united nations educational, scientific and cultural organization

international atomic energy agency

the **abdus salam** international centre for theoretical physics

SMR 1302 - 22

WINTER SCHOOL ON LASER SPECTROSCOPY AND APPLICATIONS

19 February - 2 March 2001

Novel Laser Sources for Applied Spectroscopy - Conclusion

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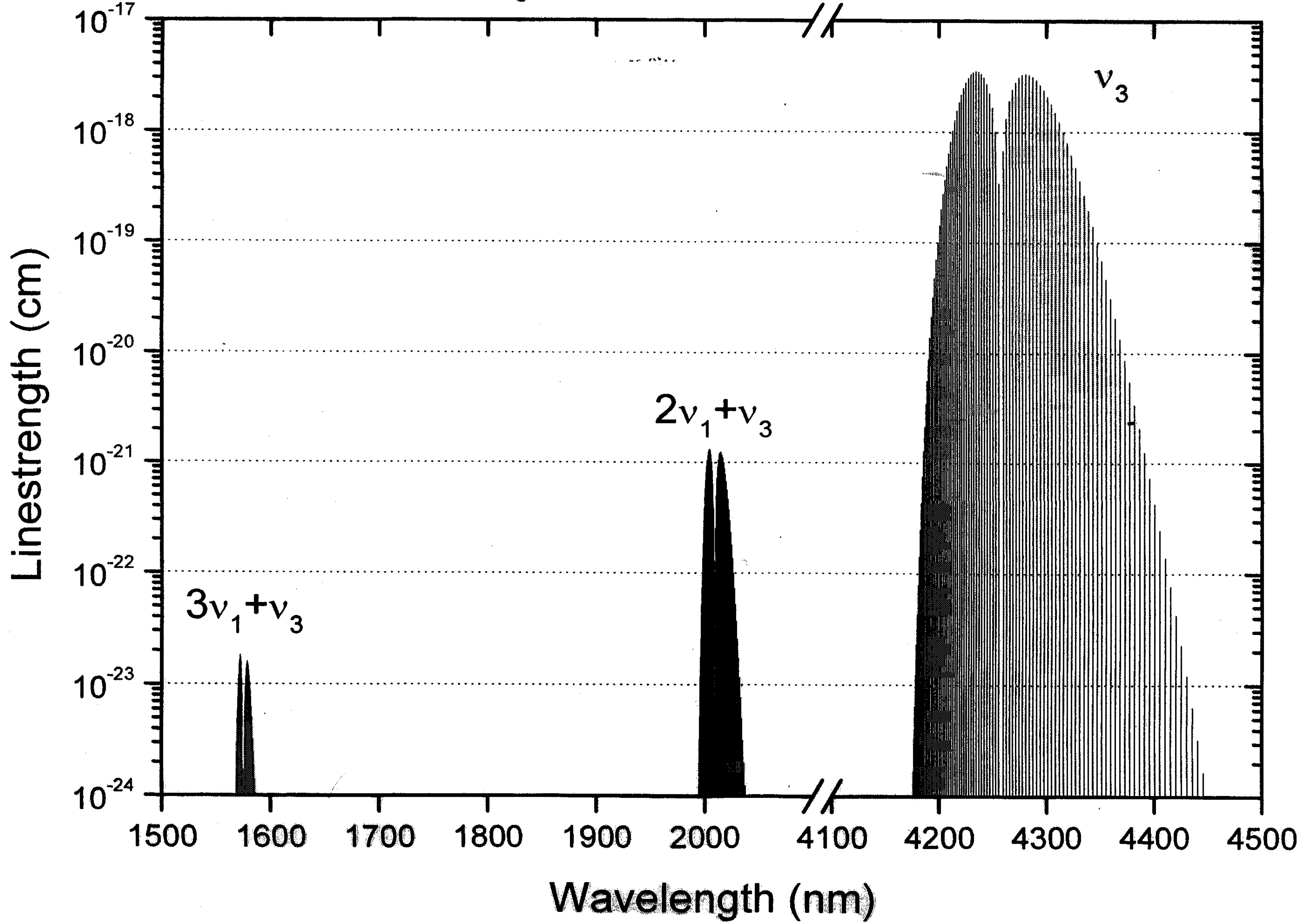
These are preliminary lecture notes, intended only for distribution to participants.

$^{12}CO_2$



Linestrength (cm)
10^-17
10^-18
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
ν3
2ν1+ν3
3ν1+ν3
1500
1600
1700
1800
1900
2000
4100
4200
4300
4400
4500
Wavelength (nm)

DESIRABLE FEATURES

- Real time and continuous monitoring
- Remote operation
- Sensitivity
- Discrimination among different molecules ⇒ Resolution

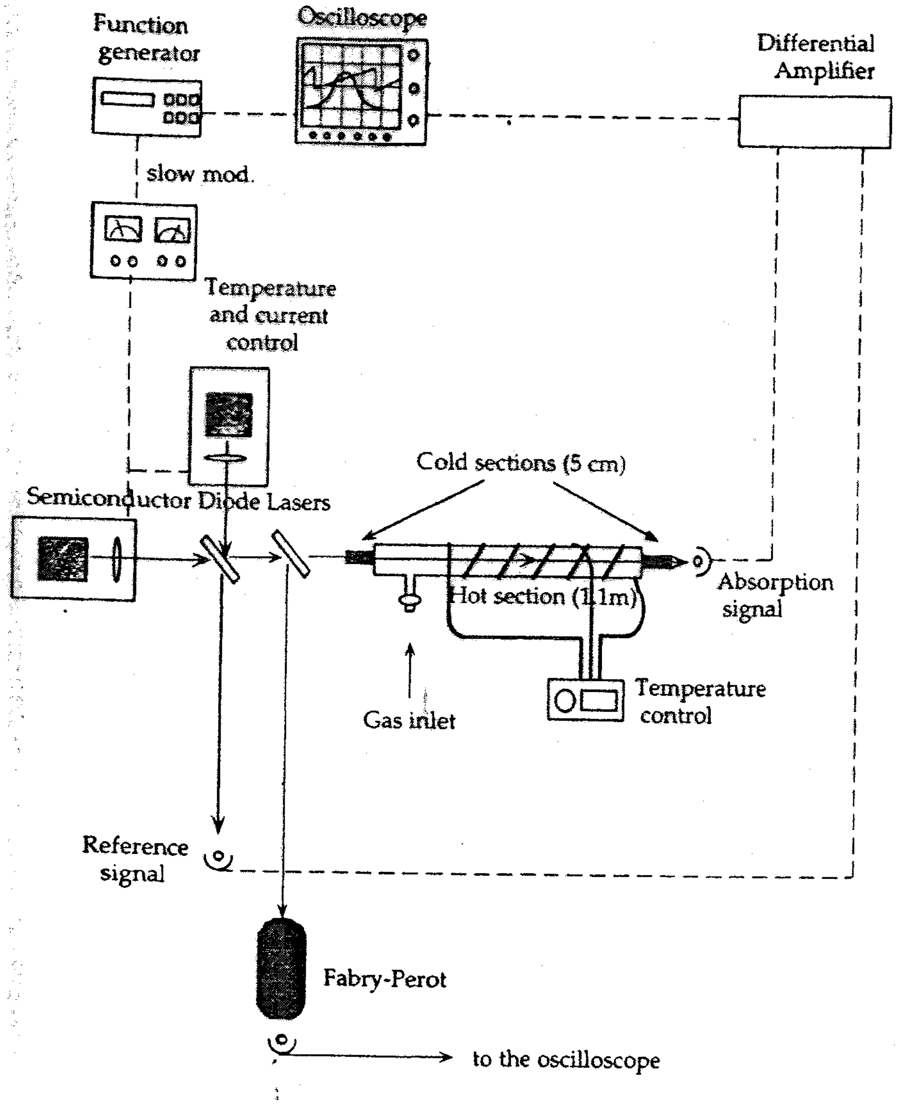
Trade off.

- Simultaneous detection of different species
- Field instrument ⇒ Low energy consumption, small size, low weight
- Low cost
- Ruggedness
- Accuracy

→ non puoi fotografare un paesaggio con un microscopio!

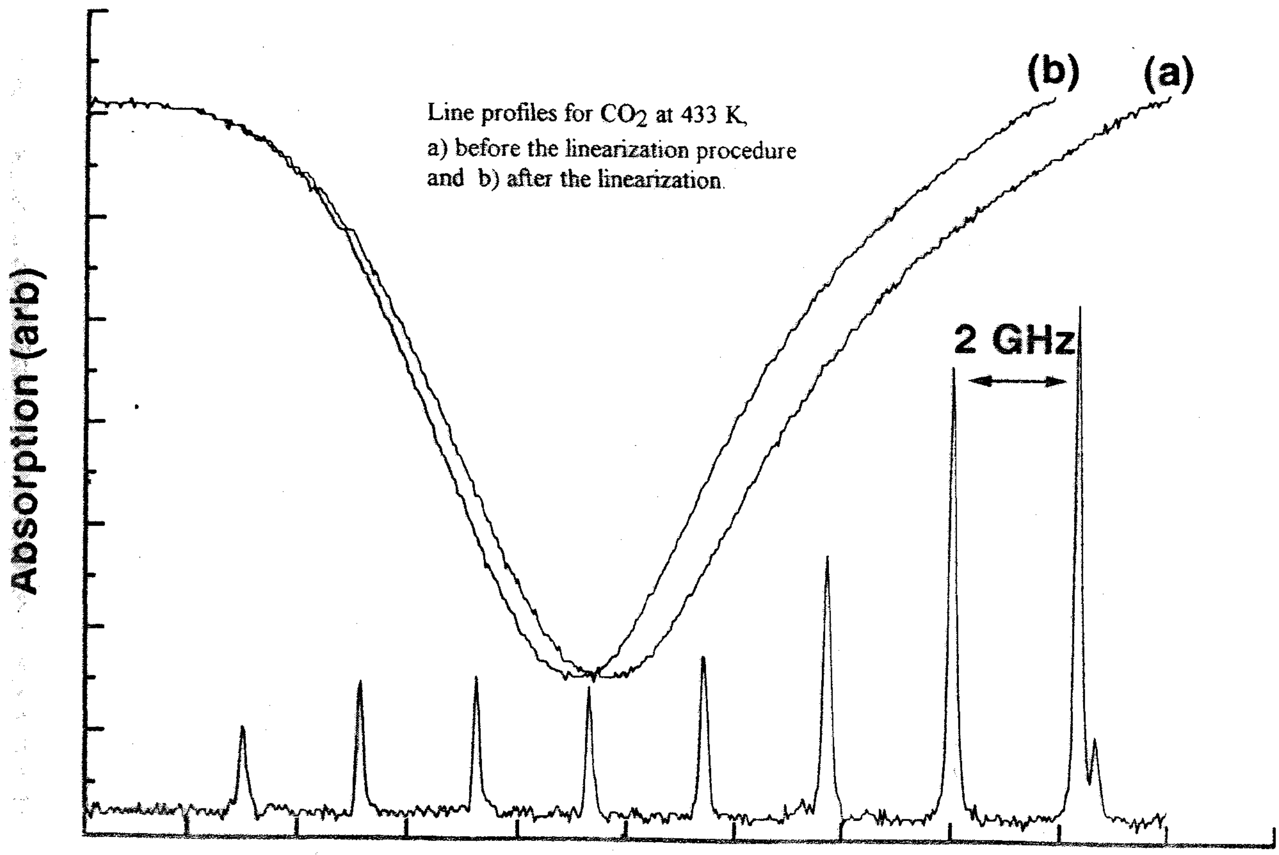
Solution...

Semiconductor Laser Diodes



Gianfroni, Gabrysch, Corsi, De Natale

App. Opt. 36, 9481 (1997)



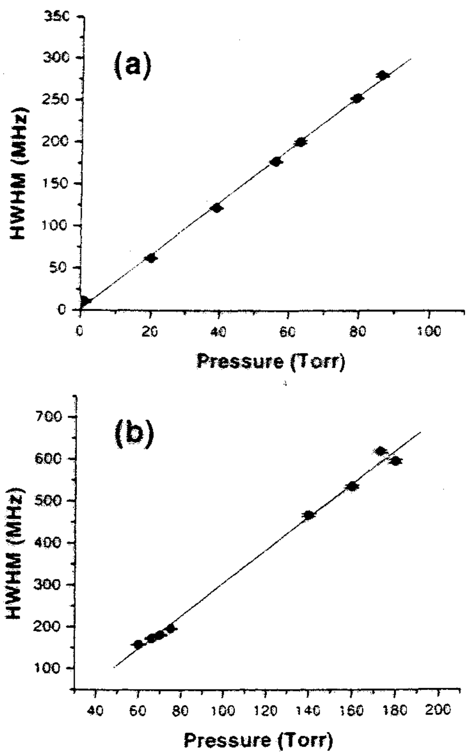


Fig. 2. Measured Lorentzian half-widths (HWHM) versus pressure for (a) pure CO_2 and (b) a fixed pressure of CO_2 (50 Torr) broadened by H_2O. Error bars are shown relative to the pressure uncertainty, and the error on the ordinate is within the point size.

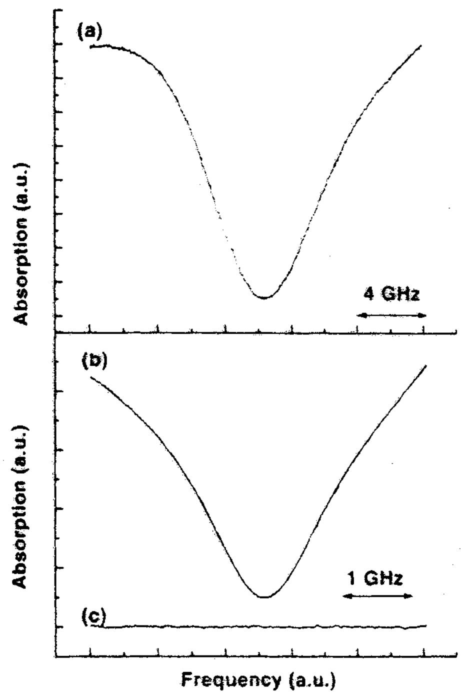


Fig. 5. Experimental absorption profiles at 433 K for (a) the (1, 0, 1)←(0, 0, 0) $2_{1,2}$–$3_{1,3}$ line of H_2O (P = 110 Torr) and (b) the (3, 0^0, 1)←(0, 0^0, 0) P(16) line of CO_2 (P = 148 Torr). The solid curve is the fit, and the residuals are plotted in (c).

TABLE I

Comparison among broadening coefficients for the H_2O and CO_2 lines at a temperature T = 433 K. The meaning of the symbols is explained in the text.

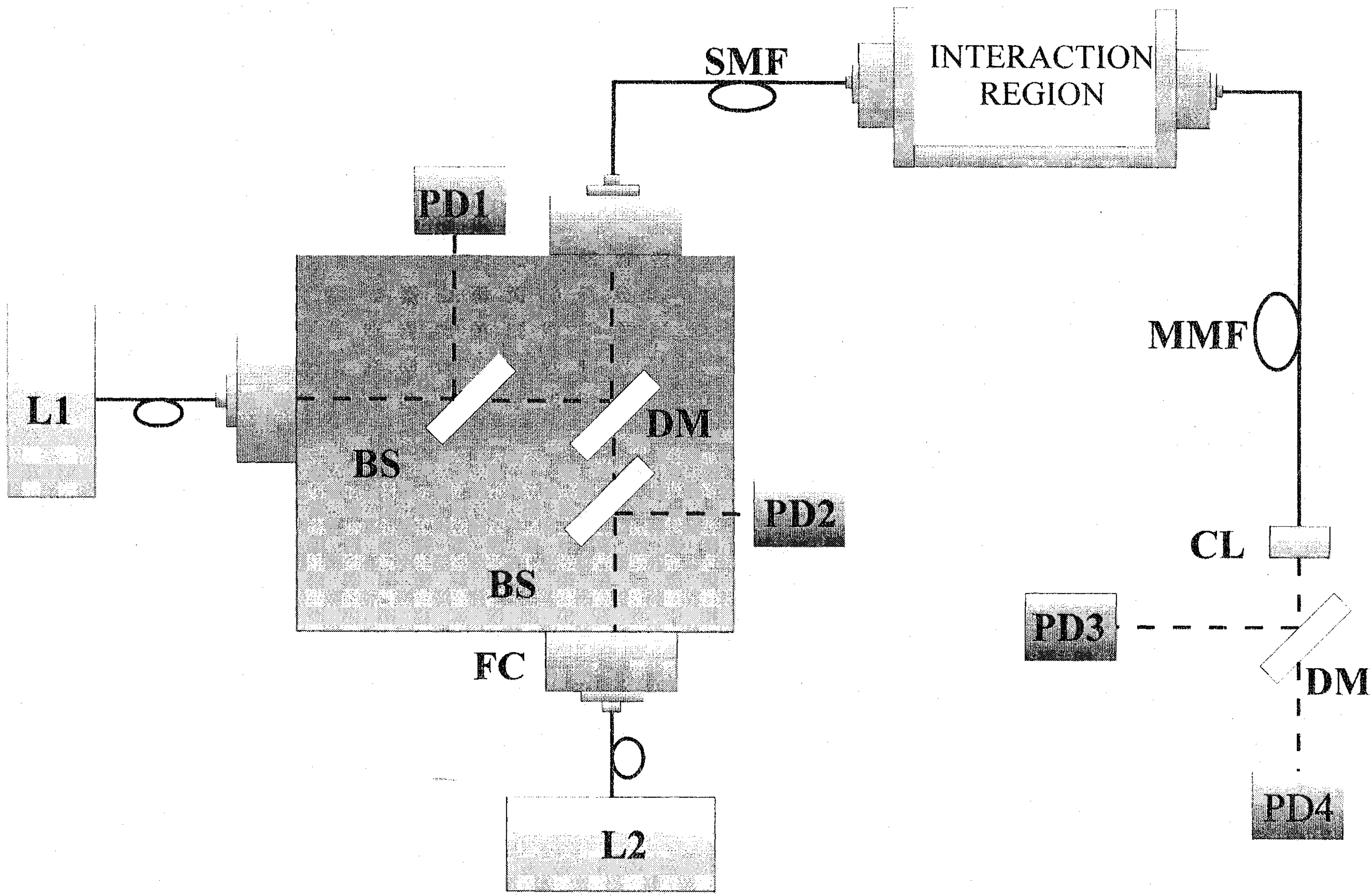
	Present Data	from Literature
Broadening coefficients for H_2O (1, 0, 1) - (0, 0, 0) $2_{1,2}$ - $3_{1,3}$ line (MHz/Torr)	γ_{H2O} =28.2±0.6 γ^{CO2} = 6.0±0.4	γ_{H2O} = 13±1[(a)] γ^{CO2} = 4.3±0.4[(b)]
Broadening coefficients for CO_2 (3, 0^0,1)-(0, 0^0,0) P(16) line (MHz/Torr)	γ_{CO2} = 3.2±0.1 γ^{H2O} = 4.0±0.1	γ_{CO2} = 3.2±0.3[(c)]

(a) Average of the twelve data in Tab. 4 from Ref. [10]. The exponent giving the temperature dependence is taken from Ref. [11].

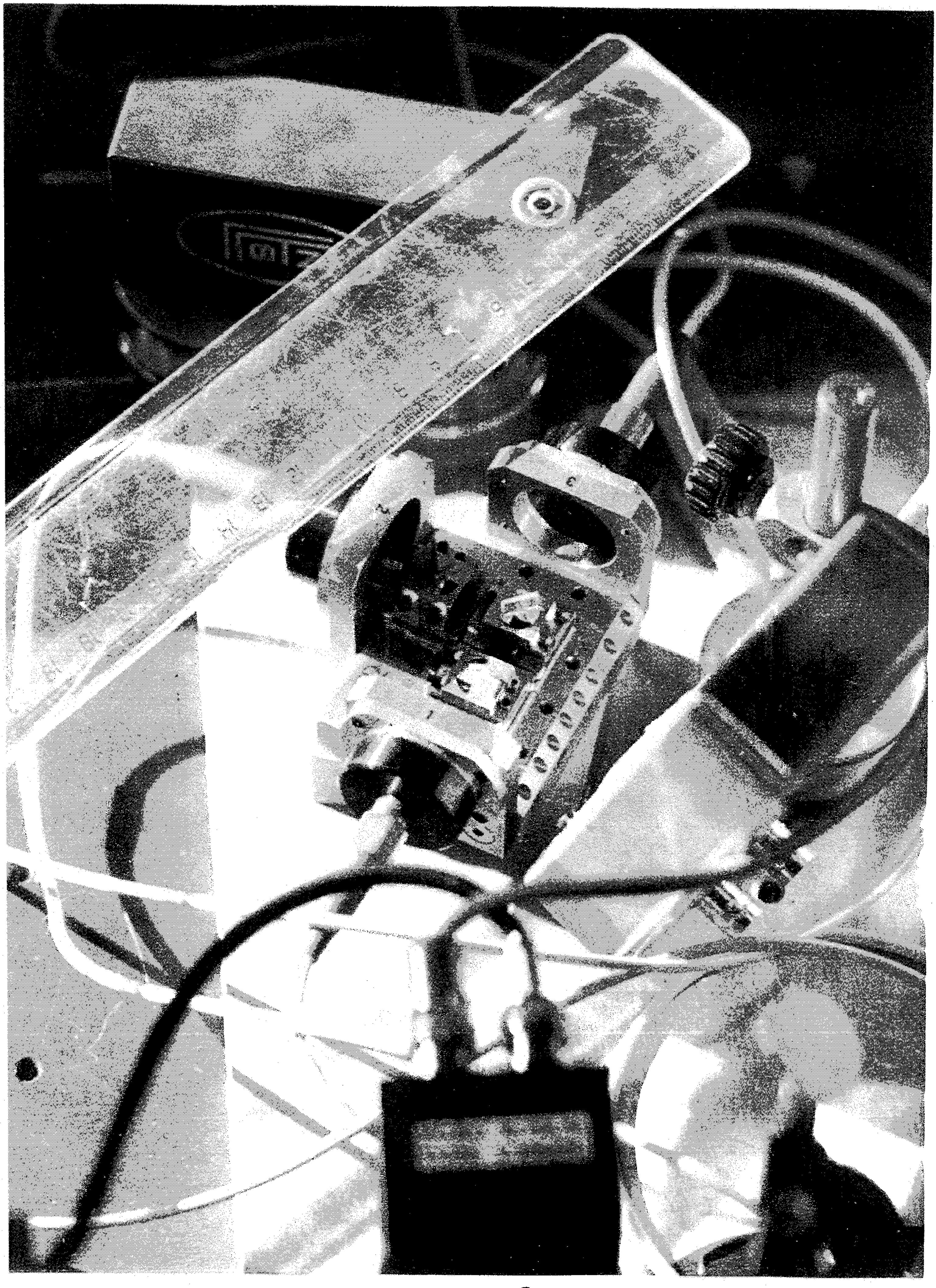
(b) Average of the twelve data in Tab. 2 from Ref. [9].

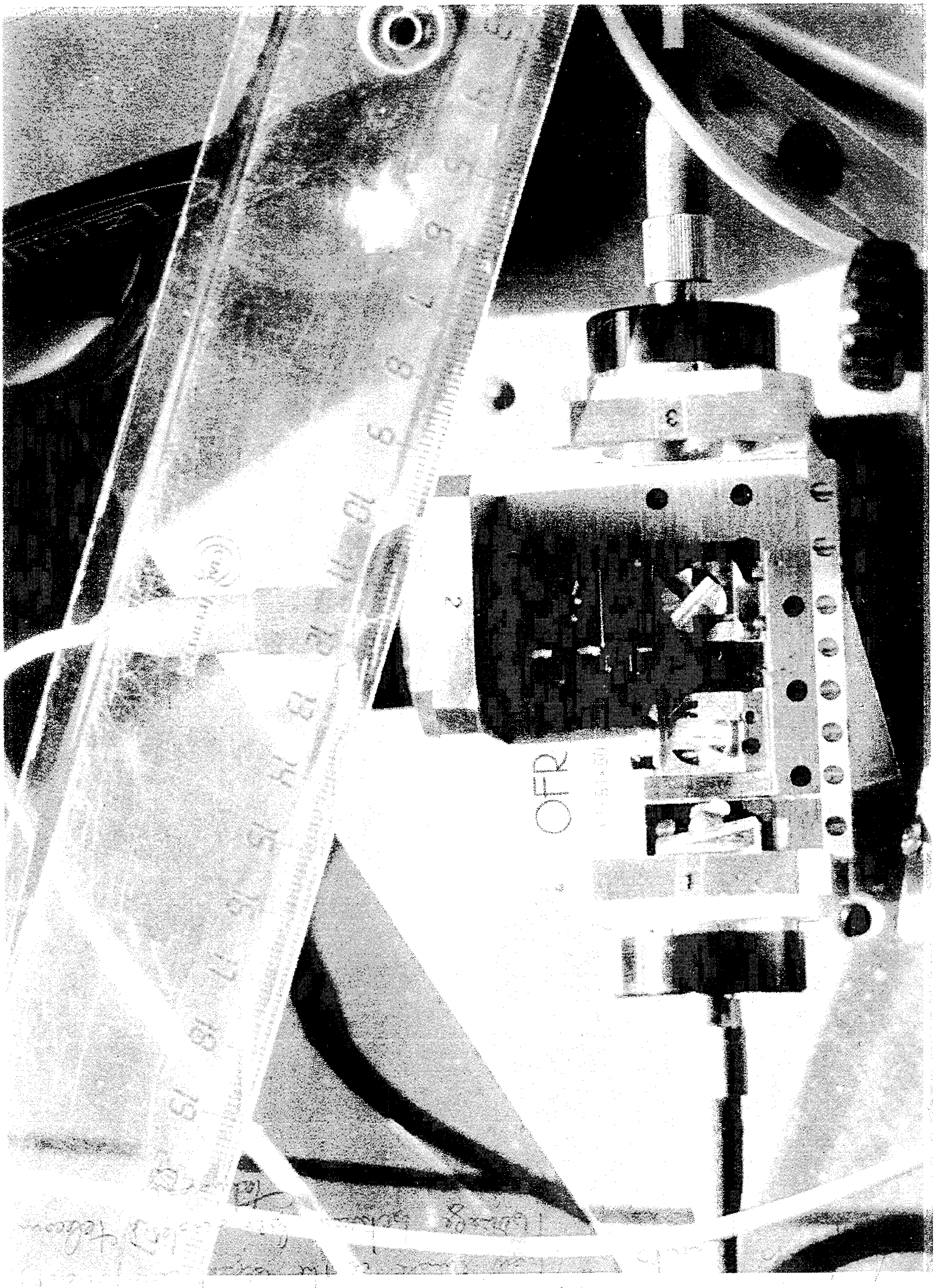
(c) From Ref.6. The temperature coefficient n is from Hitran96 database (n=0.7)

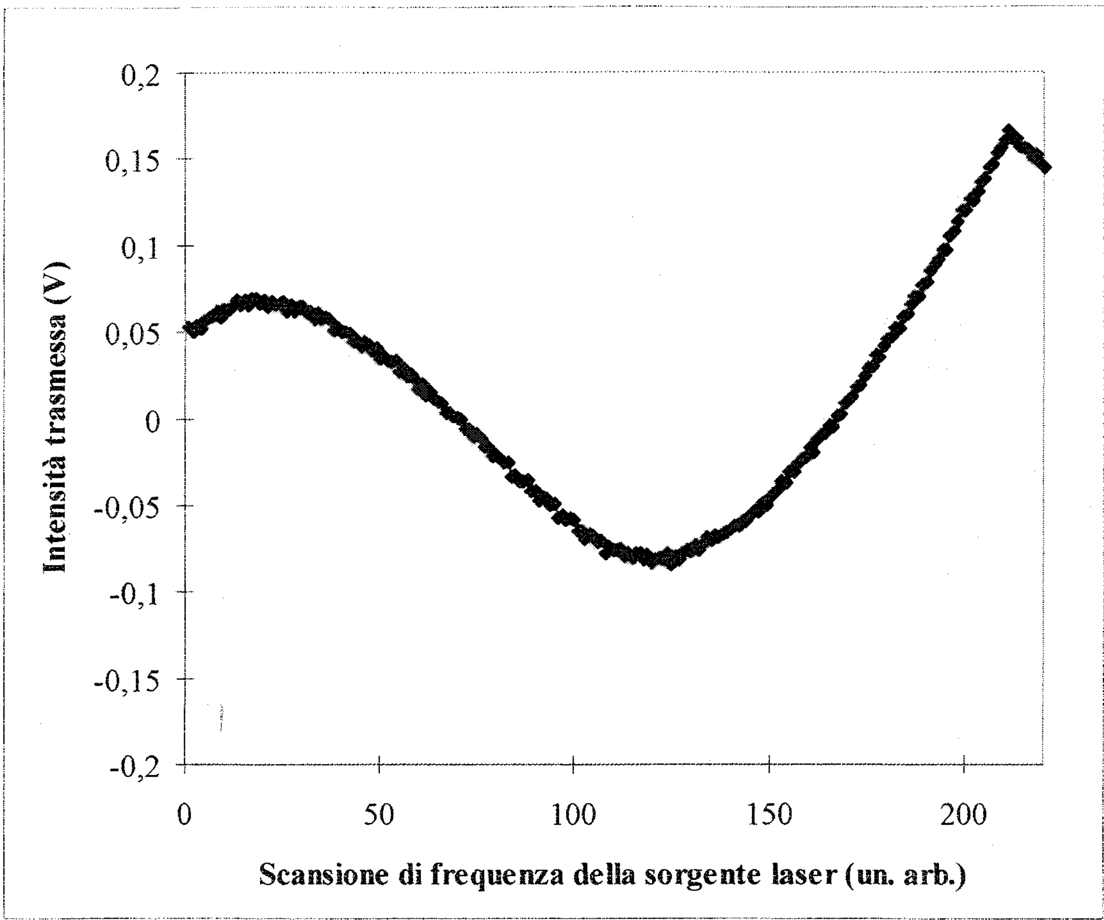
P. De Natale et al., in "Applications of Photonic Technology", SPIE Vol. 3491, 783-787 (1998)



L= laser; PD=photodiode; FC= input/output fiber port; BS= beam-splitter; DM= dichroic mirror SMF= single mode fiber; MMF= multimode fiber; CL= collimating lens



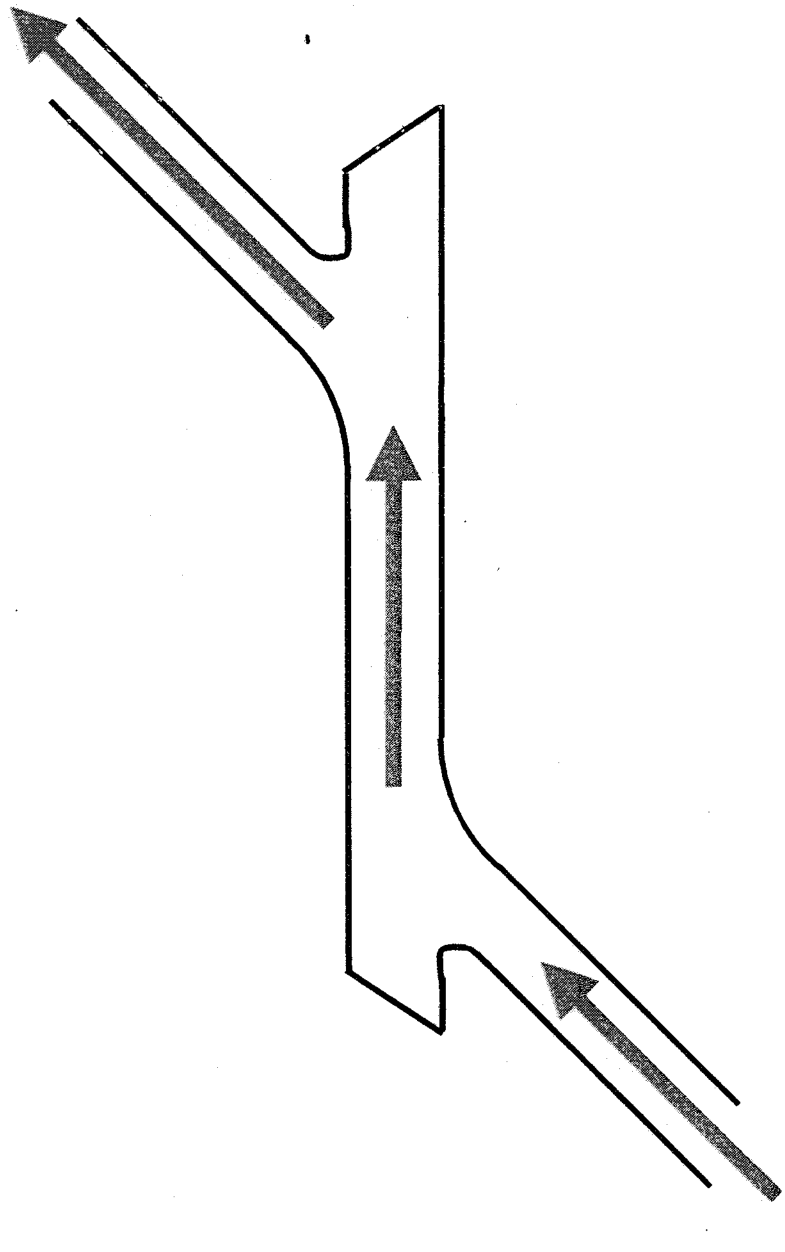

OFR



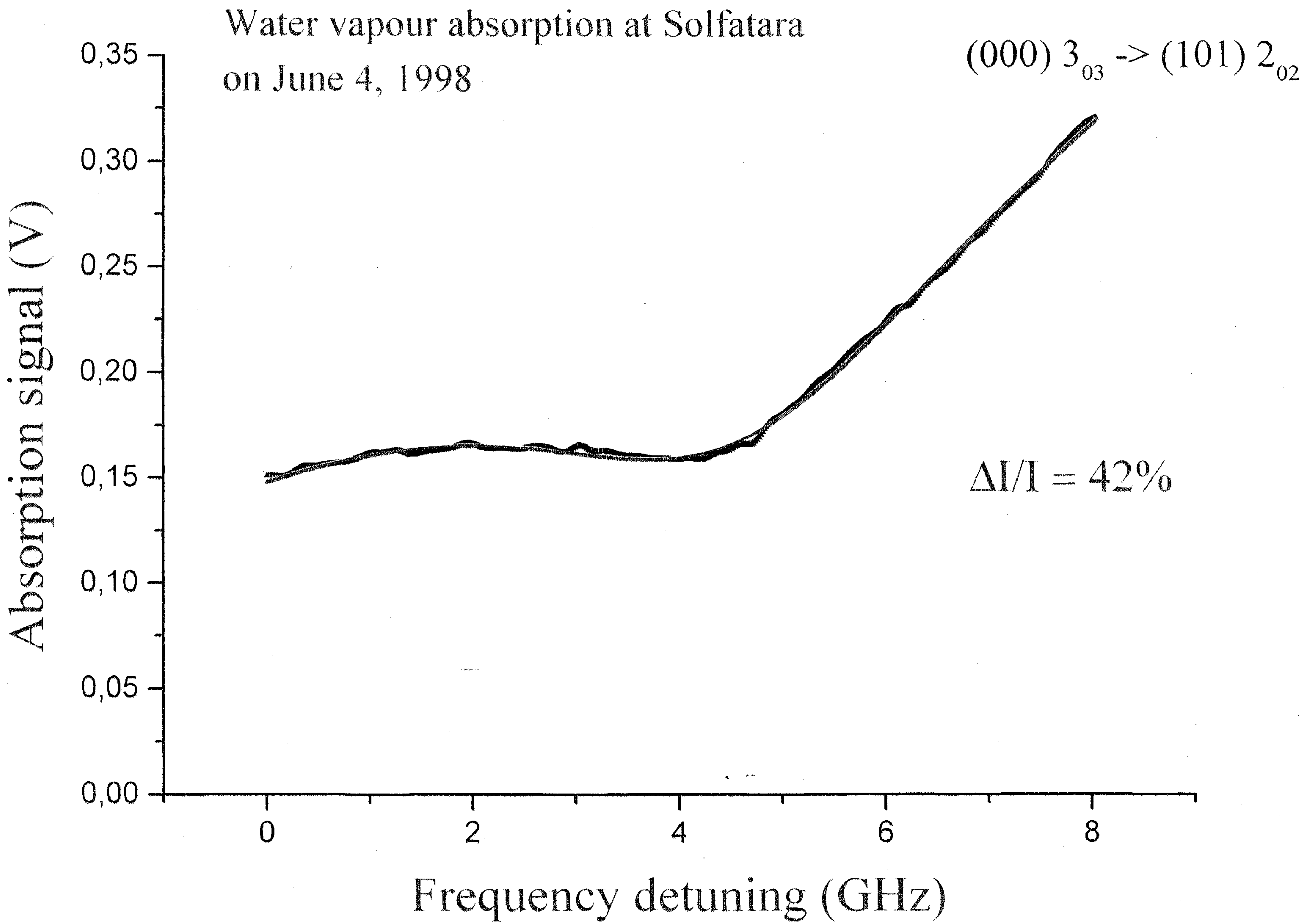
riga H_2O $(1,0,1)-(0,0,0)$ $2_{1,2}-3_{1,3}$

$\lambda \simeq 1.392\ \mu m$

schema "open path"



L. Gianfrani, P. De Natale, G. De Natale, Appl. Phys. B 70, 467-470 (2000)

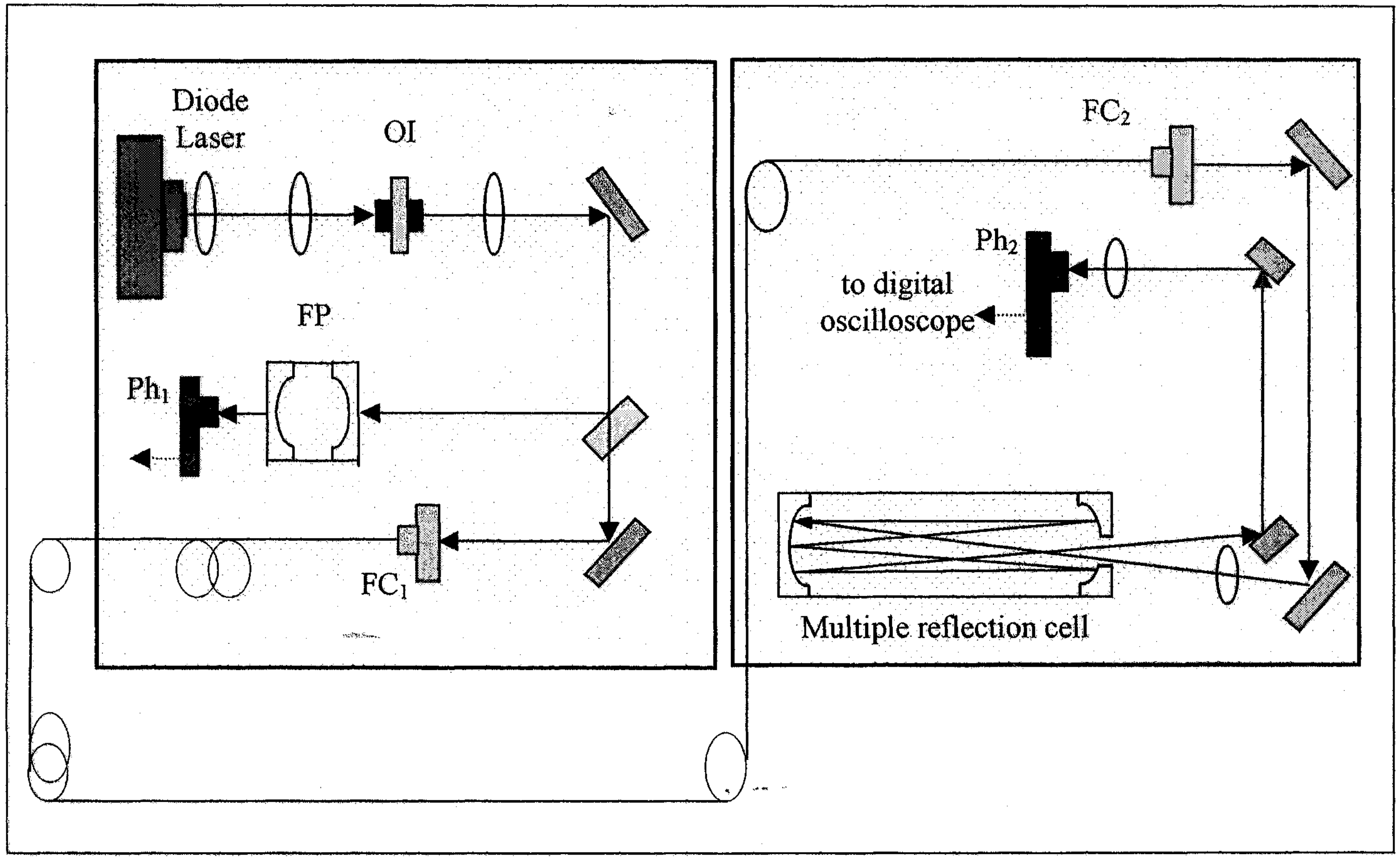


How to go beyond, thus increasing the Sensitivity?

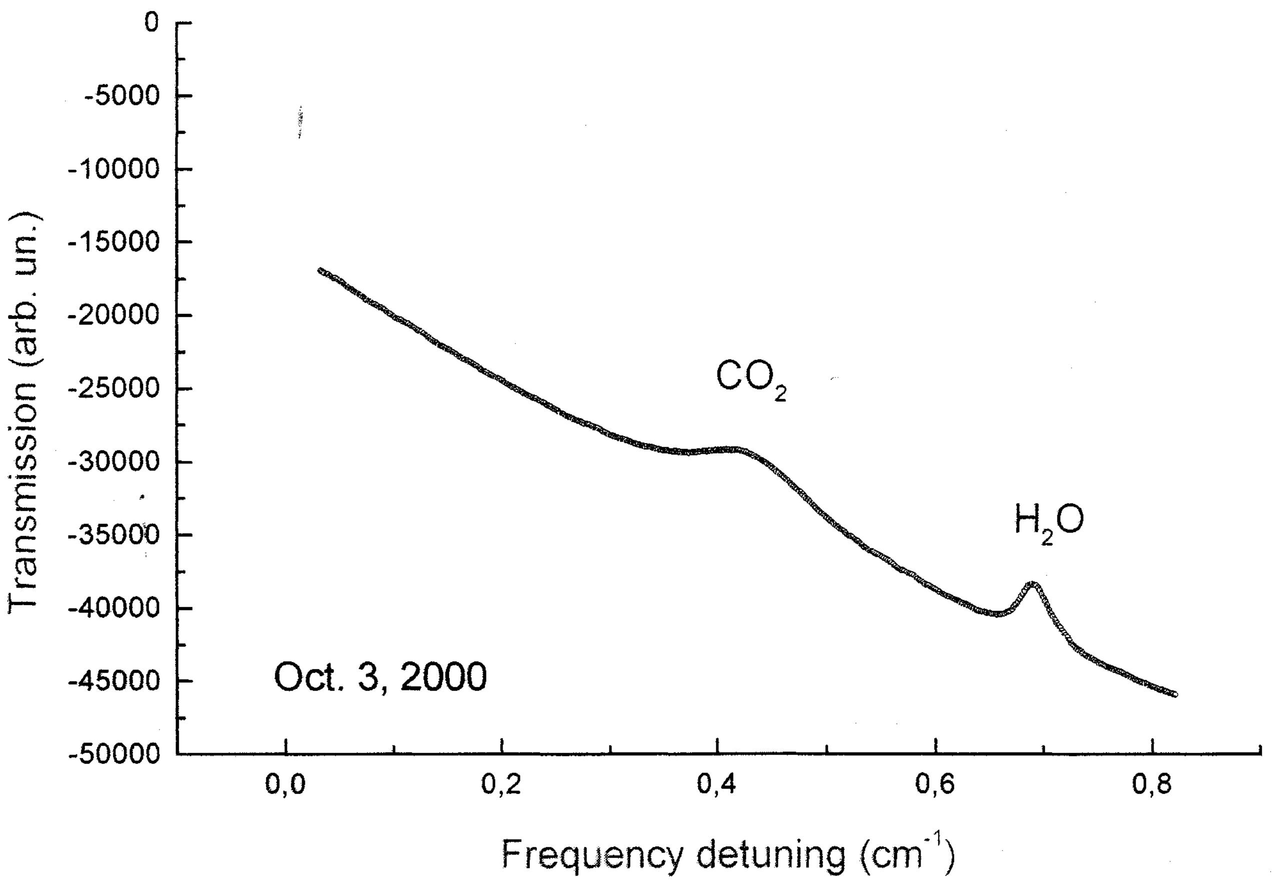
Still laser diodes!

At the border of the available spectral range we find ≈ 2 μm wavelength room-temperature operated laser diodes

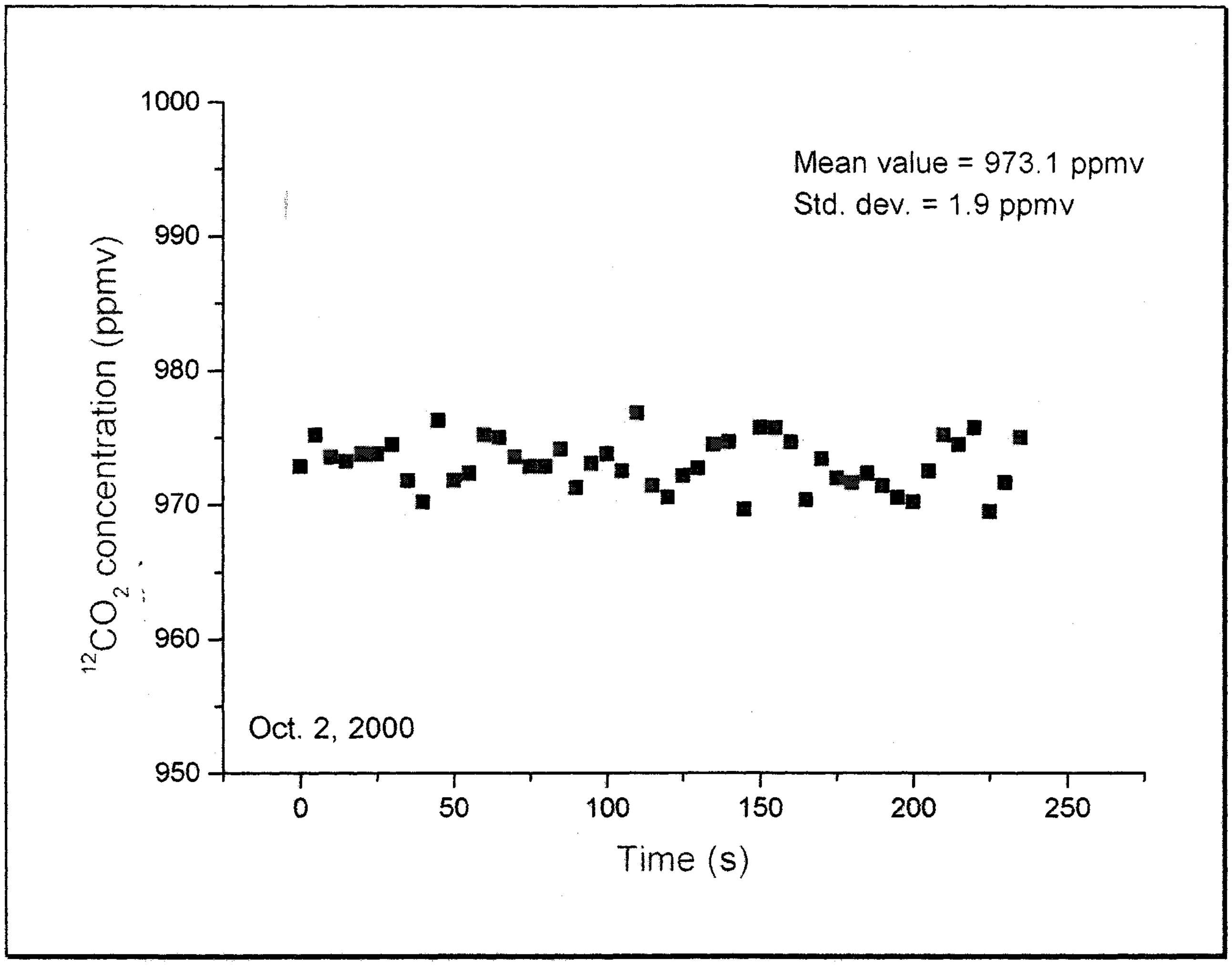
SCHEMA DELLO SPETTROMETRO



-13-

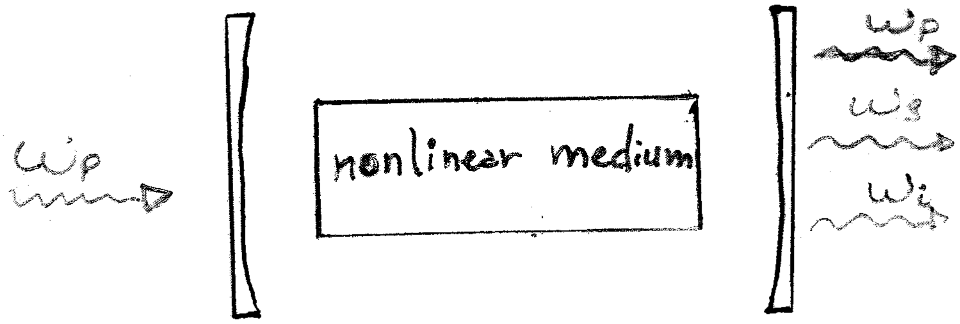


Accuratezza ≈ 1 %



Riproducibilità nel breve termine ≈ 2 ‰

OPTICAL PARAMETRIC OSCILLATOR



Energy conservation: $\omega_p = \omega_s + \omega_i$

Momentum conservation: $\bar{k}_p = \bar{k}_s + \bar{k}_i$

→ change of refractive index

- Doubly Resonant Oscillator (DRO)
- Singly Resonant Oscillator (SRO)

Widely-tunable parametric oscillator for high-resolution spectroscopy

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e-mail: Klaus.Schneider@uni-konstanz.de

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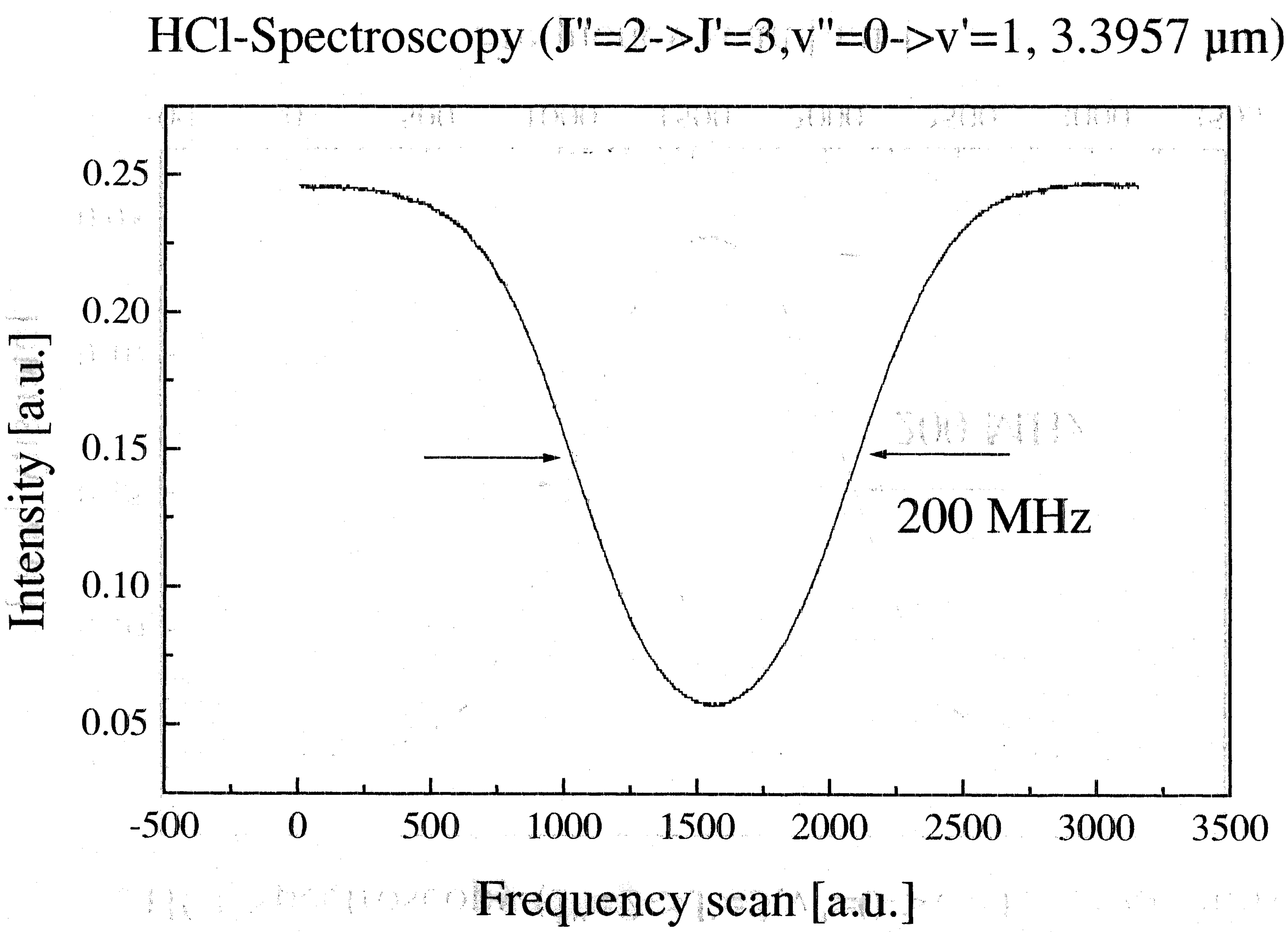
[b]*present address: LENS, Largo E. Fermi, 2, 50125 Firenze, Italy*

We report a continuous-wave, single-frequency parametric oscillator for the 1.45-4 μm range with high conversion efficiency and good long term stability. Spectroscopic measurements on HCl were possible, due to the excellent spectral properties of our device.

Presented at
CLEO/IQEC '98
S. Francisco, U.S.A.


HCl-Spectroscopy (J''=2->J'=3,v''=0->v'=1, 3.3957 μm)
Intensity [a.u.]
0.25
0.20
0.15
0.10
0.05
-500
0
500
1000
1500
2000
2500
3000
3500
Frequency scan [a.u.]
200 MHz

K. Schneider et al.:
Widely-tunable parametric oscillator for high-resolution spectroscopy

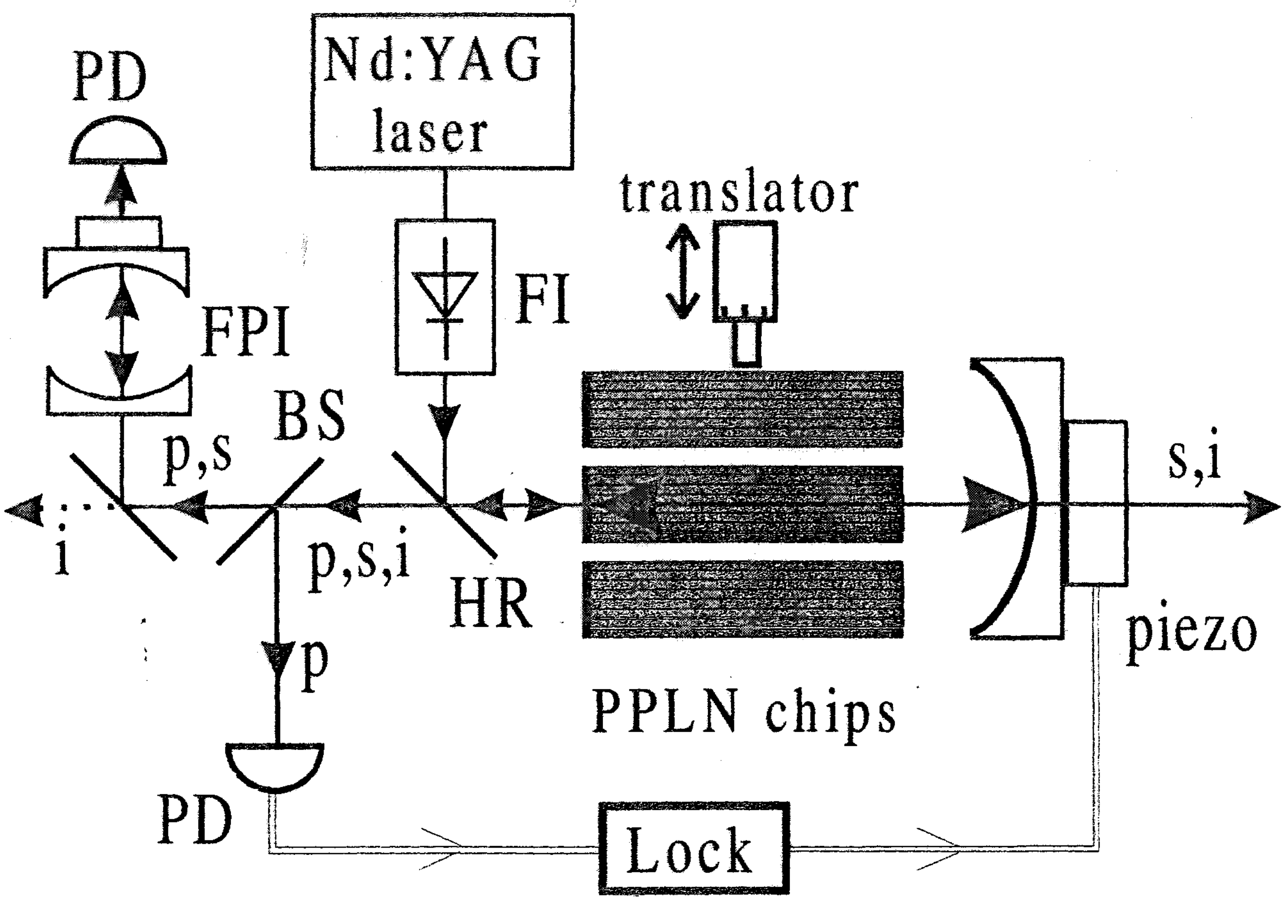


Figure 1

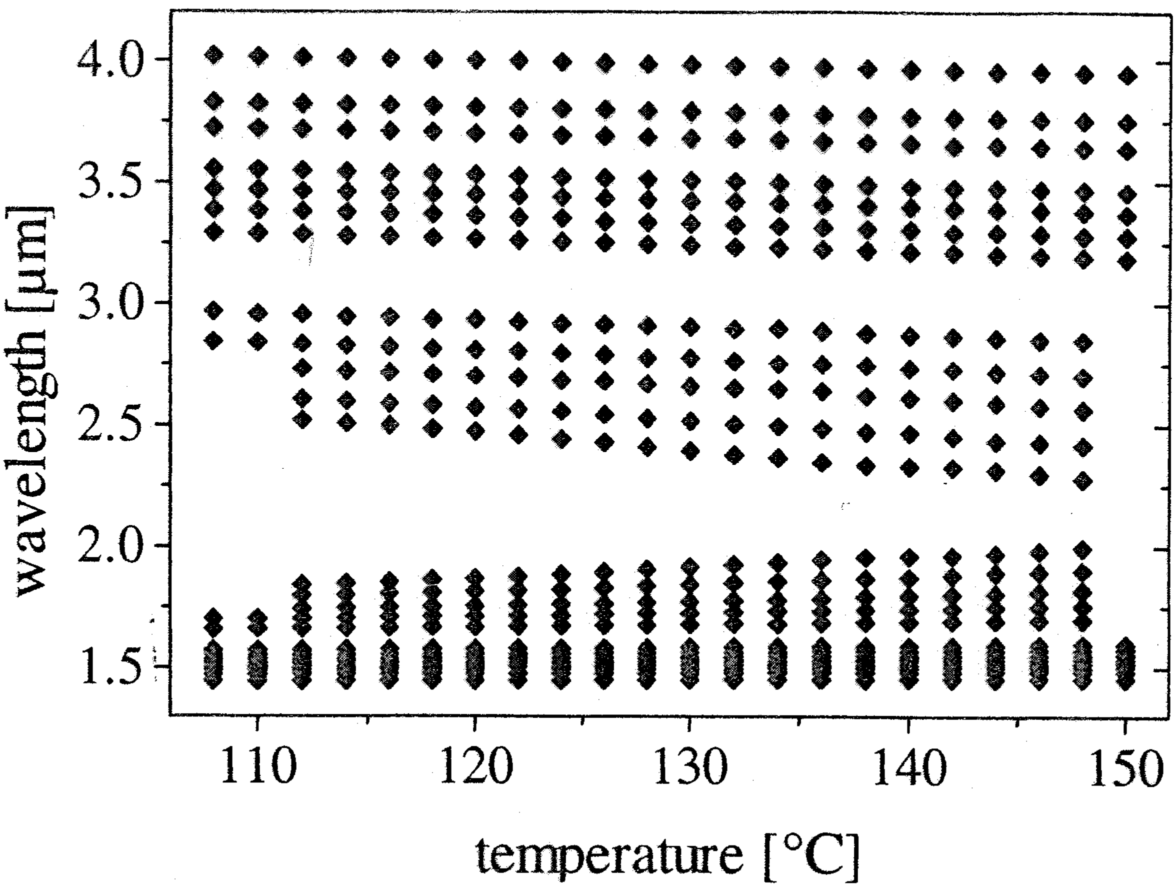

4.0
3.5
3.0
2.5
2.0
1.5
wavelength [μm]
110
120
130
140
150
temperature [°C]

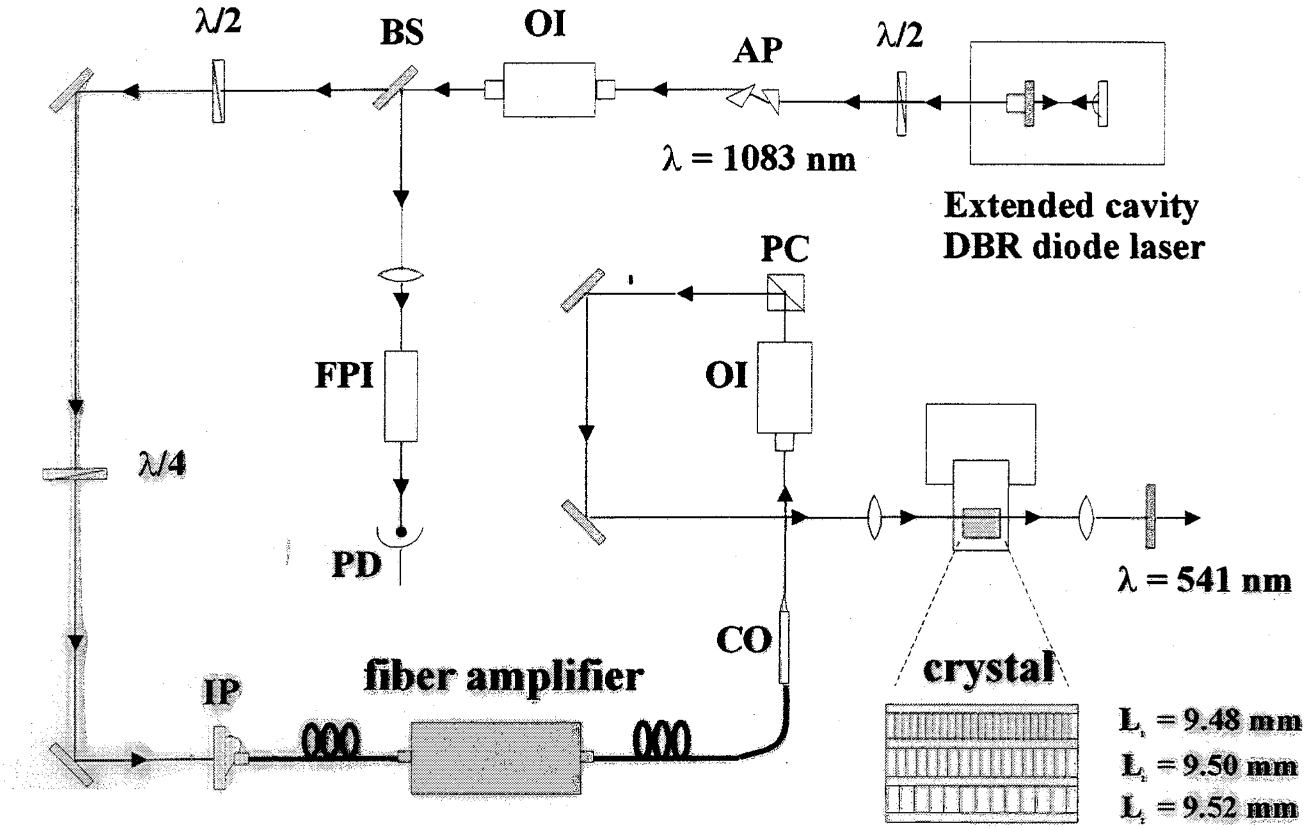
Figure 2

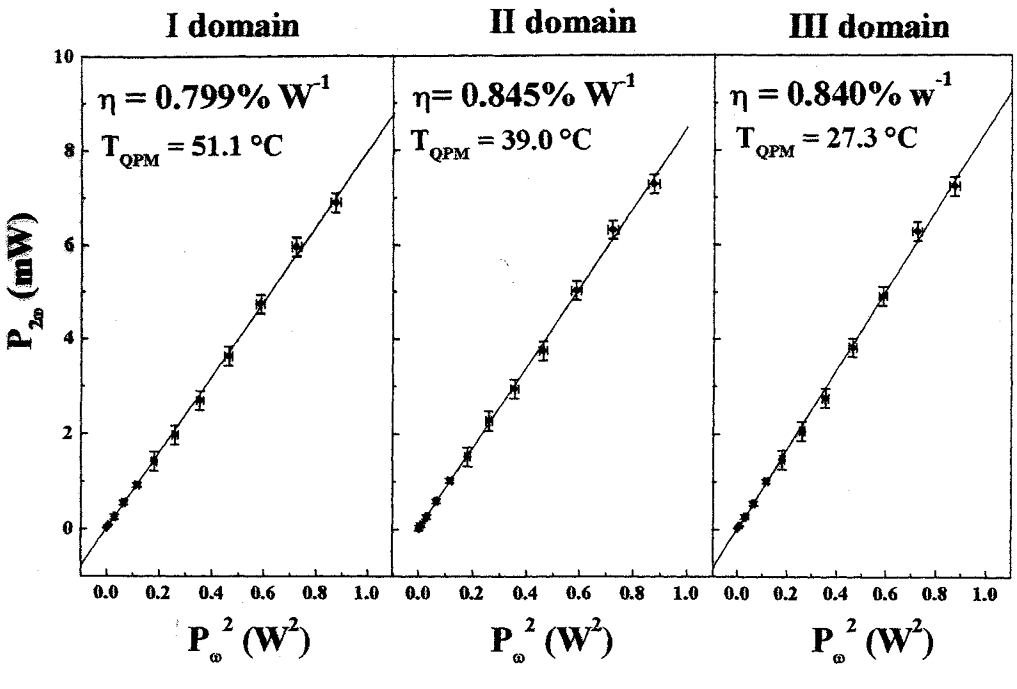
ADVANTAGES OF A (DISTRIBUTED FEED BACK SEMICONDUCTOR) LASER-BASED SPECTROMETER

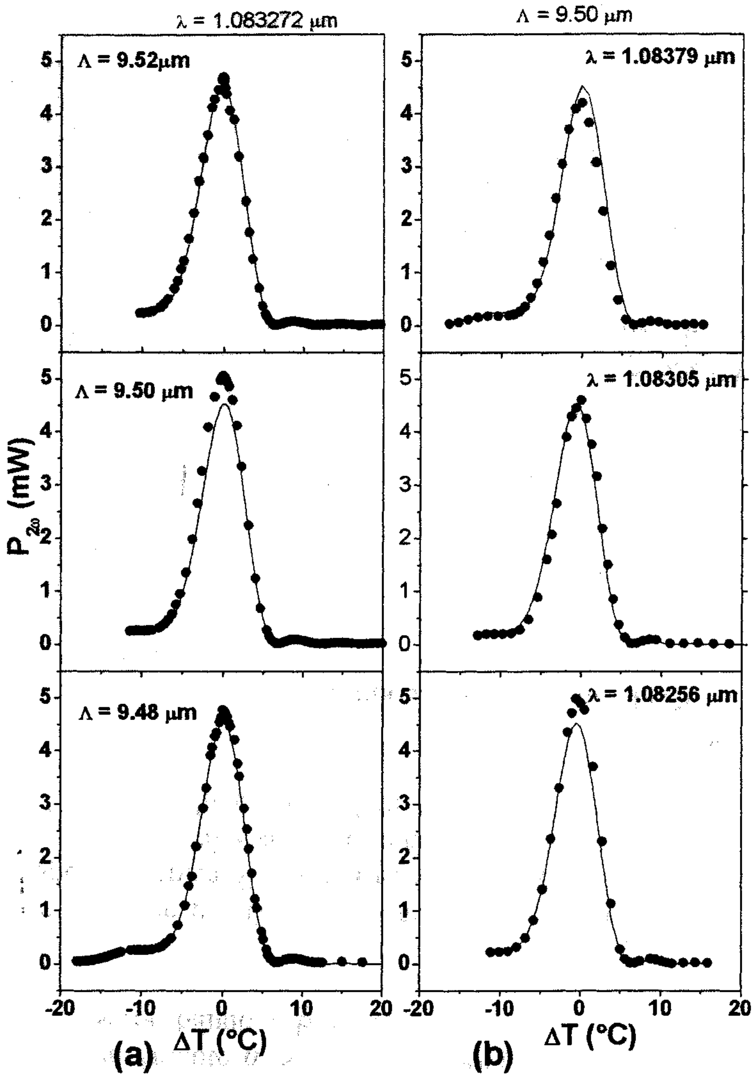
- Very high molecular selectivity.
- Single mode, tunable source.
- Very compact, battery operated laser.
- Remote operation with fibers.
- Multiplexed operation.
- Short acquisition times (tens of ms)
  → high precision measurements.

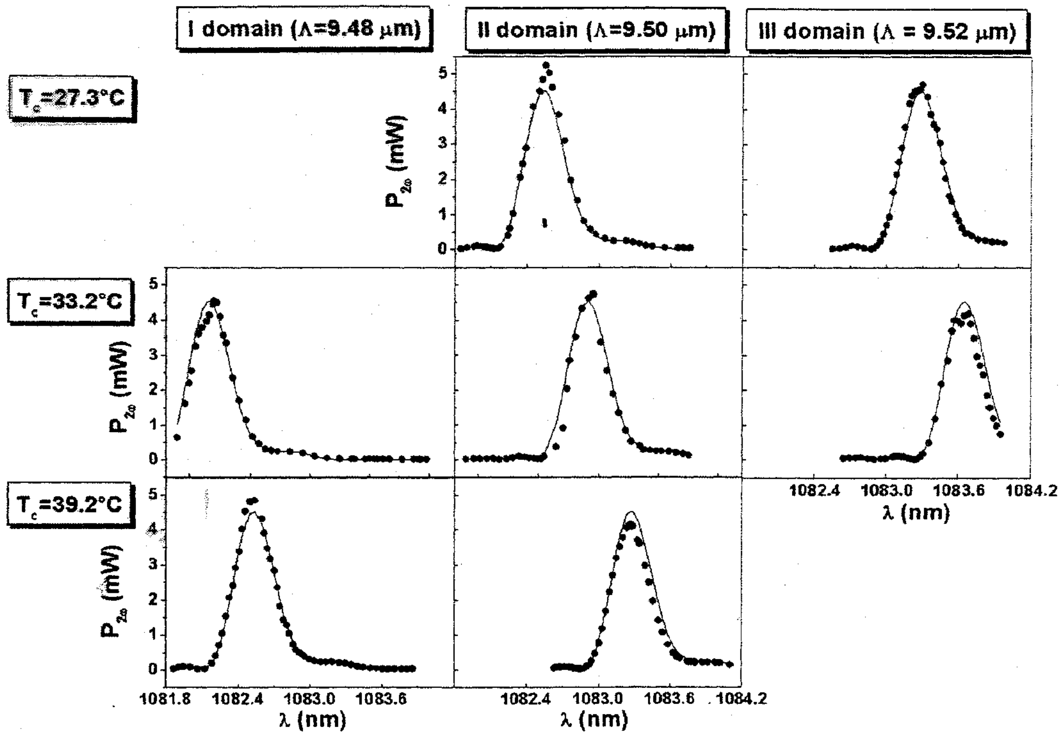
Next Step....

- GaAs waveguided QPM non-linear devices
- Transparency range up to $\lambda \simeq 12\,\mu m$
- Strong non-linearity, strongly guiding
  ($P_{in} \simeq 200\,mW$, $P_{out} \simeq 1\,mW$, <u>single pass</u>)
- Possible integration with semiconductor diode lasers.


λ/2
BS
OI
AP
λ/2
λ = 1083 nm
Extended cavity
DBR diode laser
PC
FPI
OI
λ/4
PD
λ = 541 nm
CO
fiber amplifier
crystal
IP
L₁ = 9.48 mm
L₂ = 9.50 mm
L₃ = 9.52 mm


I domain
II domain
III domain
η = 0.799% W-1
TQPM = 51.1 °C
η= 0.845% W-1
TQPM = 39.0 °C
η = 0.840% w-1
TQPM = 27.3 °C
P2ω (mW)
Pω2 (W2)
0
2
4
6
8
10
0.0
0.2
0.4
0.6
0.8
1.0

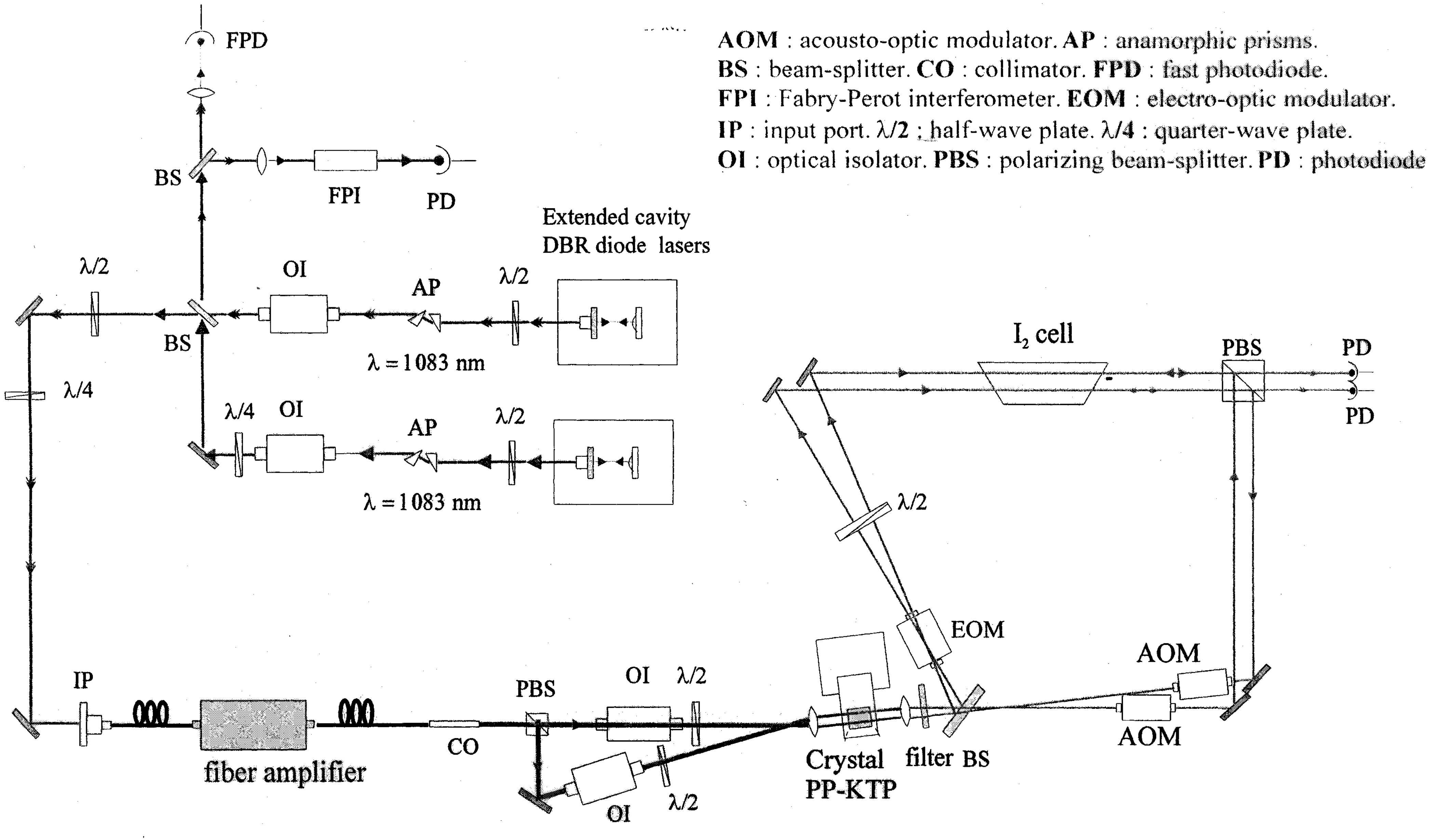

λ = 1.083272 μm
Λ = 9.50 μm
Λ = 9.52μm
λ = 1.08379 μm
Λ = 9.50 μm
λ = 1.08305 μm
Λ = 9.48 μm
λ = 1.08256 μm
P2ω (mW)
ΔT (°C)
(a)
(b)



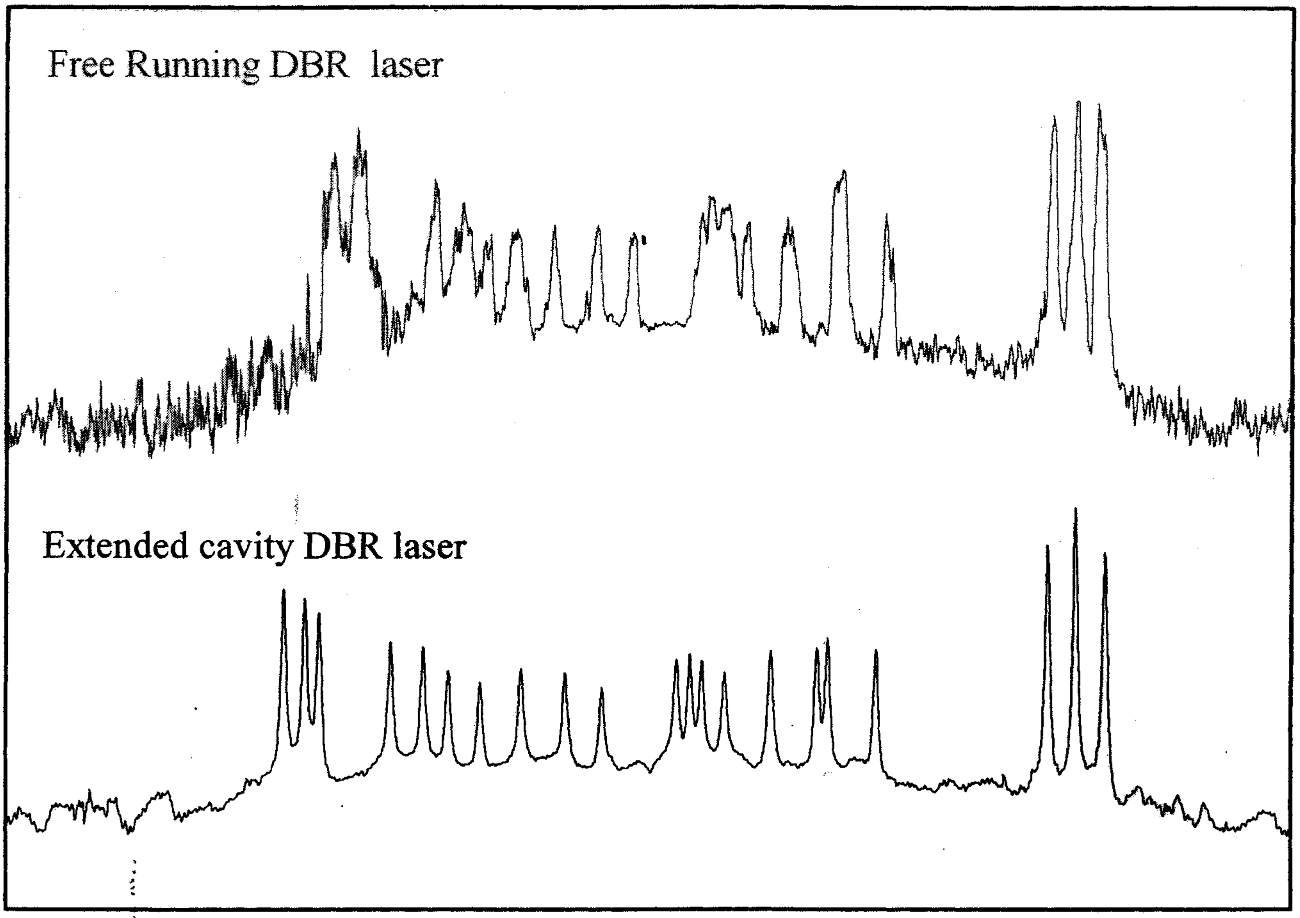
I domain (Λ=9.48 μm)
II domain (Λ=9.50 μm)
III domain (Λ = 9.52 μm)
T$_c$=27.3°C
T$_c$=33.2°C
T$_c$=39.2°C
P$_{2ω}$ (mW)
λ (nm)
1081.8
1082.4
1083.0
1083.6
1084.2

Iodine FM spectroscopy at 541.5 nm

AOM : acousto-optic modulator. **AP** : anamorphic prisms.
BS : beam-splitter. **CO** : collimator. **FPD** : fast photodiode.
FPI : Fabry-Perot interferometer. **EOM** : electro-optic modulator.
IP : input port. **λ/2** : half-wave plate. **λ/4** : quarter-wave plate.
OI : optical isolator. **PBS** : polarizing beam-splitter. **PD** : photodiode



I_2 Absorption line at 18462.12 cm^{-1}

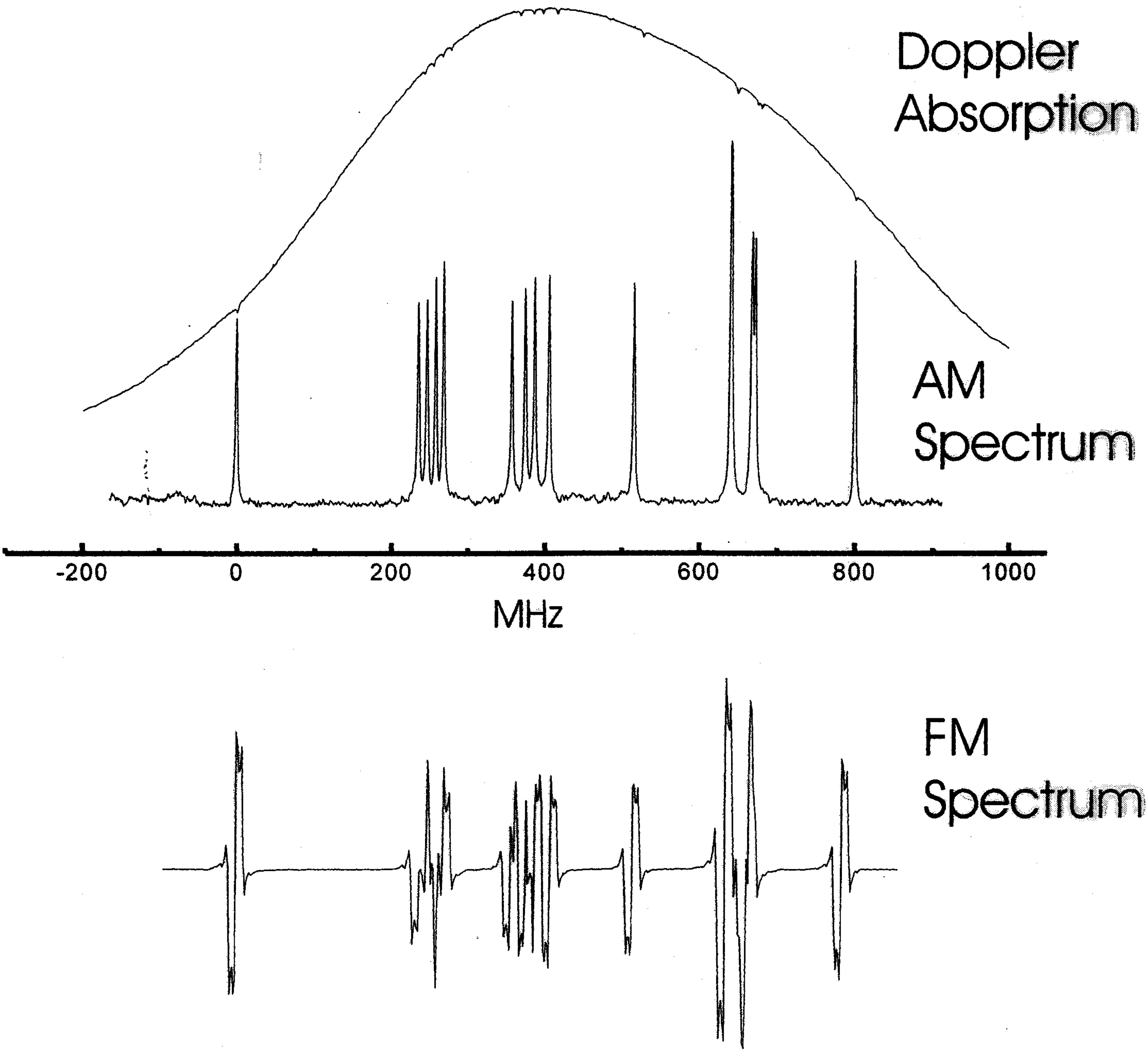


Semiconductor diode lasers with optical feedback have been very important for

MOLECULAR Spectroscopy

Iodine hyperfine spectrum at 541 nm

I_2 B-X R(34) 27-0 Doppler line and hyperfine components



Cancio et al., Opt. Comm. 176, 453 (2000)

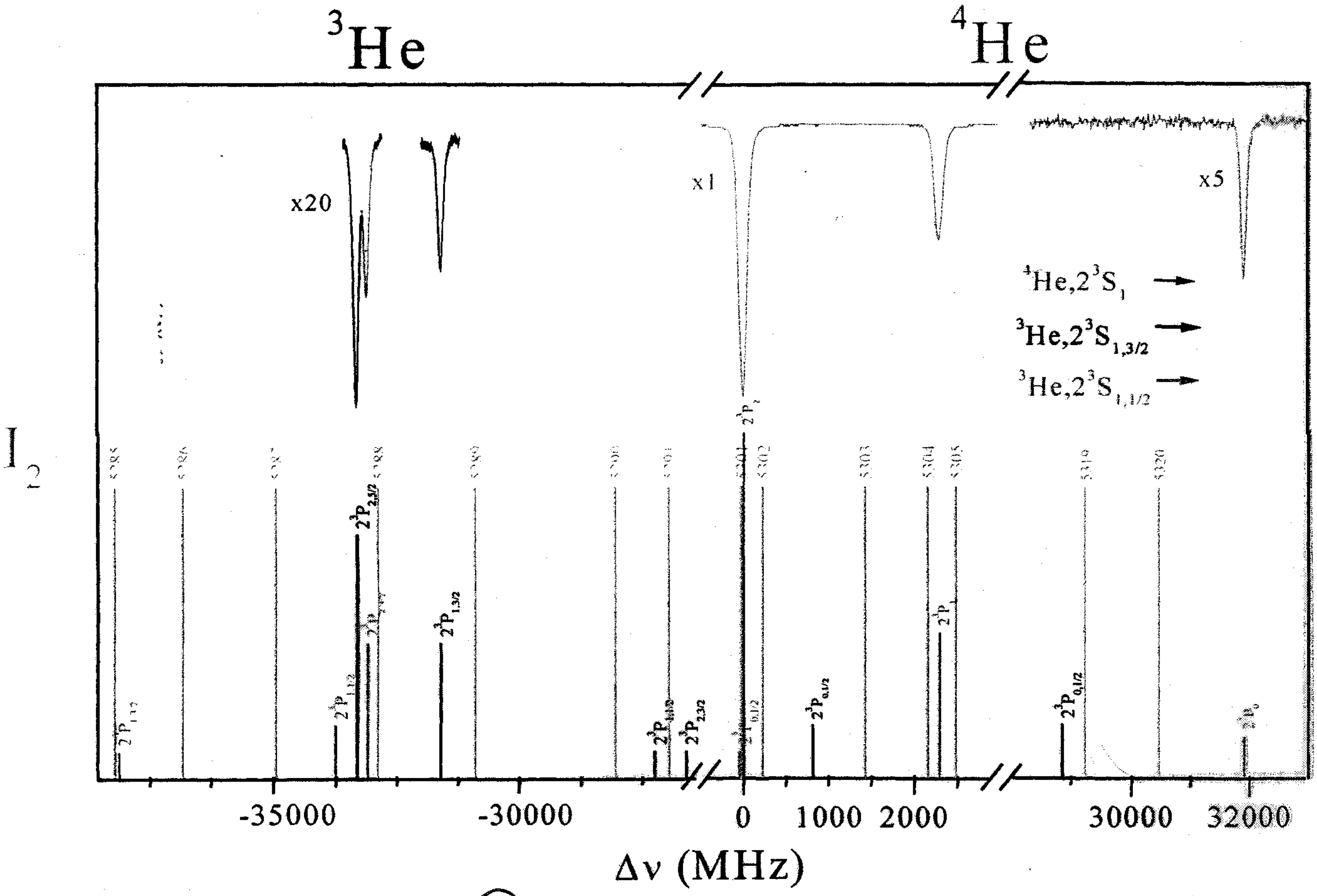
Fundamental measurements in atomic He

- Accurate ^{4}He Fine structure measurements

$\Downarrow$ + QED theory

α determination

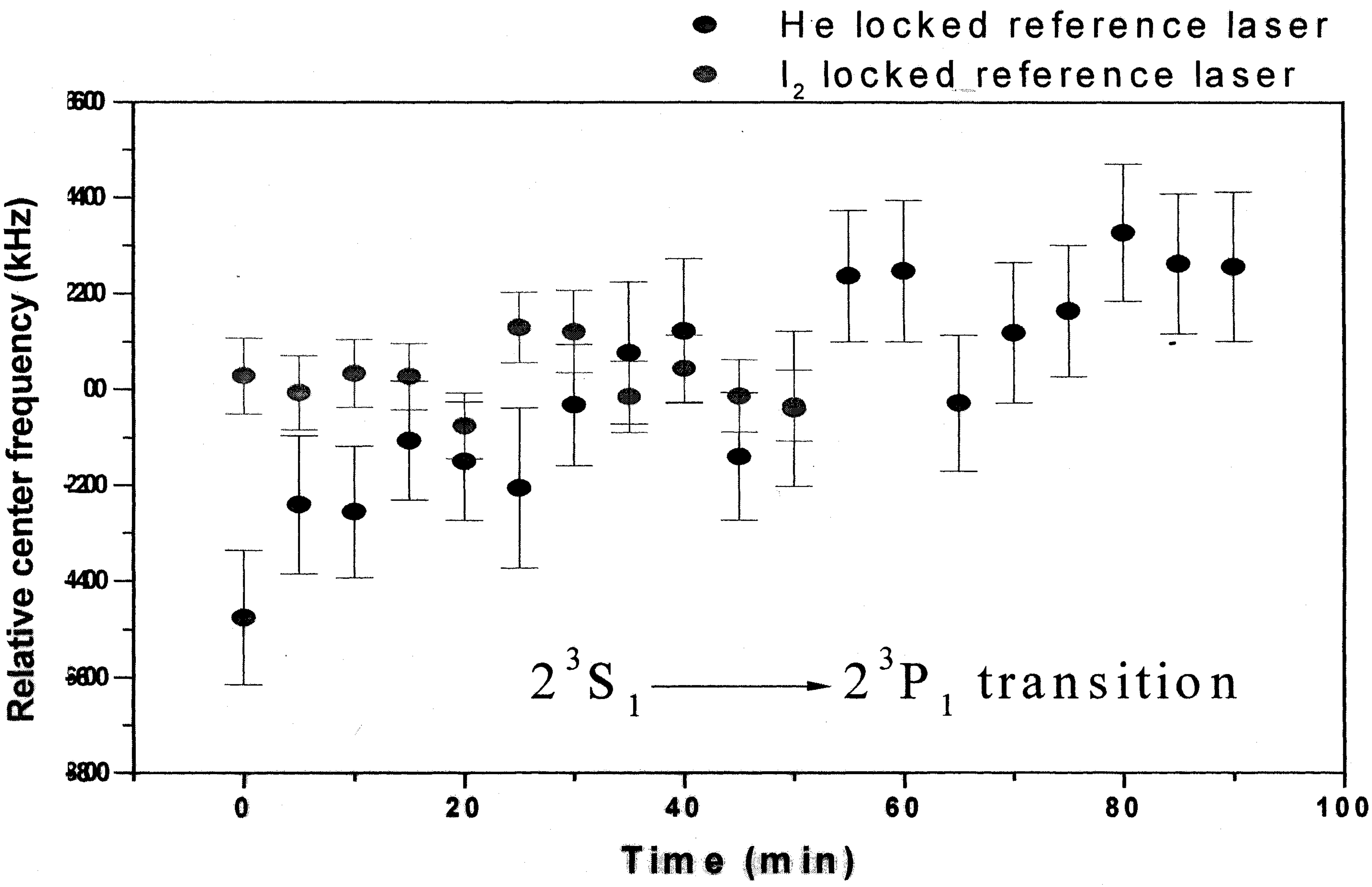
- Isotope shift measurements between ^{3}He and ^{4}He and hyperfine structure measurements in ^{3}He



Minardi et al., Phys. Rev. Lett. 82, 1112 (1999)

- Absolute frequency measurements of 1083 nm Helium transitions

Reproducibility of Helium measurements



-32-