Single-frequency operation of a Cr:YAG laser from 1332-1554 nm

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Paper CThJ1, CLEO/QELS 2000

San Francisco, CA

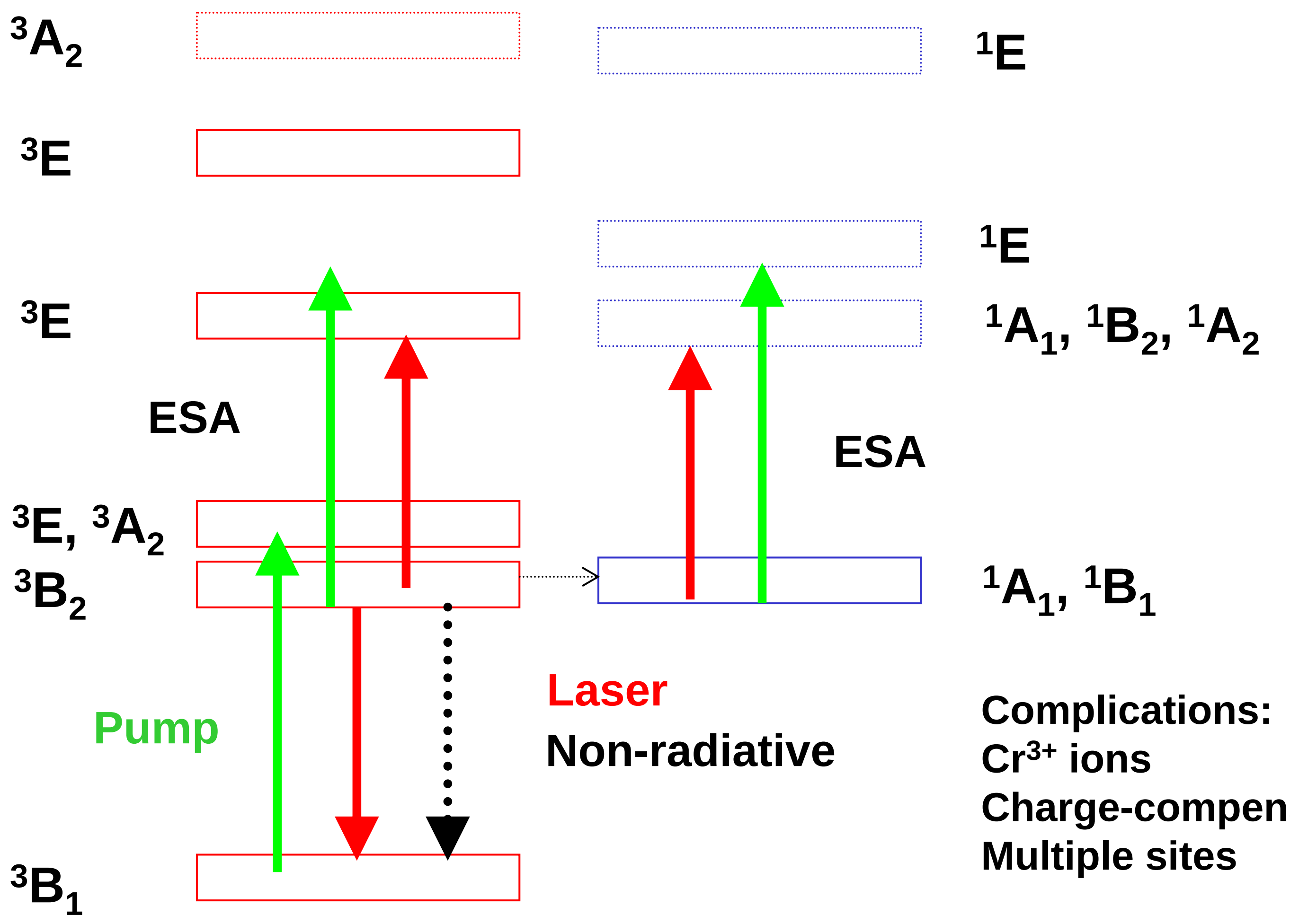
May 11, 2000

Q-peak
APPLIED PHOTONIC SYSTEMS

Outline

- Properties of Cr:YAG
- Cr:YAG laser design considerations
- Broadband laser results
- Single frequency design and results
- Summary

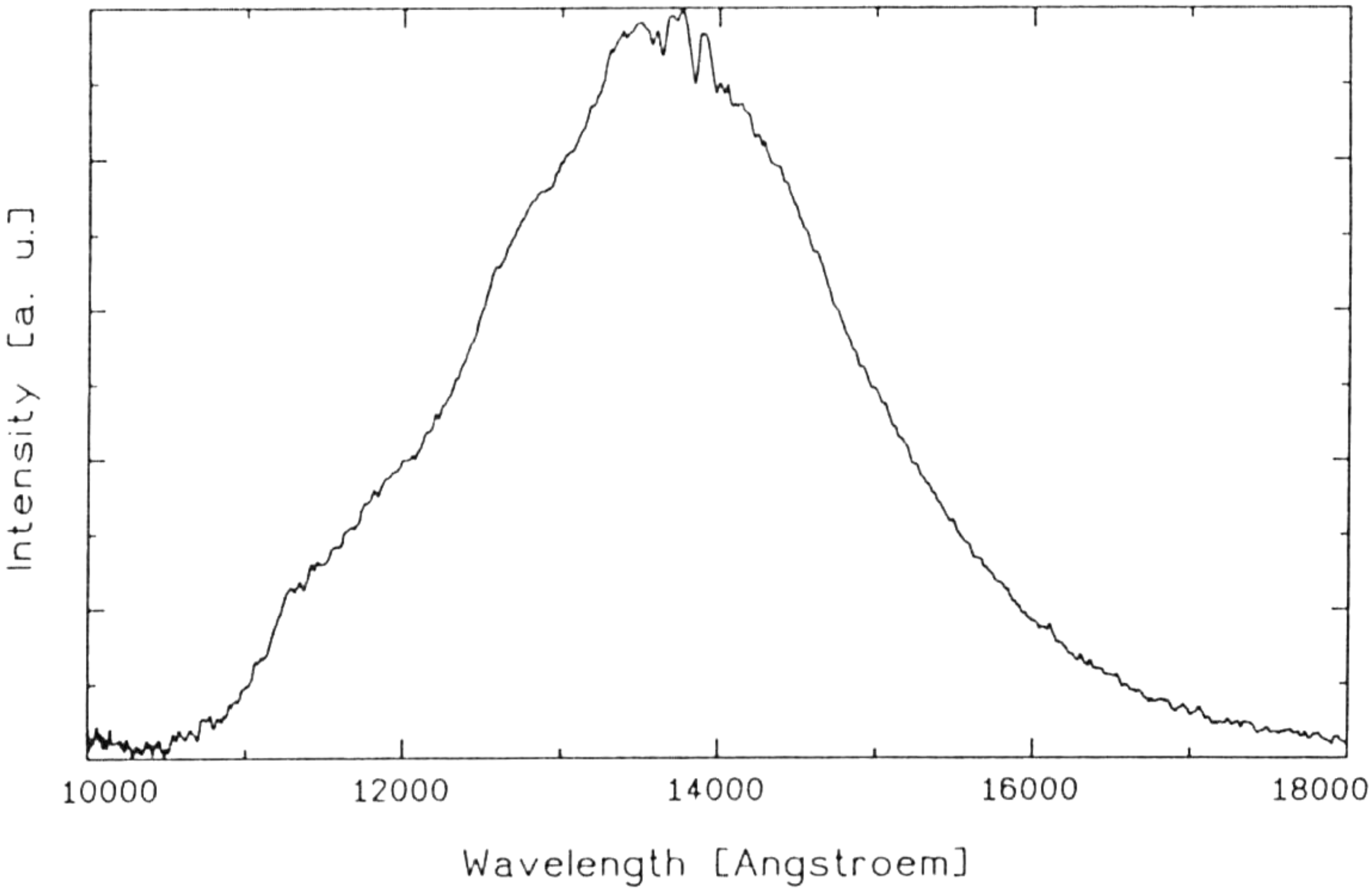
Cr^{4+}:YAG energy-level diagram (D_{2d})



Complications:
Cr^{3+} ions
Charge-compensation ions
Multiple sites

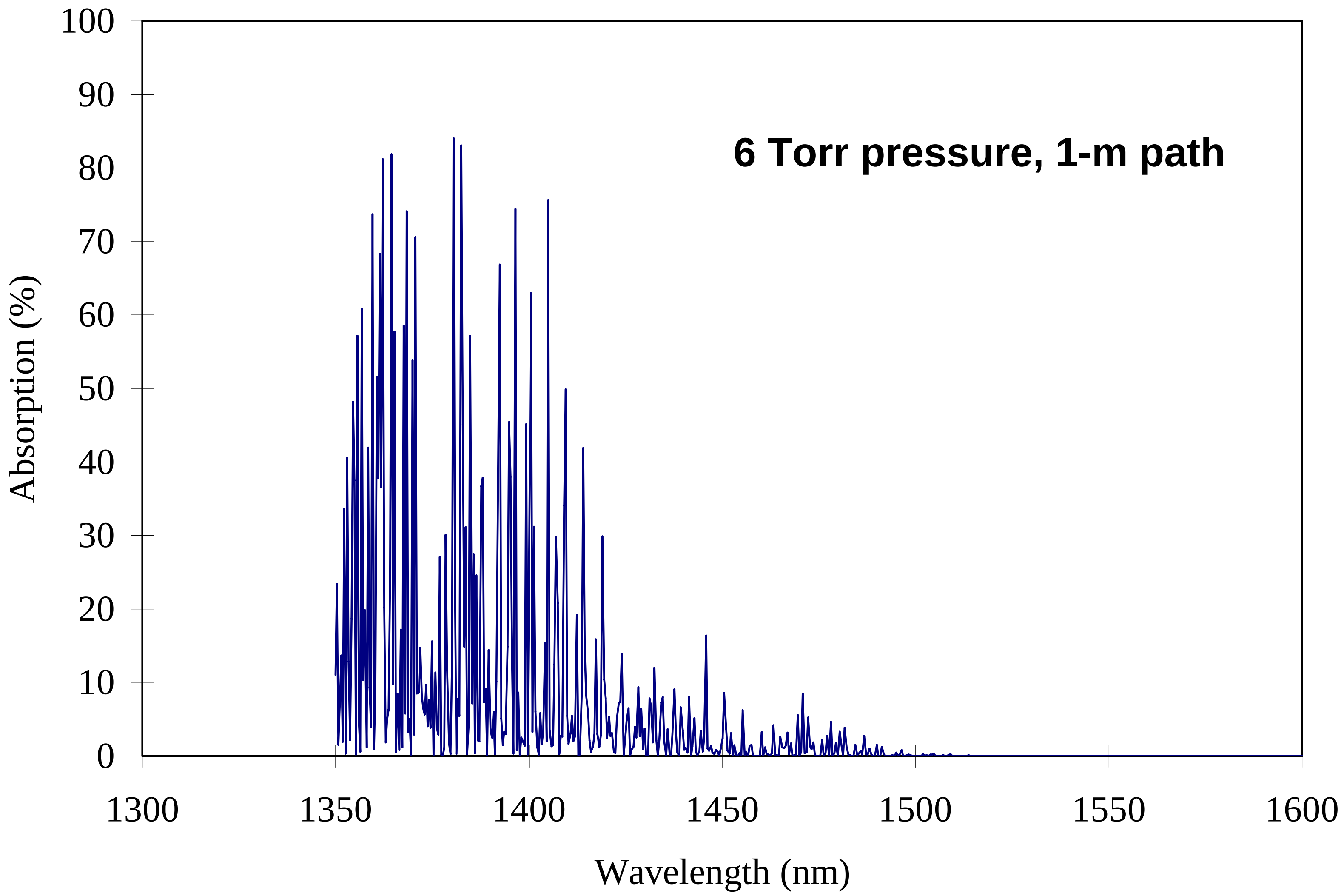
Ref: Chang et al, OSA TOPS Vol. 19, ASSL

Cr:YAG emission (not gain) spectrum



Eilers *et al*, IEEE JQE 29, 2508 (1993)

Water-vapor absorption is an issue

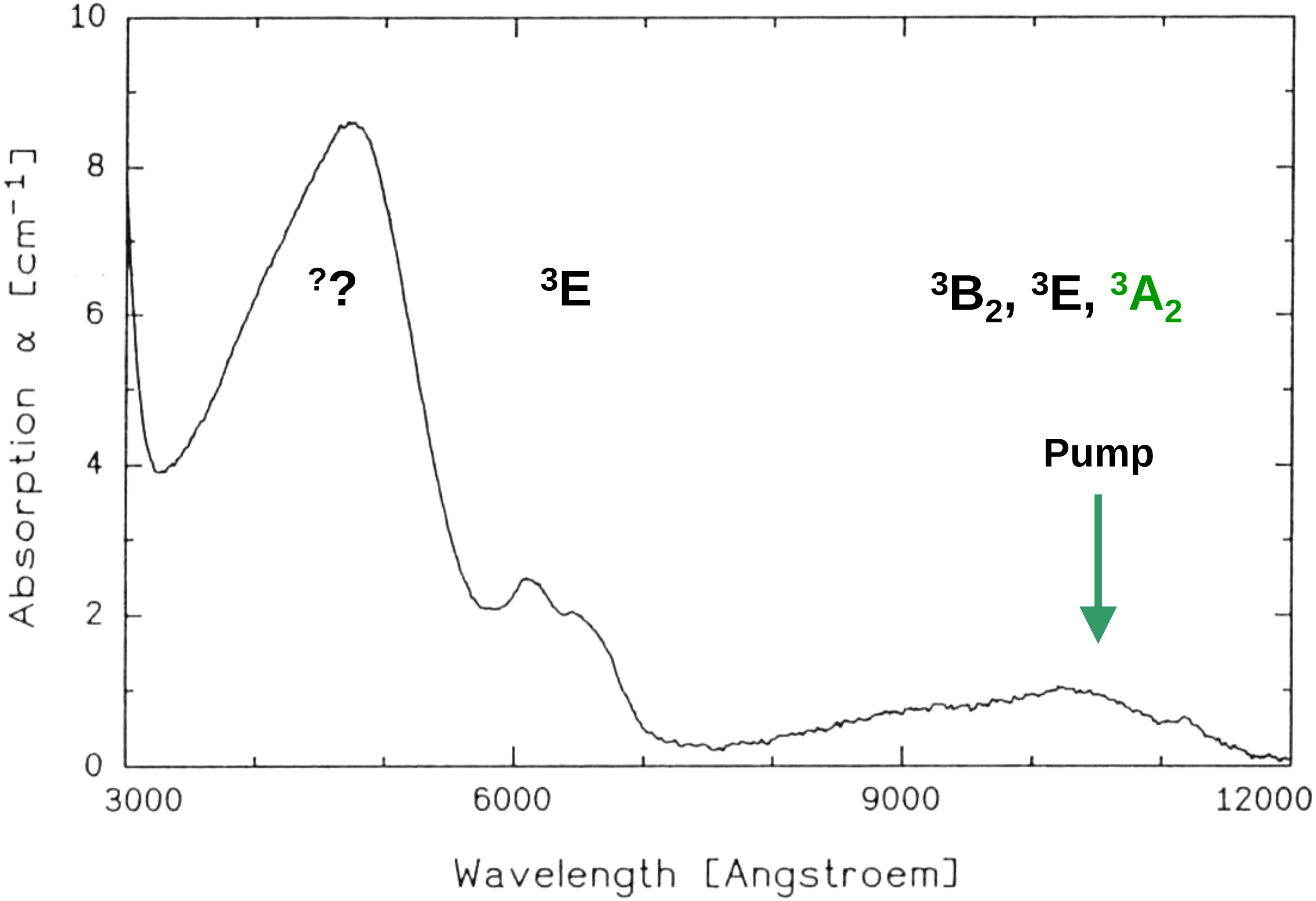


Tetrahedral symmetry for Cr in YAG leads to large transition cross sections, short lifetime

Crystal	Center wavelength (nm)	Tuning range (nm)	Eff. gain cross section (10-19 cm2)	Lifetime (μs)	Max. eff.
Ti:sapphire	800	680-1100	2.5-3	3.2	1.0
Cr:LiSAF	850	780-1050	0.32	67	0.53
Cr:YAG	1430	1340-1570	3	4	0.25
Cr:ZnSe	2400	2300-2500	8	7	1.0
Ce:LiSAF	292	280-297	60	0.028	0.35-0.7

Note: we measured 4.5-4.6 microseconds Cr:YAG lifetime at 300 K (radiative QE is likely less than unity, since 4 K lifetime is 25-30 usec)

Cr:YAG absorption spectrum

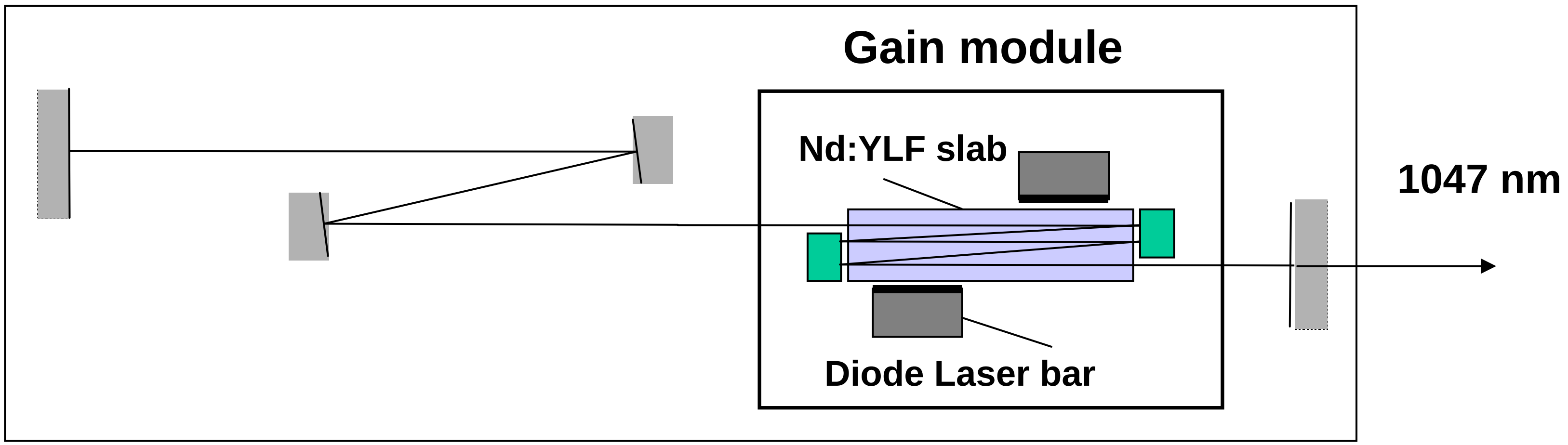


Eilers *et al*, IEEE JQE 29, 2508 (1993)

Design considerations for cw Cr:YAG lasers

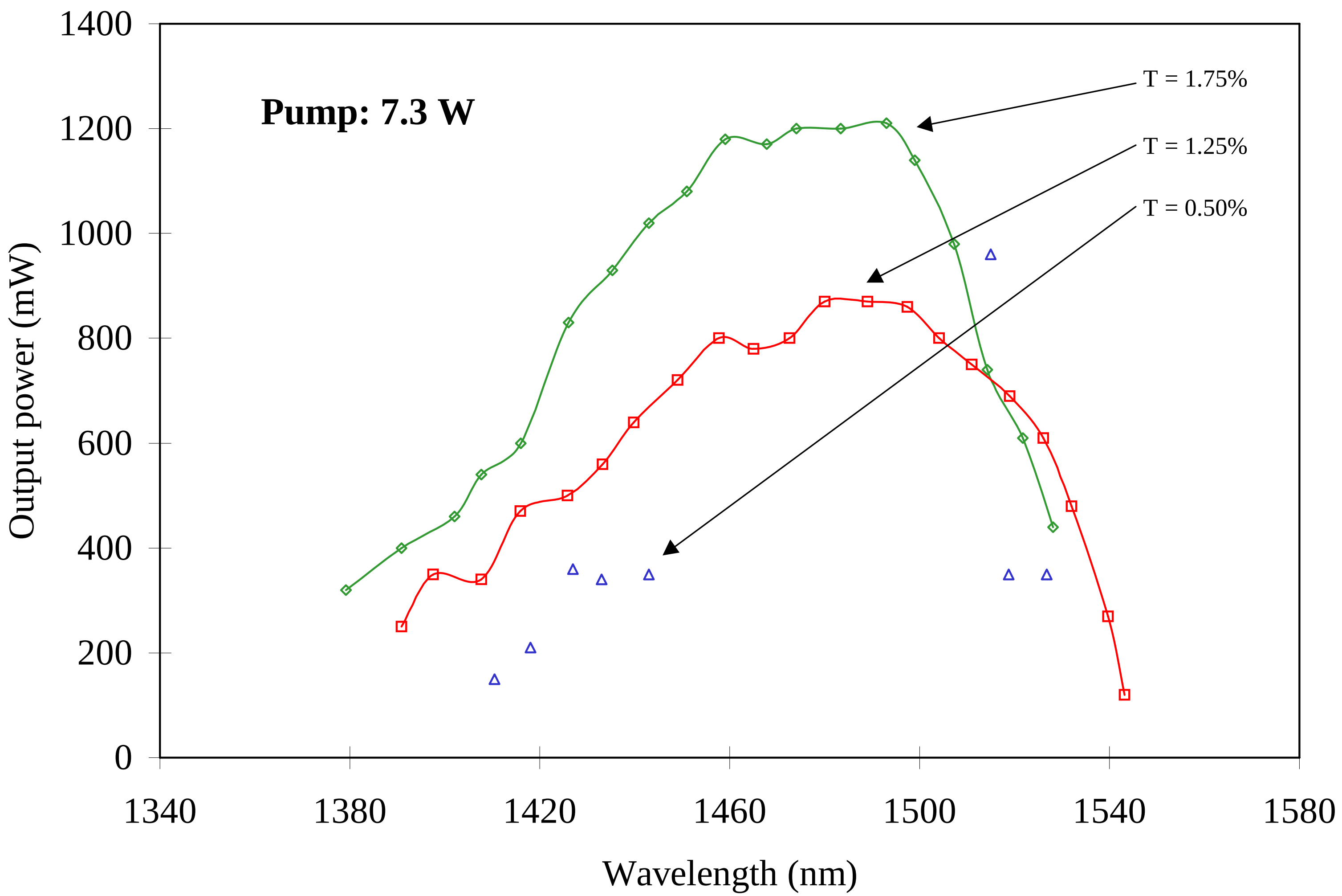
- **For various reasons, the concentration of Cr^{4+} centers is limited, so pump absorption is typically 1 cm^{-1}**
  - ***This limits pump focusing because of diffraction of pump beam in crystal absorbing region. Favors diffraction-limited pump laser.***
- **ESA of pump, bleaching of ground state absorption and thermal quenching call for minimizing pumping levels**
  - ***Both output coupling and cavity losses must be minimized to permit reasonable efficiencies. Gain is limited.***
  - ***Crystal temperature rise must be minimized to avoid increasing the threshold pump level***
- **Despite variations in crystal environment for active ion, the broadband nature of the vibronic transition means the laser is essentially homogeneously broadened**
  - ***Elimination of spatial hole burning should lead to single-frequency operation, similar to Nd:YAG and Ti:sapphire***

Pump laser is diode side-pumped Nd:YLF



System is early prototype of Q-Peak MPS-1047 CW 10
Available TEM_{00} pump power ≈ 7 W

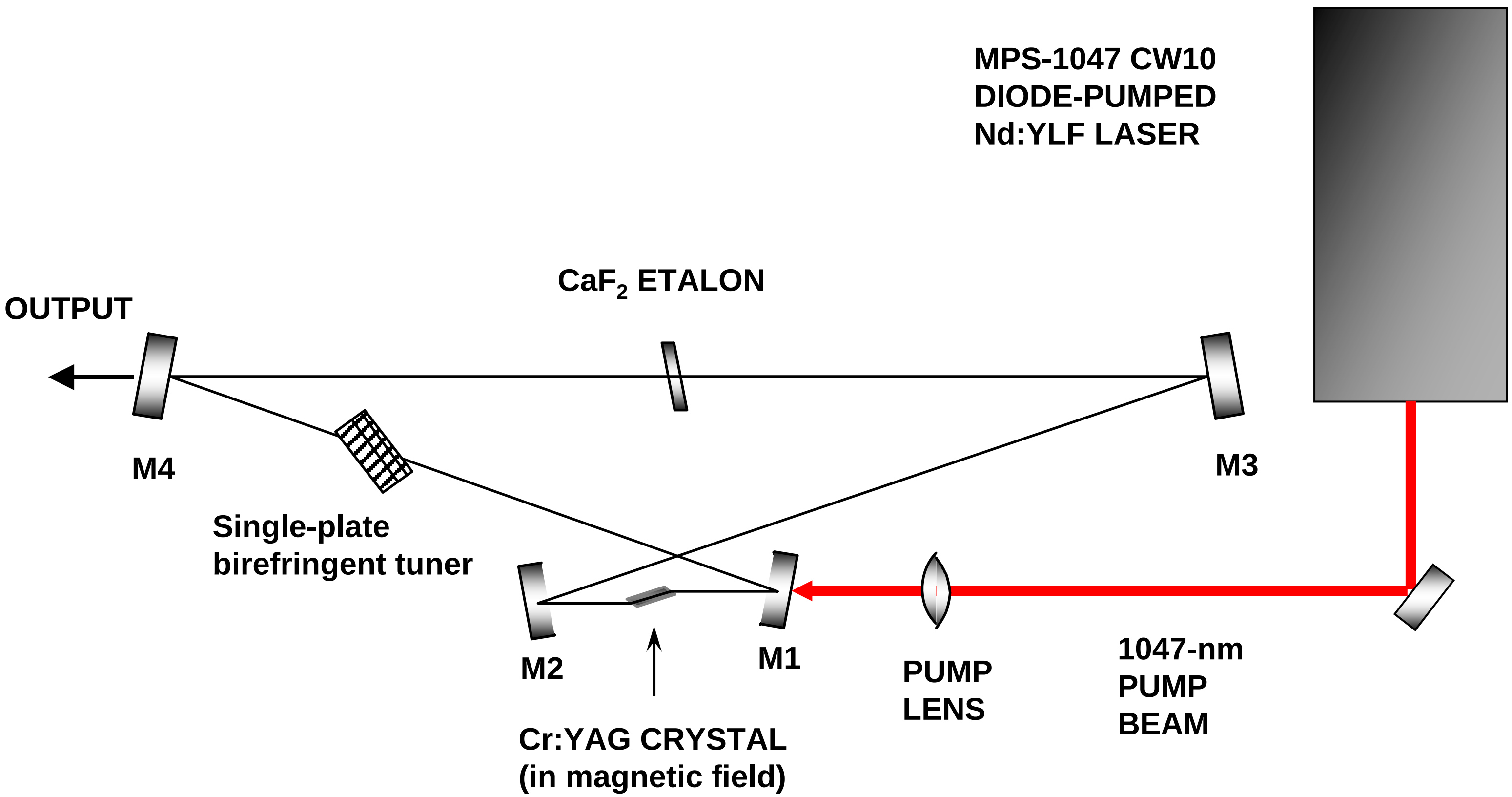
Standing-wave, Cr:YAG broadband tuning



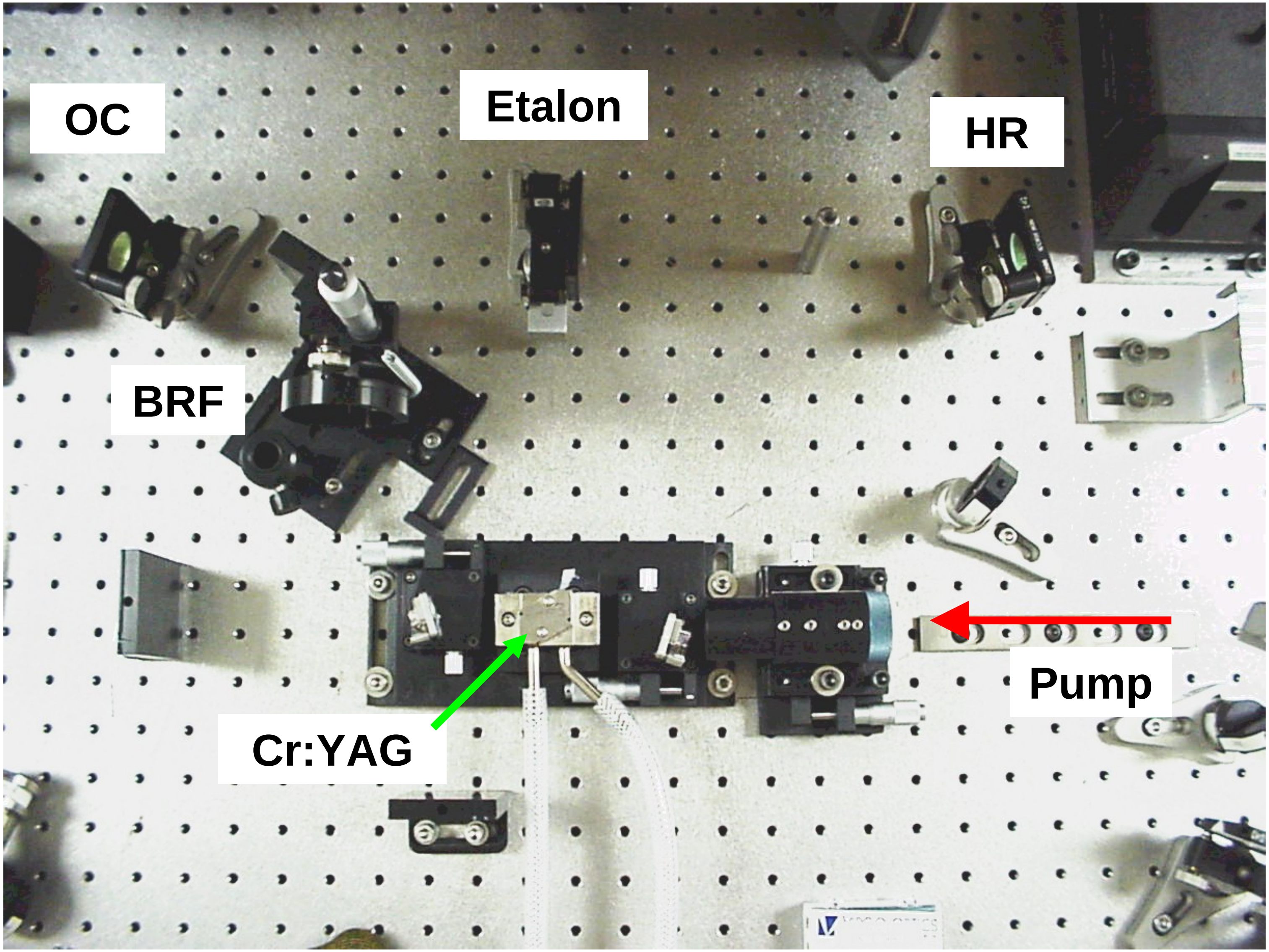
Towards tunable, single-frequency operation

- Basic approach to single-frequency operation was to make a unidirectional, 4-mirror ring cavity, similar to Ti:sapphire ring laser
- Because of the low gain in Cr:YAG and the need to minimize intracavity losses, the choice of an optical diode is critical. For the non-reciprocal element, we looked at:
  - YIG
  - TGG
  - Various glasses
  - Cr:YAG
- The best results were obtained by using the gain medium itself as the element. We placed a small magnet near the laser crystal, and aligned the cavity out of plane to compensate for the Faraday rotation

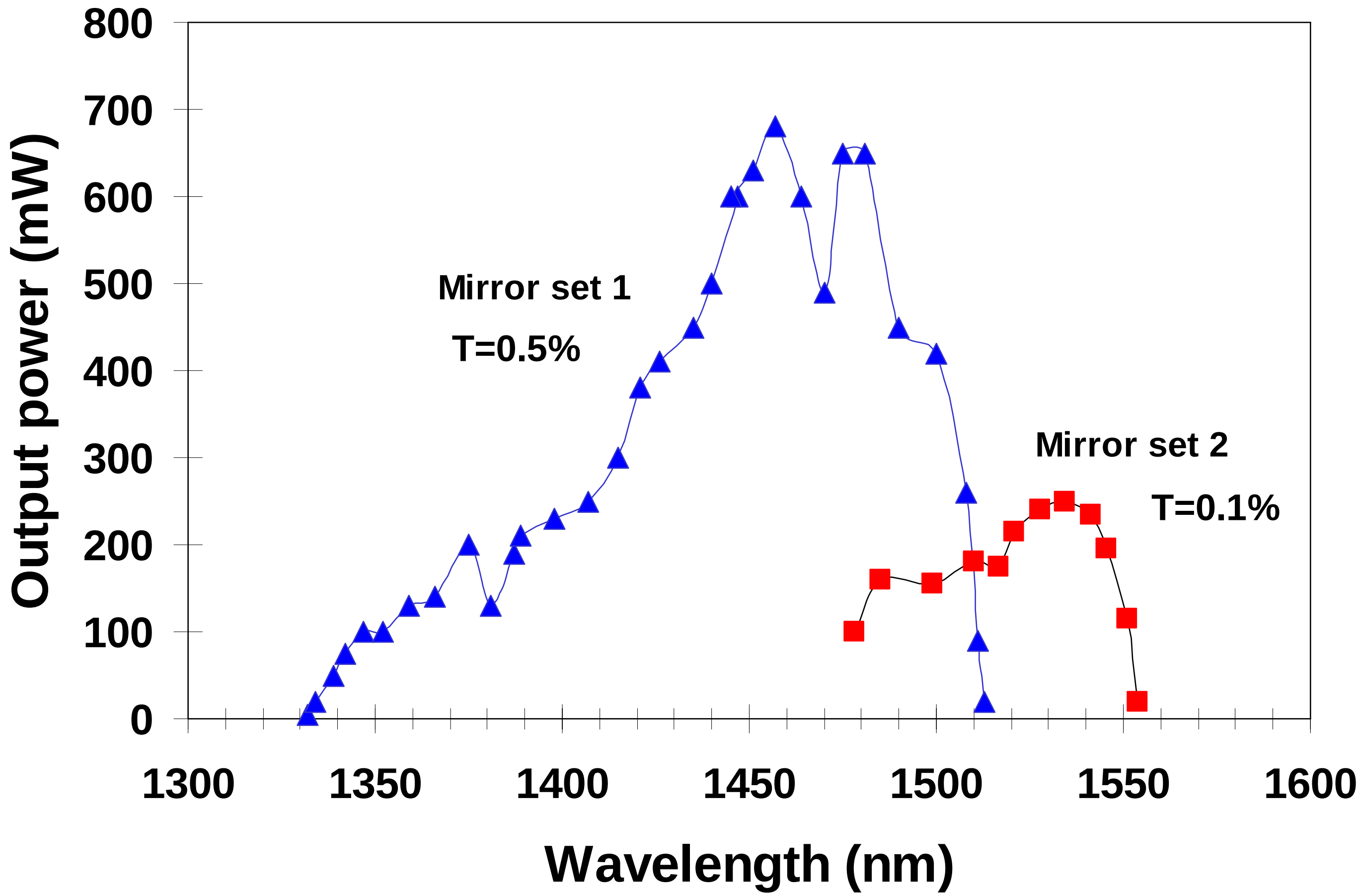
Schematic of Cr:YAG single-frequency laser



Cr:YAG laser layout



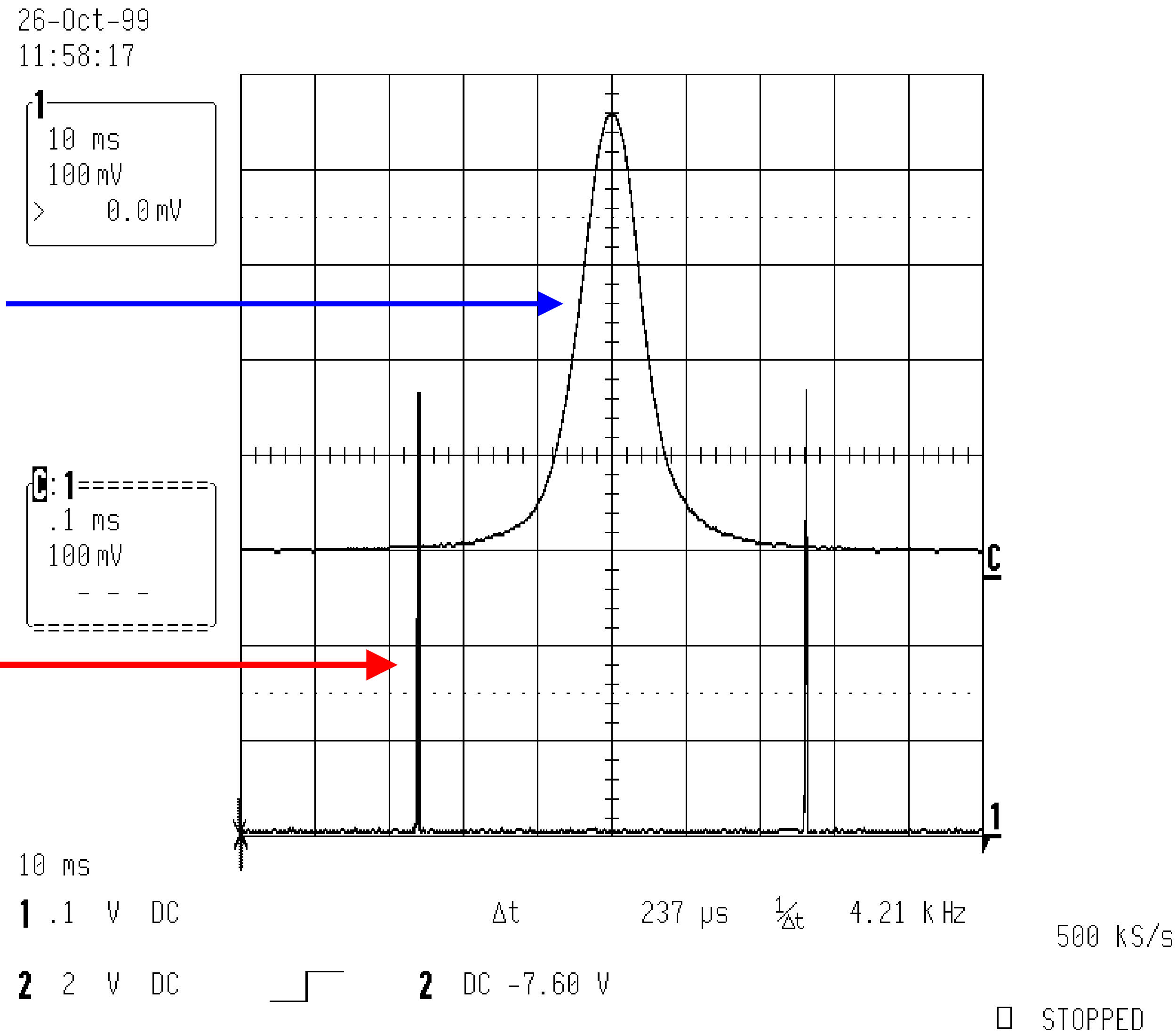
Single-frequency tuning curves



Scanning Confocal Etalon traces

Upper trace:
100x expansion
3.6 MHz linewidth
(etalon limit)

Lower trace:
Two peaks
2 GHz spacing
(etalon FSR)



Summary

- Cr:YAG has some fundamental limits to efficiency and gain because of the ion energy-level structure and interaction with the host crystal
- Despite these limits, Cr:YAG, when pumped by a diffraction-limited, multi-Watt laser, can provide Watt-level cw outputs in a broadly tunable wavelength region centered around 1470 nm
- Because the laser transition is essentially homogeneously broadened, efficient, single-frequency operation is possible by elimination of spatial hole-burning
- We obtained single-frequency, broadly tunable (1332-1554 nm) operation (0.68 W max. power) by using the laser crystal itself as the Faraday element in a unidirectional, non-planar ring cavity