal computer. Fig.2 shows a typical acquisition of the measurements performed with the first technique. The attenuation coefficient is evaluated from the contrast of the signal which is reported in the upper curve; in the lower there is the frequency spectrum of the intensity of the signal acquired, obtained with a FFT routine. The precision of the measurement is evaluated from the value of the data standard deviation.

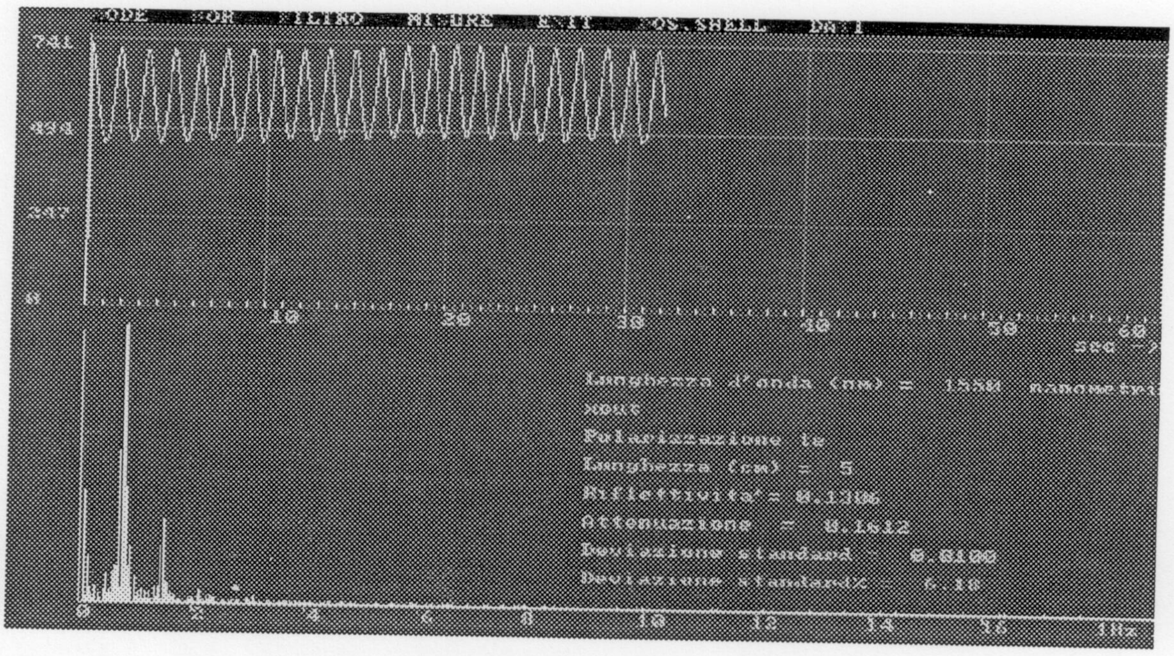

Fig.2: Image of the signal on the P.C. monitor.

The data are summarized in Table 1 for 1300 nm and in Table 2 for 1523 nm. The measurements were performed for the waveguides which support only the fundamental mode. From these tables it is possible to note that the attenuation at 1300 nm is about 0.1 dB/cm for TM polarization. Because there is negligible absorption at this wavelength this means that all the measured attenuation is due to scattering and a low value of this parameter means a good quality of the doped waveguides. Comparing these data with those measured at 1523 nm one may assume good absorption. The standard deviation is higher at 1300 nm than at 1523 nm because the 1300 nm source is less stable and the components of the setup are optimized around 1550 nm.

Table 1: Attenuation at 1300 nm.

Substrate cut	Waveguide Width µm	Attenuation dB/cm	Standard Deviaton %	Polarization State
X-cut	5.0	0.17	2.07	TE
"	5.5	0.17	3.43	TE
"	5.0	0.11	8.43	TM
"	5.5	0.10	5.90	TM
"	6.0	0.13	4.35	TM
"	6.5	0.10	4.93	TM
Z-cut	5.0	0.11	5.28	TE
"	5.5	0.12	4.84	TE
"	6.0	0.11	4.86	TE
"	6.5	0.11	4.84	TE
"	5.0	0.15	3.81	TM

Table 2: Attenuation at 1523 nm

Substrate cut	Waveguide Width µm	Attenuation dB/cm	Standard Deviaton %	Polarization State
X-cut	5.0	0.64	1.29	TE
"	5.5	0.66	1.05	TE
"	6.0	0.75	1.01	TE
"	6.5	0.77	1.20	TE
"	5.0	0.34	1.68	TM
"	5.5	0.38	1.01	TM
"	6.0	0.42	1.49	TM
"	6.5	0.44	1.27	TM
"	7.0	0.47	1.65	TM
"	7.5	0.48	0.49	TM
"	8.0	0.49	0.87	TM
"	9.0	0.61	0.91	TM
"	10	0.53	1.53	TM
Z-cut	5.0	0.64	2.73	TE
"	5.5	0.67	2.38	TE
"	6.0	0.71	2.7	TE
"	6.5	0.74	3.00	TE
"	7.0	0.73	3.78	TE
"	7.5	0.75	1.25	TE
"	8.0	0.79	1.54	TE
"	9.0	0.79	0.95	TE
"	5.0	1.01	1.44	TM
"	5.5	1.07	1.47	TM
"	6.0	1.09	2.27	TM
"	6.5	1.14	1.36	TM

Table 3 shows the loss measurement performed using the wavelength sweeping of the source. The sweeping range was centered at 1523 nm with a step of 0.001 nm and a range of 50 steps. The measurement was performed for 4 waveguides.

Table 3.

Substrate cut	Waveguide Width µm	Attenuation dB/cm	Standard Deviaton %	Polarization State
X-cut	5.0	0.58	0.91	TE
"	5.5	0.62	1.26	TE
"	6.0	0.72	1.31	TE
"	6.5	0.74	1.52	TE
"	5.0	0.36	1.94	TM
"	5.5	0.41	1.37	TM
"	6.0	0.39	1.52	TM
"	6.5	0.42	1.71	TM

Comparing the values of Table 3 and Table 2, it is possible to note a good agreement between the results obtained with the two techniques on a X-cut sample.

3.2.Mode Field Diameter Measurement

For this measurement the setup resembles that reported in Fig.1 except that the souce in this case has a short coherence length in order to avoid interference problems and the photodiode is replaced by an infrared camera.

Measurements were performed at 1550 nm and 1480 nm. In Fig.3, 4, 5, 6, we report the spot size at half power (for the vertical and horizontal directions, for both polarizations and for X, Z-cut samples) versus the nominal width of the waveguide. For the larger nominal waveguide widths mode confinement is greater, resulting in stronger absorption as verified by comparison of the total losses at 1523 nm and 1300 nm.

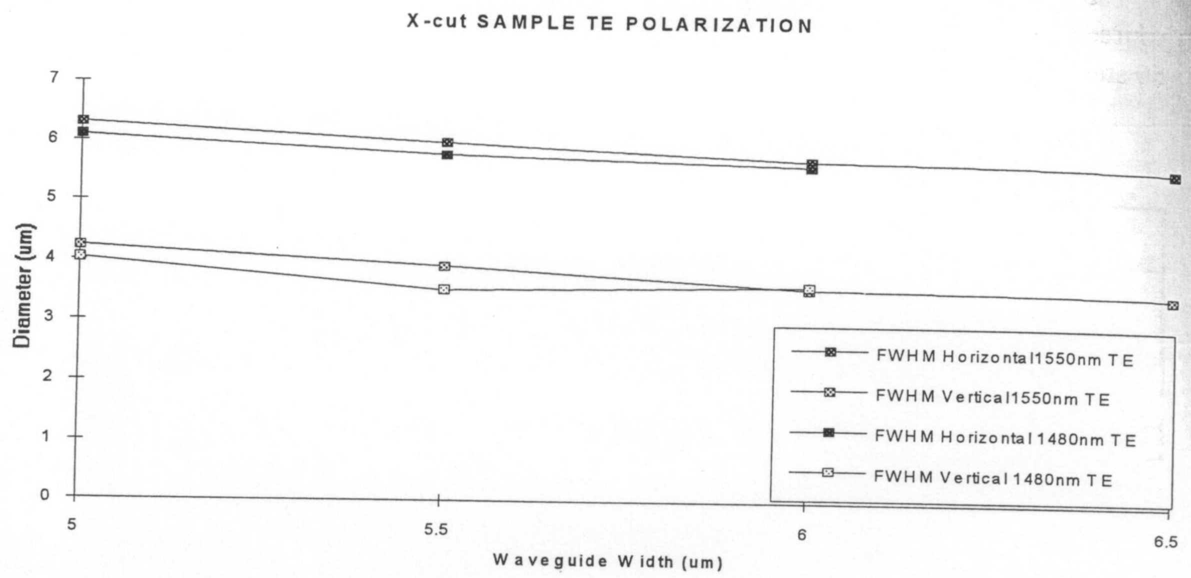

Fig.3: Mode field diameter of the X-cut sample, TE polarization.

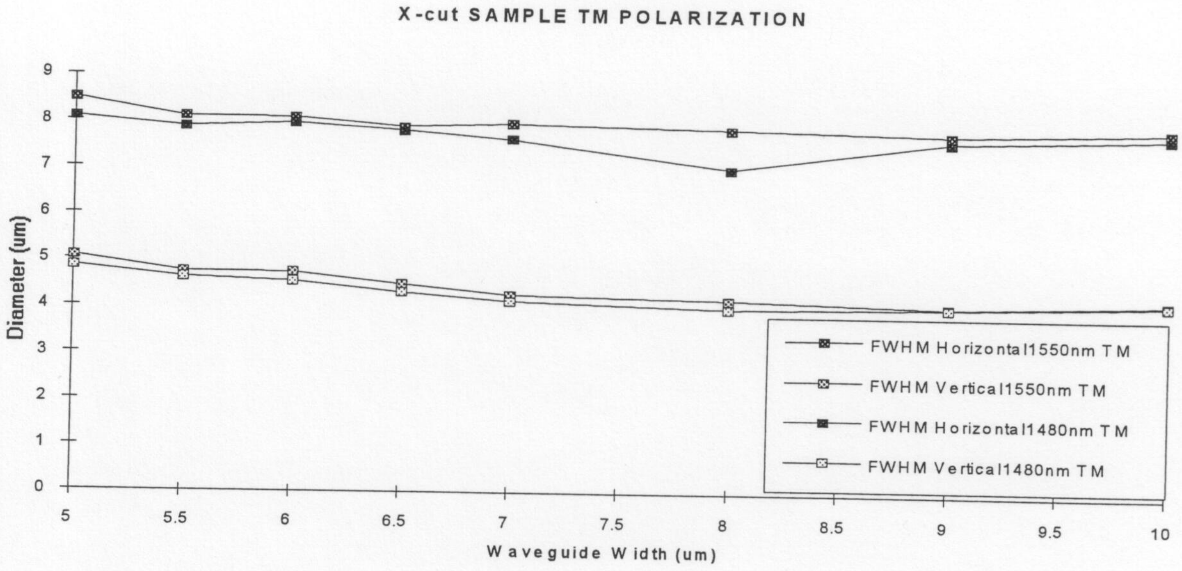

Fig.4: Mode field diameter of the X-cut sample, TM polarization.

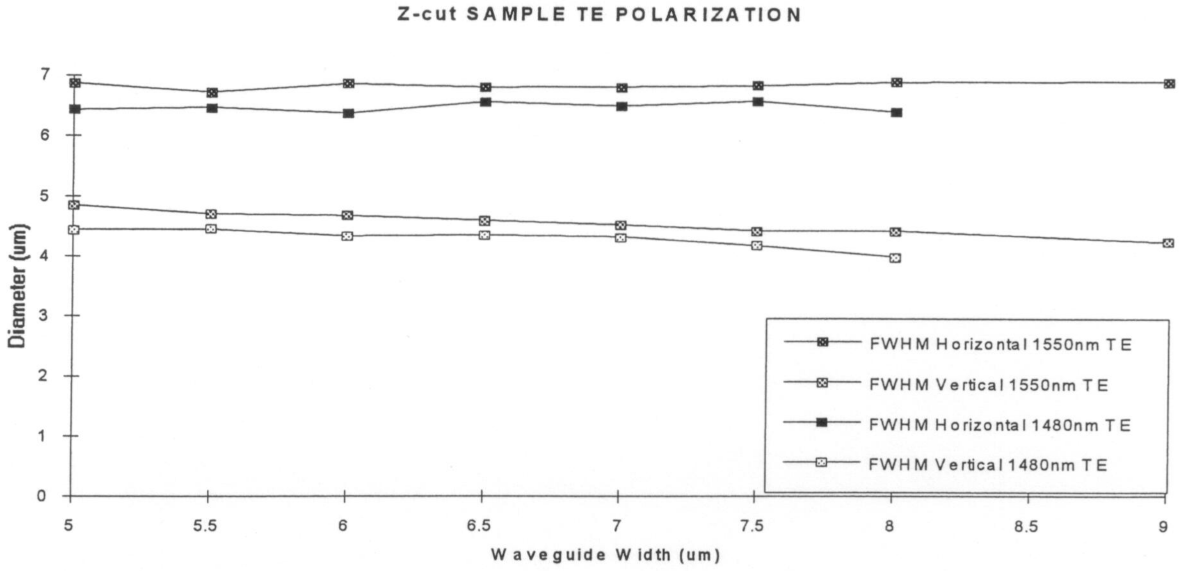

Fig.5: Mode field diameter of the Z-cut sample, TE polarization.

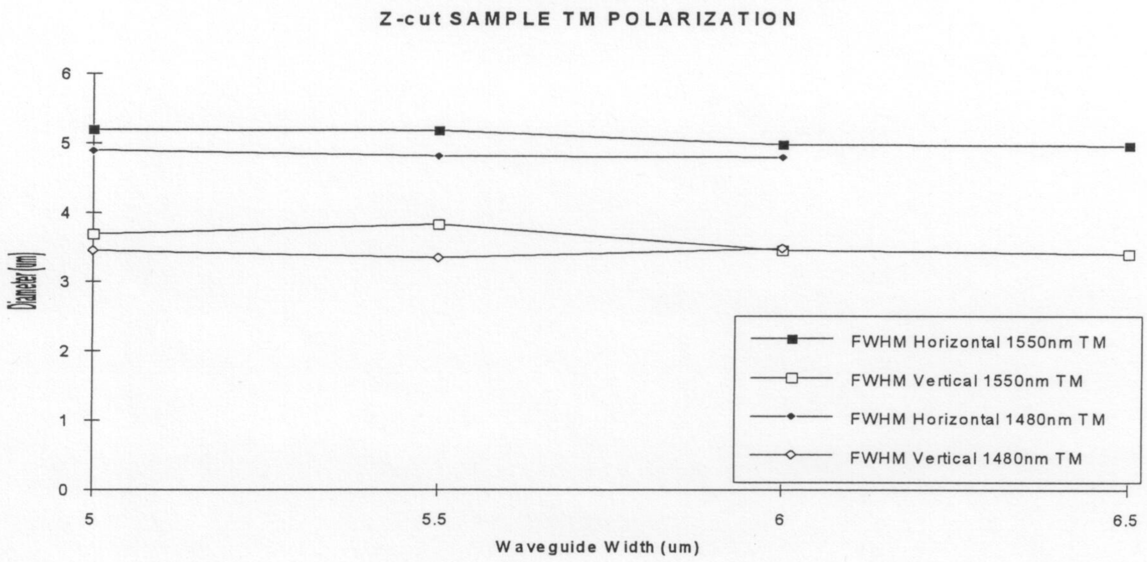

Fig.6: Mode field diameter of the Z-cut sample, TM polarization.

4.GUIDE WAVE ABSORPTION AND SPONTANEOUS EMISSION

4.1.Energy levels of the Er:$LiNbO_3$

The energy levels of Er:$LiNbO_3$ are shown in Fig. 7. They are split by the Stark effect in the crystal field. The metastable upper level for the emission at 1530 nm is the $^4I_{13/2}$ manifold. In Fig. 7 some possible transitions, allowing optical pumping, are indicated.

It can be seen that the $^4I_{13/2}$ level can be populated by a fast relaxation from an excited state, giving rise to a spontaneous fluorescence in the wavelength range 1500-1600 nm. If a population inversion is obtained, stimulated emission at about 1530 nm can be obtained.

These data indicate the wavelength ranges of interest for Erbium doped $LiNbO_3$ waveguides.

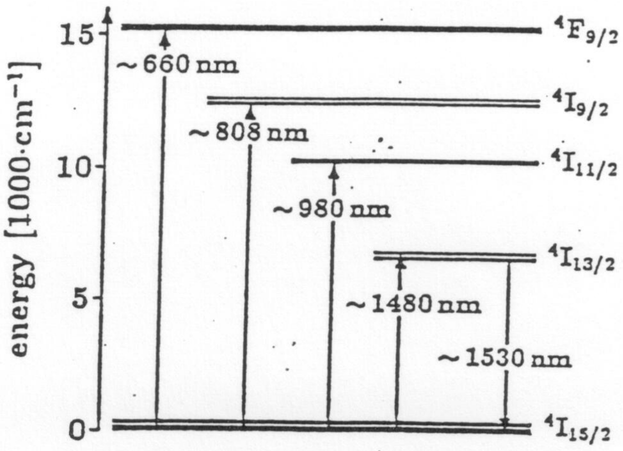

Fig.7: Energy levels of Er:$LiNbO_3$

4.2.Results of spectral measuraments

The different absorption bands have been investigated using, as signal source, a semiconductor LED for the range 1420-1620 nm and a white spectral lamp for the range around 980 nm; The spontaneous emission spectra has been observed in the range 1520-1620 nm.

In Fig. 8, 9, are reported the measured transmission spectra of a 7.0μm waveguide, on the X-cut and Z-cut Er:$LiNbO_3$ samples respectively, for both TE and TM modes. Each spectrum is obtained choosing, as a reference, the spectrum of an undoped waveguide with the same waveguide parameters.

A significant peak of absorption of about 20 dB is observed around 1532 nm corresponding to the transition from the ground state to the $^4I_{13/2}$ manifold.

Another smaller absorption peak has been registered at 980 nm (see Fig. 10) corresponding to the transition between the ground state and the $^4I_{11/2}$ manifold.

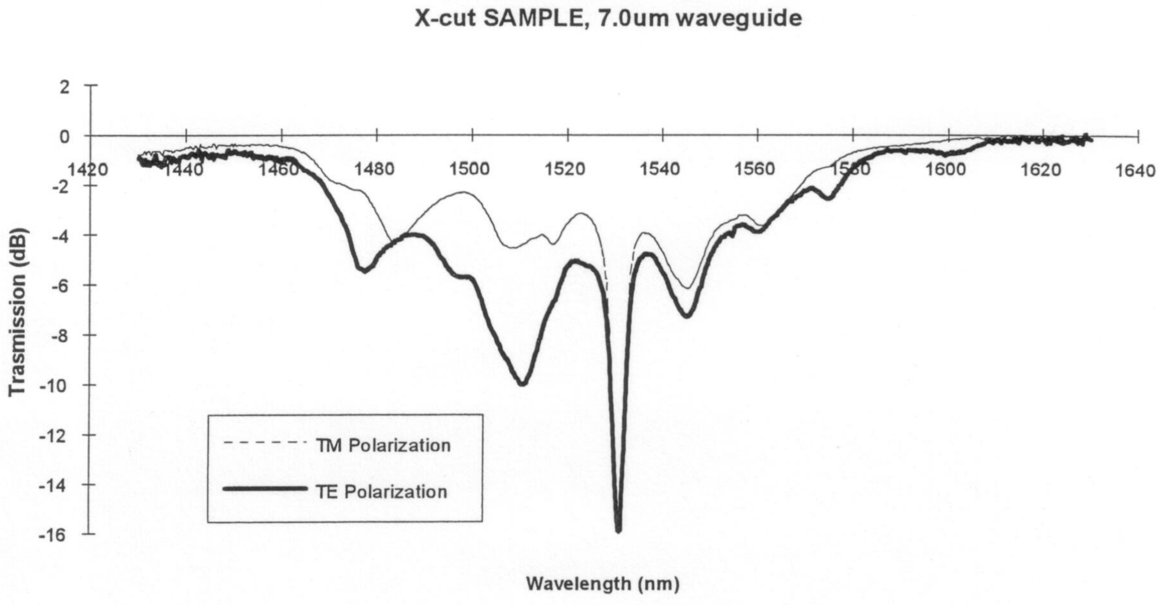

Fig. 8: Trasmission spectra of a X-cut sample, 7.0 μm waveguide, TE and TM polarization

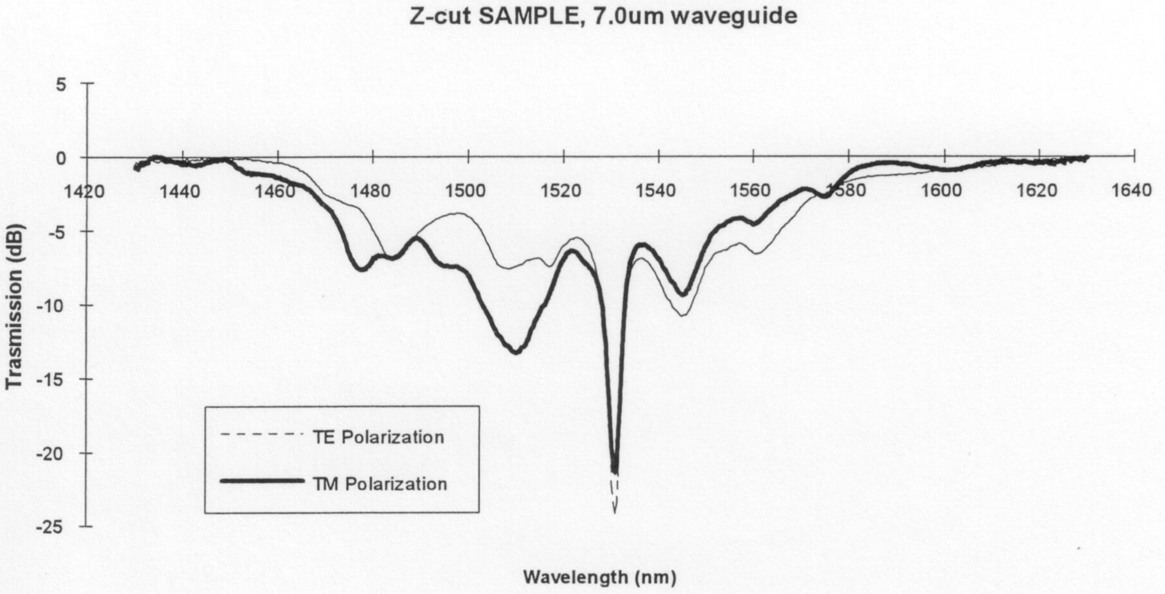

Fig. 9: Trasmission spectra of a Z-cut sample, 7.0 μm waveguide, TE and TM polarization.

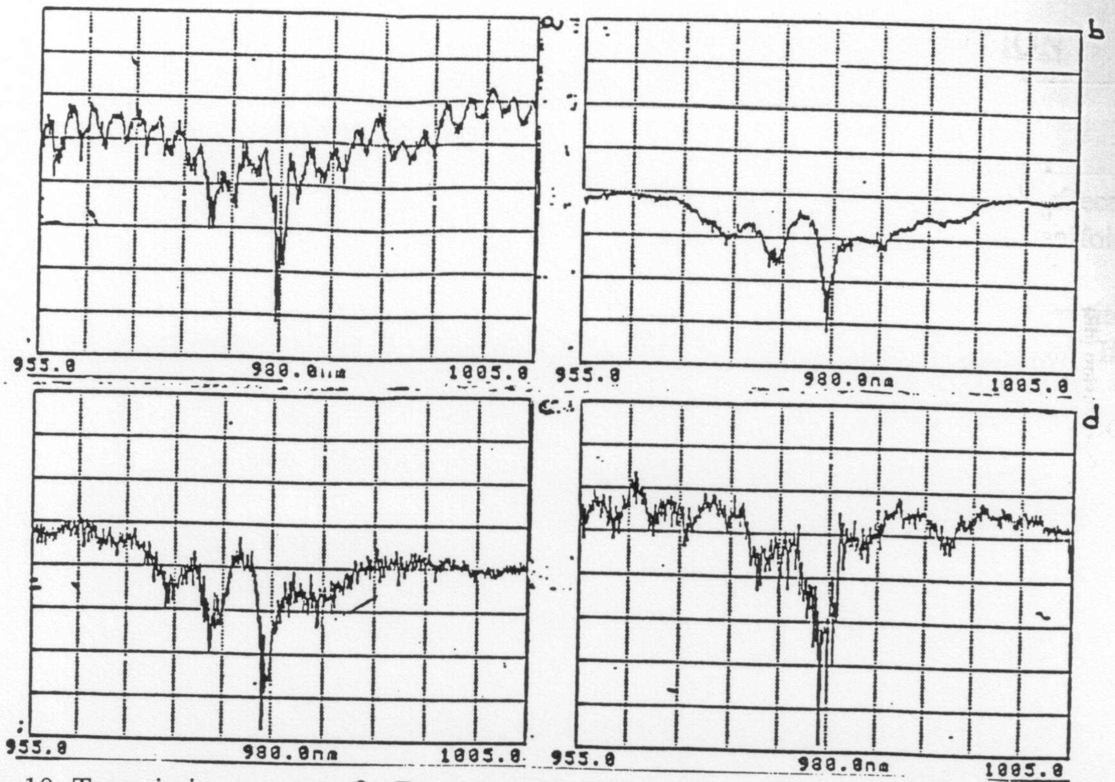

Fig. 10: Trasmission spectra of a Z-cut sample, 5.0μm waveguide, TM polarization (a), TE polarization (b) and of a X-cut sample, TM polarization (c), TE polarization (d) in A.U.

The oscillations in Fig. 10a and 10d are due to the beating between the fundamental mode and the higher order modes of the waveguide. The experimental setup for the spontaneous emission measurement is reported in Fig. 11. The pump signal was butt coupled to the sample (1). The output from the sample was coupled to a monomode fibre using two microscope objectives (2) and to a WDM used to separate the pump and the spontaneous emission.

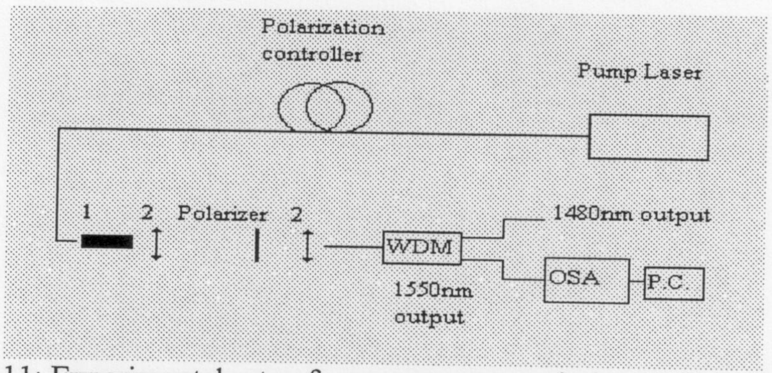

Fig.11: Experimental setup for spontaneous emission measurement.

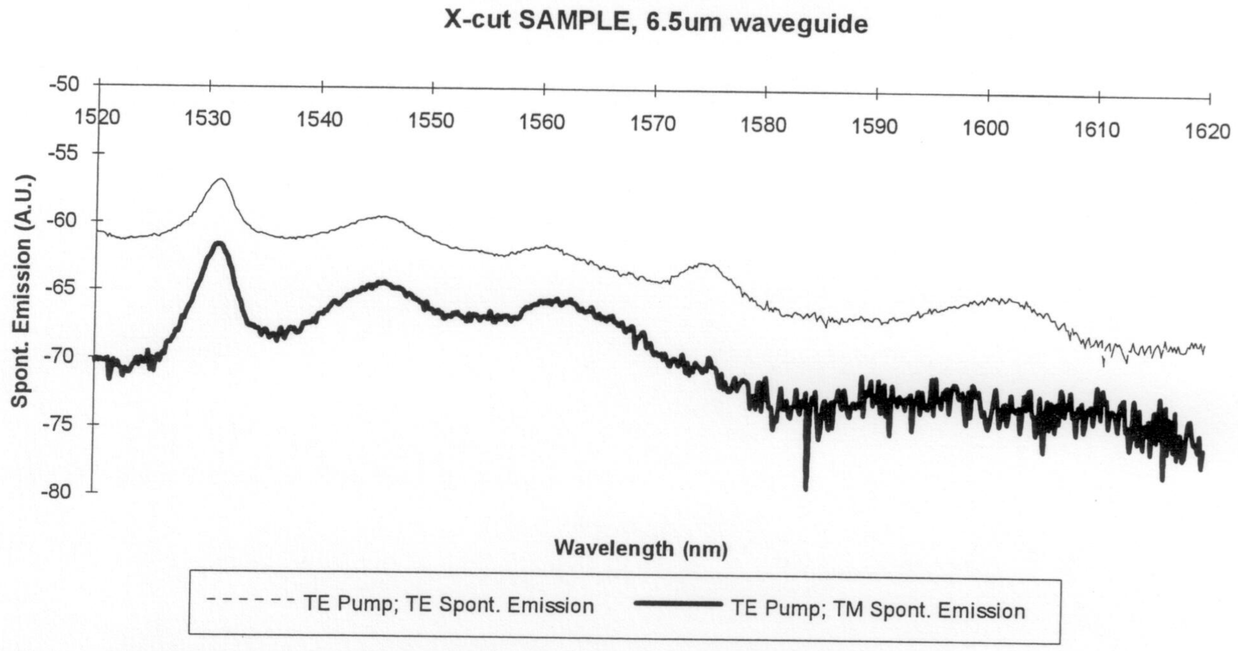

Fig. 11: Spontaneous emission spectra, X-cut sample, 6.5 μm waveguide.

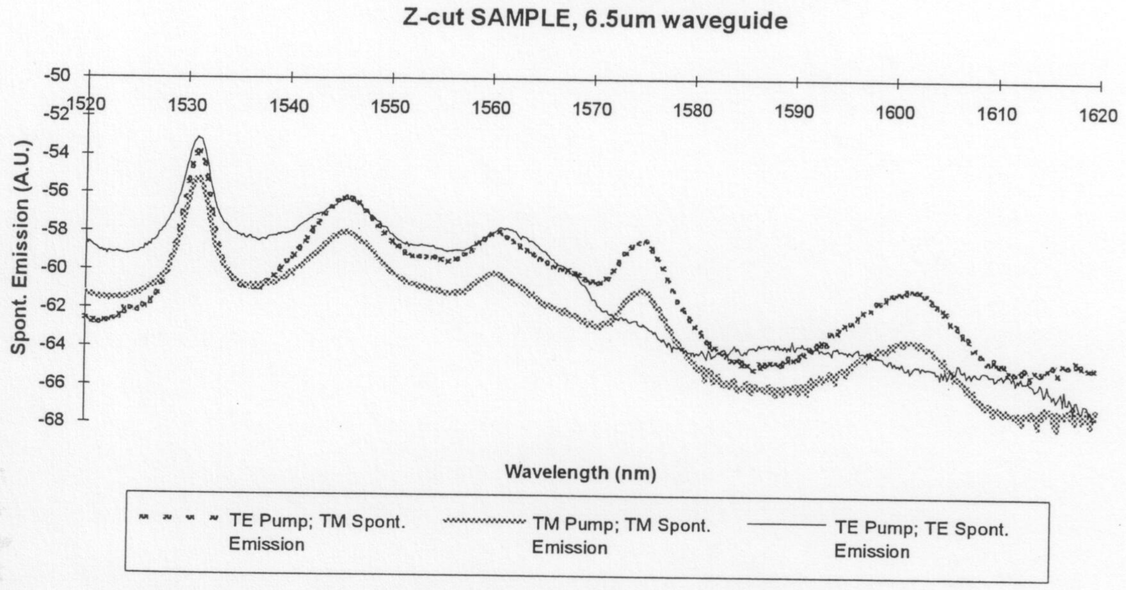

Fig. 12: Spontaneous emission spectra, Z-cut sample, 6.5 μm waveguide.

Fig. 11 and 12 show the spontaneous emission spectra of the doped waveguide pumped with a 1480 nm semiconductor laser. The difference between the emission levels related to the polarization is due also to a difference of the optical alignement in the experimental setup. As we can observe there is a strong emission peak at 1532 nm.

5.CONCLUSIONS

We have fabricated and investigated Ti-diffused waveguide structures in Er:$LiNbO_3$. We have reported the experimental setup and the results for the measurements of losses, mode field diameter, absorption and spontaneous emission spectra. The losses at 1300 nm, measured with the low finesse Fabry-Perot technique, indicate a good quality of the waveguide. whereas the losses at 1523 nm indicate a good absorption efficiency.

The transmission spectra have been investigated around 980 nm and 1550 nm. In particular we observed strong absorption peaks at 980 nm, 1480 nm and 1532 nm. These data are consistent with the Erbium energy level transitions. From the spontaneous emission measurements we anticipate a strong stimulated emission at 1532 nm. We can therefore consider our waveguides suitable for the realization of highly efficient lasers and amplifiers.

6.REFERENCES

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