Measurements of optical loss in $GaAs/Al_2O_3$ nonlinear waveguides in the infrared using femtosecond scattering technique

S. Venugopal Rao [(1)], K. Moutzouris [(1)], M. Ebrahimzadeh [(1)]
A. De Rossi [(2)], G. Gintz [(2)], M.Calligaro [(2)], V. Ortiz [(2)], and V. Berger [(2)]

(1) School of Physics and Astronomy, University of St. Andrews, North Haugh, Fife, KY16 9SS, Scotland, UK
(2) THALES, Laboratoire Central de Recherches, Domaine de Corbeville, 91400 Orsay, France

INTRODUCTION

- **Optical loss**: Important in the assessment of semiconductor nonlinear waveguides (SHG, DFG, and OPO's)
- **Difficulties**
  - ➢ Inaccurate knowledge of effective refractive indices
  - ➢ Unknown facet reflectivities
- **Techniques used** Cutback method, Prism coupling, Photo-thermal deflection, **Fabry-Perot (FP) interference method**, Photo-luminescence, Optimized end-fire coupling, Self-pumped phase conjugation, Multisection single-pass technique and **Scattering technique**
  - o **Advantages**
    - ✓ For waveguides with losses >1 dB/cm
  - o **Disadvantages**
    - × Not universally appealing: Complexity (eg. self-pumped phase conjugation) or Destructive nature (eg. cut back)
    - × Measurements at a single wavelength
- **FP technique:** The most successful approach for evaluation of losses <1 dB/cm.

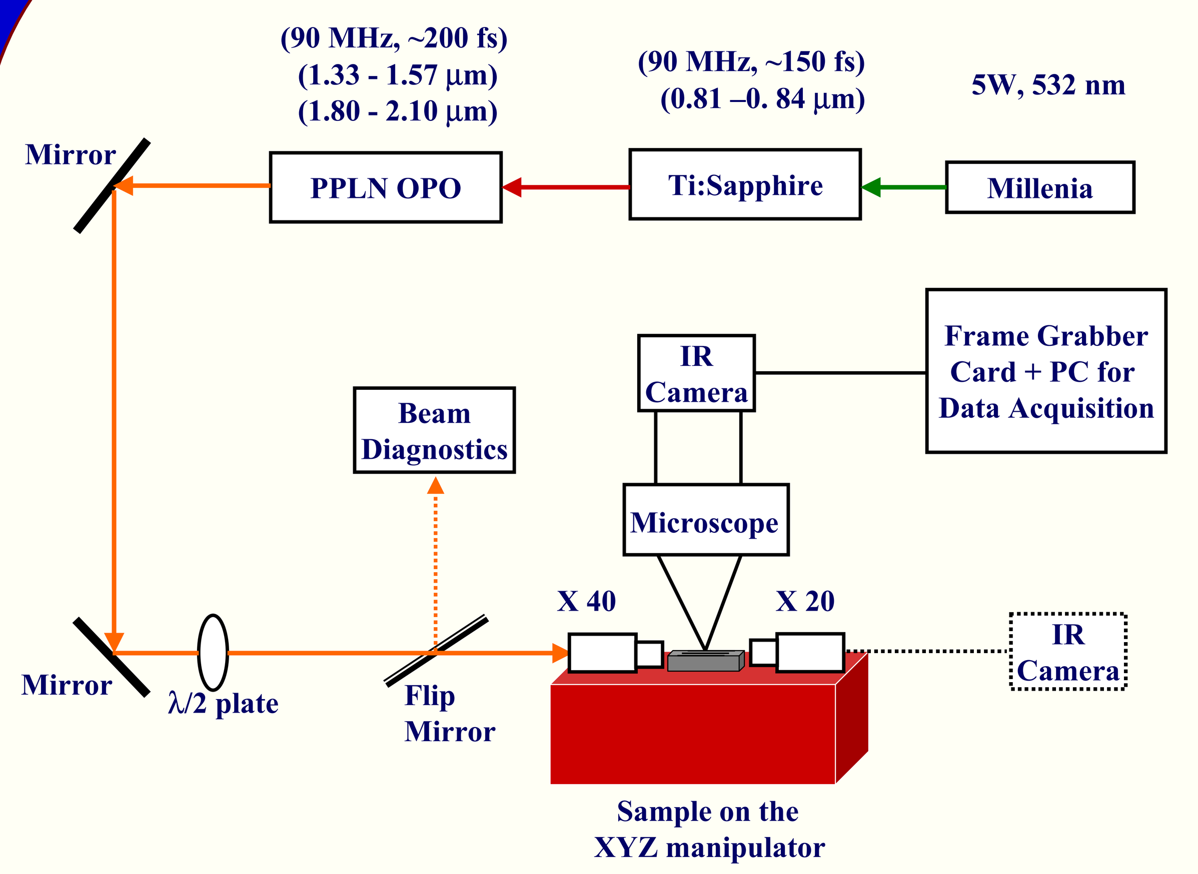
Pros	Cons
✓ Simple	✕ Stringent frequency stability requirements
✓ Robust	✕ Accurate knowledge of facet reflectivities
✓ Non-destructive	✕ Precision in the facet parallelism of the waveguide etalon

- **Scattering technique**

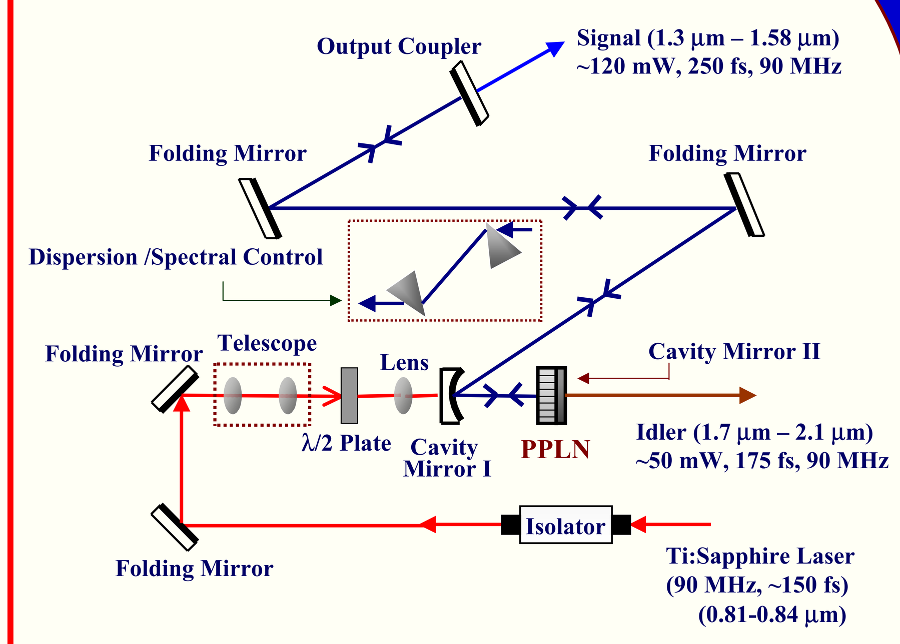
Pros	Cons
✓ Uncomplicated	✕ Not very accurate data for <0.5 dB/cm losses
✓ No stringent requirements	
✓ Non-destructive	

- **Advantages of using an fs OPO:**
  - o Continuous tunability
  - o Knowledge about interaction/propagation of fs pulses within waveguide (useful for TDM and WDM)

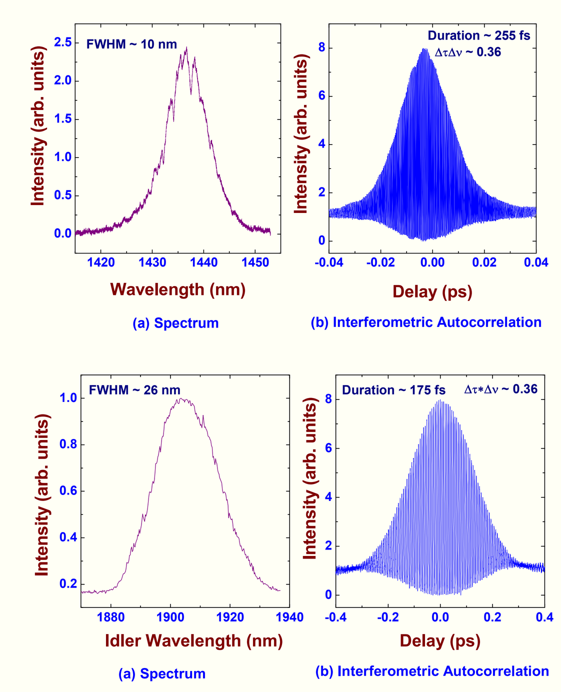
EXPERIMENT



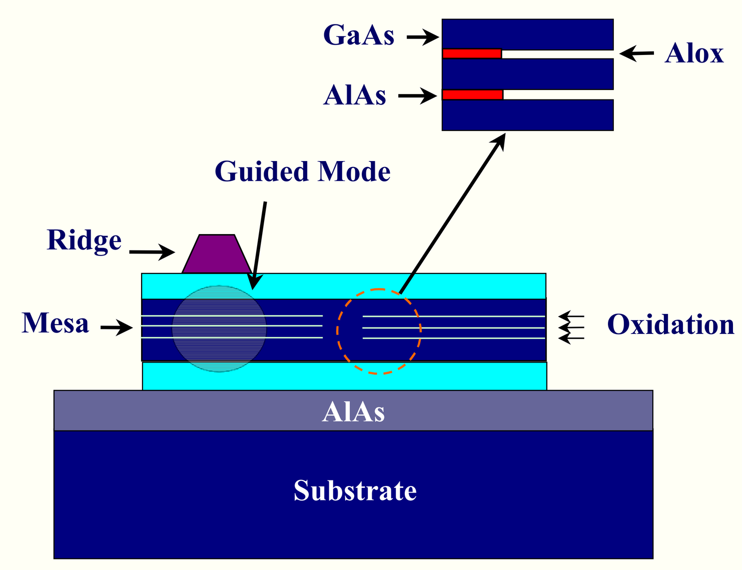
Source



Source Characteristics



Sample

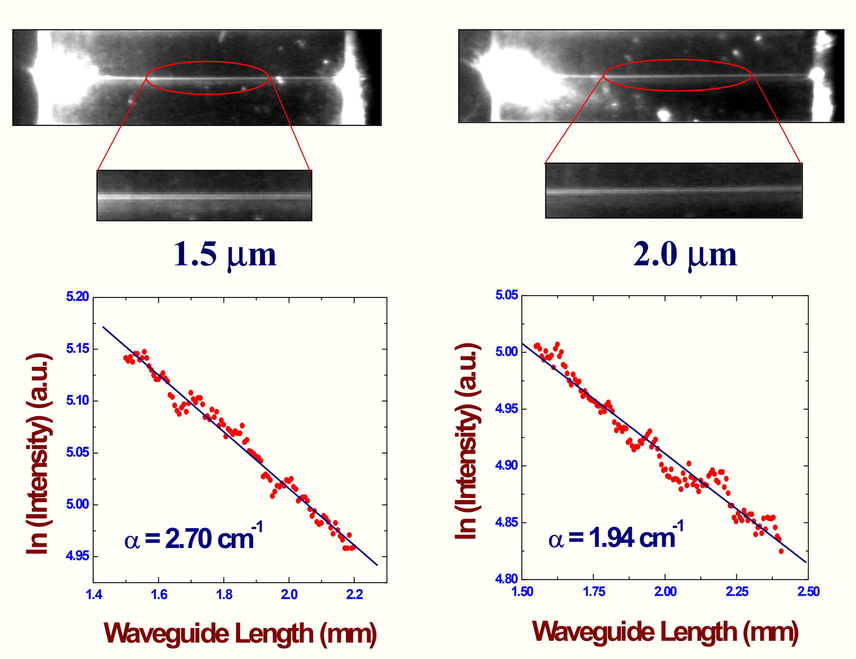


- (GaAs <001> substrate) / 1000 nm AlAs / 1000 nm $Al_{0.7}Ga_{0.3}As$ / 4 X (37 nm AlAs / 273 nm GaAs) / 37 nm AlAs / 1000 nm $Al_{0.7}Ga_{0.3}As$ / 30 nm GaAs.

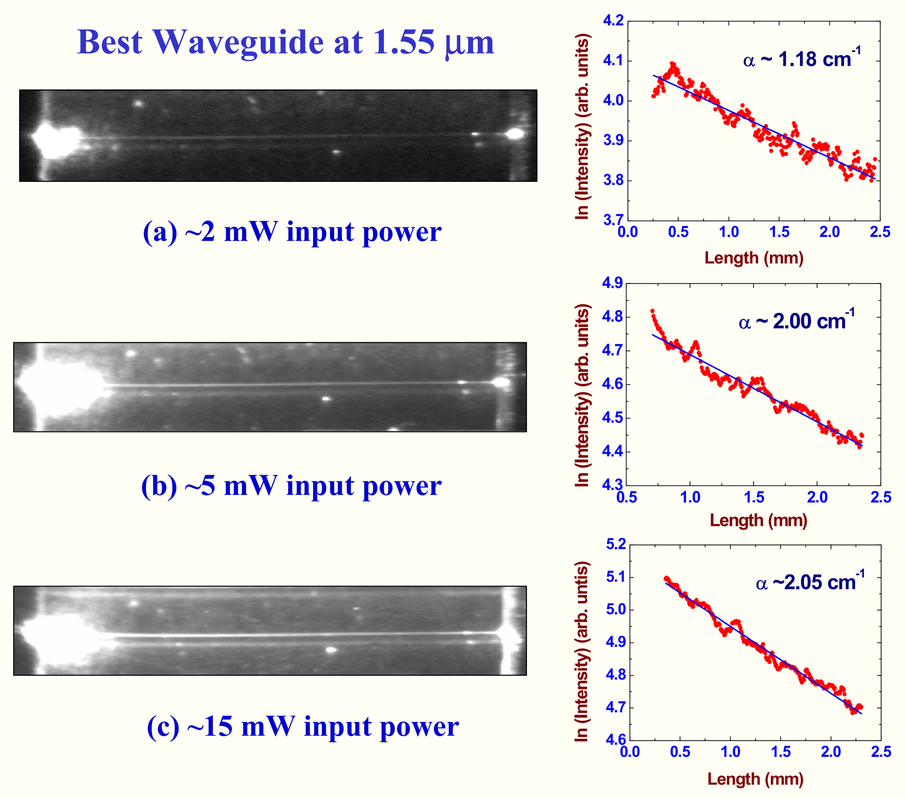
Process steps:

1. Ridge etching (optical confinement)
2. Mesa etching (lateral oxidation)
3. Oxidation
4. Annealing (interface quality)

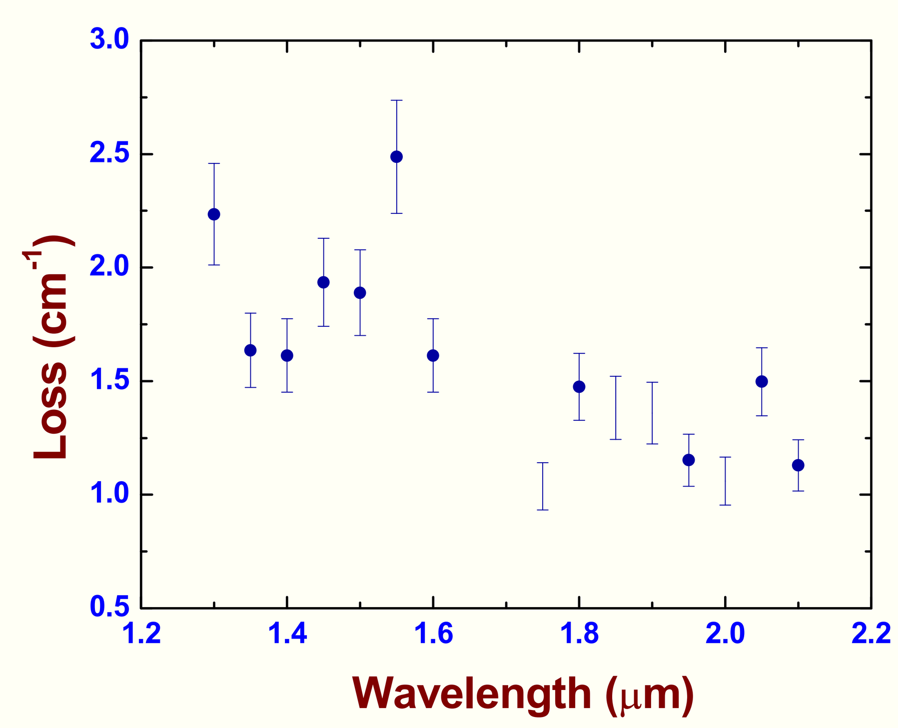
RESULTS



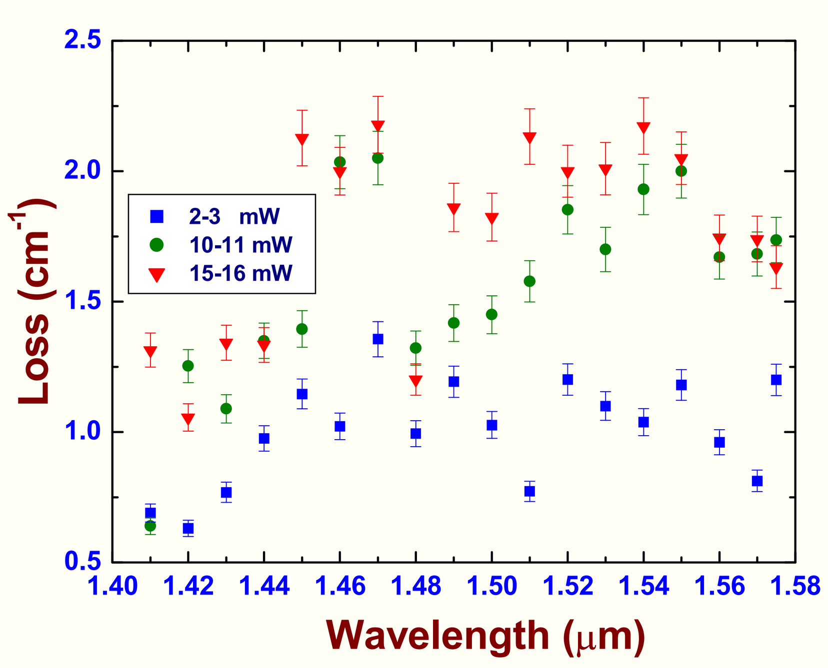
Best Waveguide at 1.55 µm

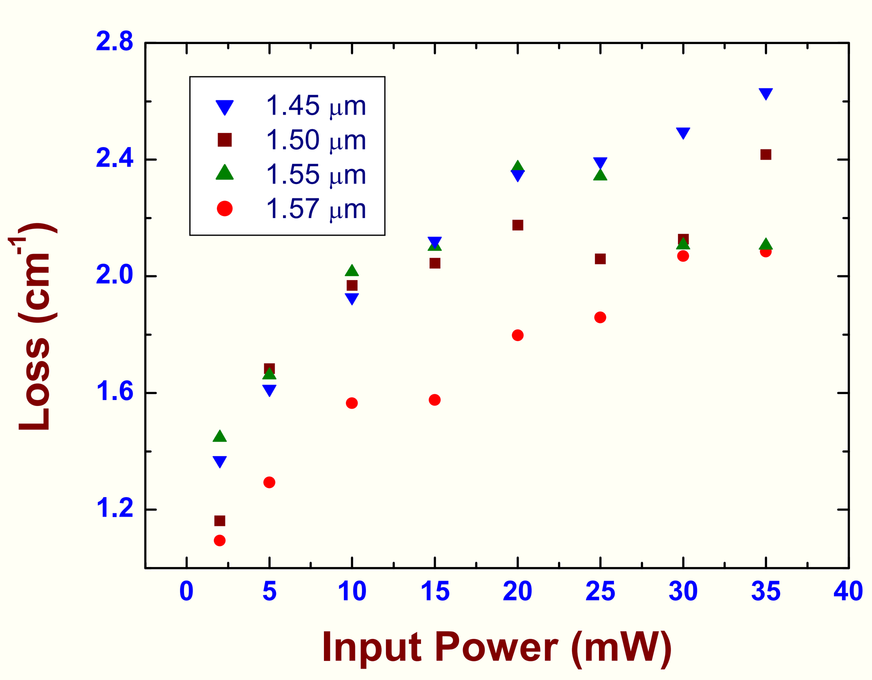


➢ $I_L = I_0 e^{(-\alpha L)}$, where I_L is the scattered intensity after a propagation length L through the waveguide; I_0 is the initial intensity at the start of the path, and α is the overall loss coefficient

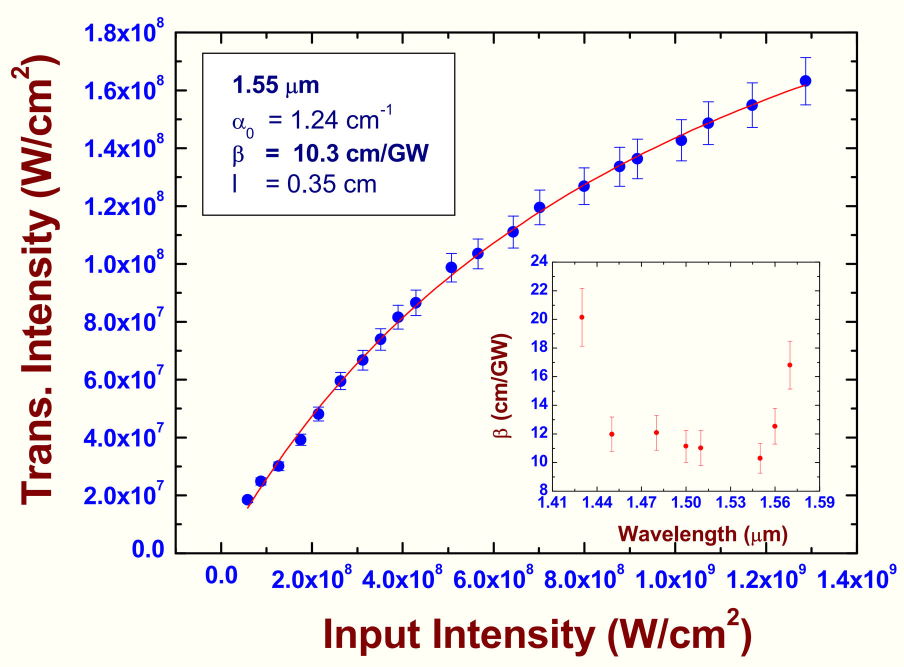


- ➢ α ~ ~5-11 dB/cm in the range 1.35-1.58 µm and 1.75-2.10 µm ⇒ loss coefficients of ~1.15-2.55 cm⁻¹. Using cw FP technique α is ~1.0 cm⁻¹ at 1.30 µm
- ➢ Higher Loss at shorter wavelengths compared to longer wavelengths: Scattering ($1/\lambda^2$) or TPA?



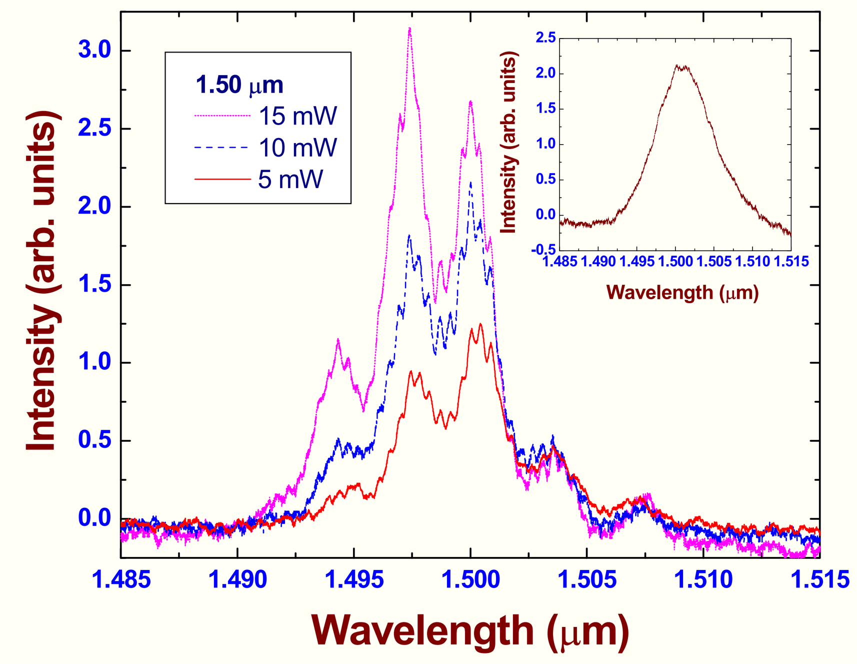


- ➢ Loss higher for TM and TE+TM polarization compared to TE polarization
- ➢ No clear dependence on the mode structure: same loss for TE_{00} and higher order modes.
- ➢ α ~1.0 cm⁻¹ ~2 mW ; ~1.5 cm⁻¹ and ~2.0 cm⁻¹, respectively, for ~10 mW and ~15 mW
- ➢ Overall loss = Linear loss due to absorption
  + Loss due to scattering from waveguide
  + Loss due to scattering from Alox
  + Loss due to Two Photon Absorption (TPA) (~250 fs pulses).



$$\frac{dI(r,z,t)}{dz} = -\alpha_0 . I(r,z,t) - a.\beta.I^2(r,z,t)$$

- ➢ α_0 was fixed with loss value at low input powers
- ➢ TPA coefficient β ~10-18 cm/GW.



- ➢ Temporal pulse broadening (due to GVD) is ~1.02 times, which is quite negligible.
- ➢ n_2 ~9 x 10^{-13} cm²/W at 1.55 µm
- ➢ n_2 ~7 x 10^{-13} cm²/W and ~3 x 10^{-13} cm²/W at 1.45 µm and 1.55 µm respectively

CONCLUSIONS

- Losses have been evaluated for a wide range of wavelengths in the infrared (**1.35-1.58 µm** and **1.75-2.10 µm**) using the femtosecond scattering technique
- Loss coefficients of **~1.15-2.55 cm⁻¹** were obtained for the best waveguide corresponding to **~5-11 dB/cm**. α ~ **1.0 cm⁻¹** at **1.30 using µm** (cw FP technique). Losses were higher at lower wavelengths **(<1.6 µm)**
- Intensity dependent nonlinear transmission studies enabled to identify the magnitude of TPA contribution
- At very low input powers the major contribution is from absorption + scattering from waveguide and Alox with typical values of **~1-1.5 cm⁻¹**. At higher input powers **(~15 mW)** a TP component of almost **~1.5 cm⁻¹** also contributes to the total loss measured

REFERENCES

- K. Moutzouris, S. Venugopal Rao, et al.Opt. Lett. **26**, 1785 (2001)
- R. Regener and W. Sohler, Appl. Phys. B **36**, 143 (1985); R. Arsenault, D. Gregoris, S. Woolven, and V.M. Ristic, Opt. Lett. **12**, 1047 (1987)
- M.R. Amersfoort, D. Grutzmacher, M.K. Smit, and Y.S. Oei, Electron. Lett. **27**, 1152 (1991), M. Haruna, Y. Segawa, and H. Nishihara, Electron. Lett. **28**, 1612 (1992)
- S. Brülisauer, D. Fluck, C. Solcia, T. Pliska, and P. Günter, Opt. Lett. **20**, 1773 (1995); Y. Okamura, S. Yoshinaka, and S. Yamamoto, Appl. Opt. **22**, 3892 (1983)
- Y. Sidorin, Opt. Commun. **194**, 325 (2001); M. Kumar et al. IEEE Phot. Tech. Lett. **4**, 435 (1993); M. Kumar et al. J. Appl. Phys. **82**, 3205 (1997), C.C. Yang et al. IEEE J. Quant. Electron., **29** 2934 (1993)