OPTICAL BISTABILITY AND UPCONVERSION PROCESSES IN ERBIUM DOPED MICROSPHERES

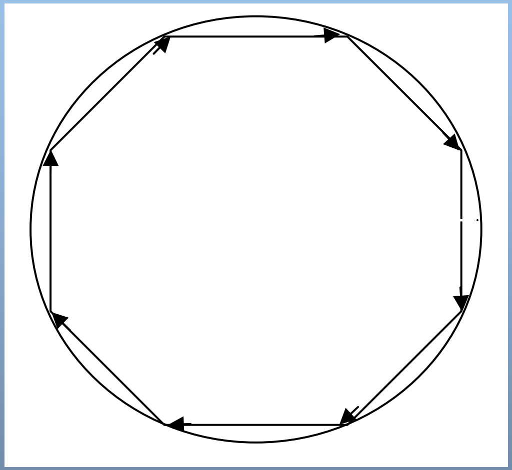
J. Ward, D. O'Shea, B. Shortt, S. Nic Chormaic
Dept of Applied Physics and Instrumentation, Cork Institute of Technology,Cork,
Dept of Physics, UCC
Tyndall National Institute, Cork

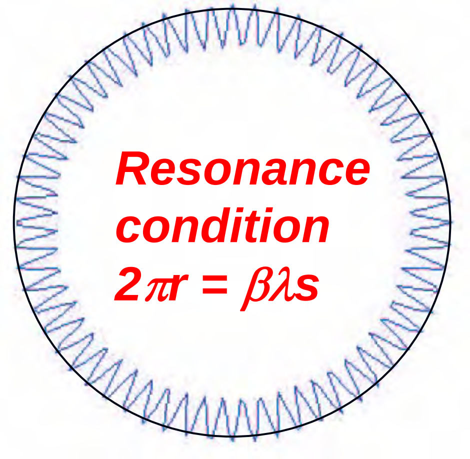
Overview

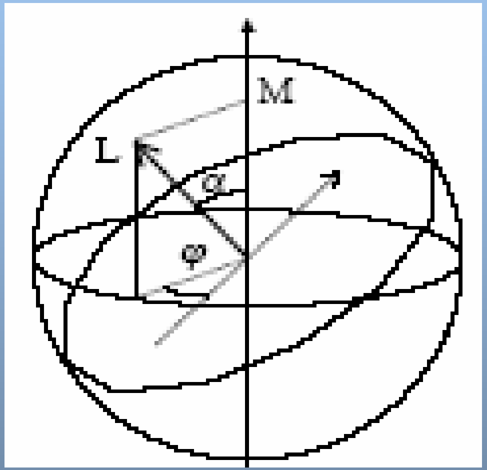
- Physical mechanisms
- Theory
- Applications
- Microsphere fabrication
- Coupling to a microsphere
- Experimental set-up
- ZBLALiP
- IOG2
- Future work

Physical mechanisms

Light travelling inside sphere, strikes glass-air interface at angle of incidence greater than critical angle – get total internal reflection TIR
If sphere is of good quality light can undergo multiple reflections … leads to long photon storage lifetimes, high Q factor and low mode volume







Physical mechanisms

Modes in a sphere can be described by 3 integer numbers *n, l* and *m.*

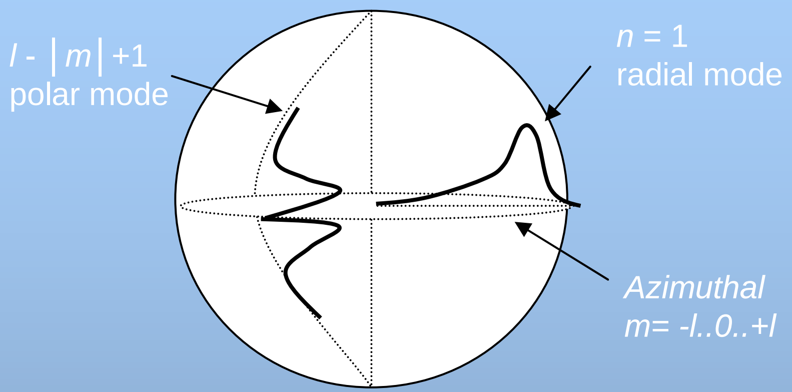
Propagation constant = β

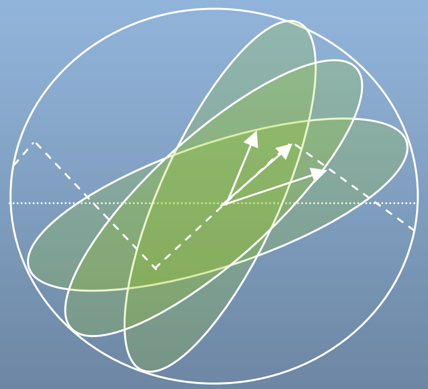
Modes can be thought of as zig zagging about either side of the equatorial plane.

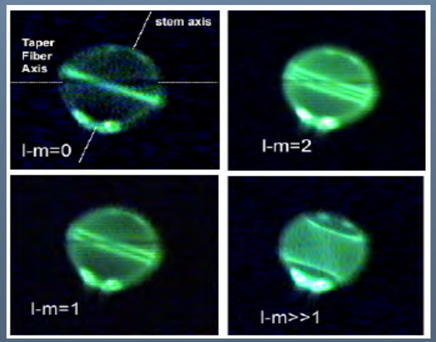
Different *m* numbers imply that modes travel in zig-zag paths with different inclinations with respect to the equatorial plane.

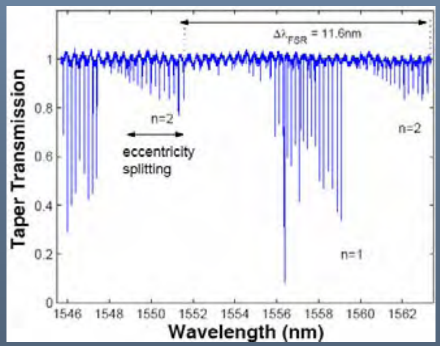
In a perfect sphere all path lengths are equal therefore there is degeneracy between polar components.

In reality deformations lift degeneracy









Vahala, Caltech

Microspheres theory

Solve scalar wave equation $$\nabla^2\psi(r)+n^2k^2\psi(r)=0$$

- four solutions corresponding to the TE and TM components of the sphere electric and magnetic fields

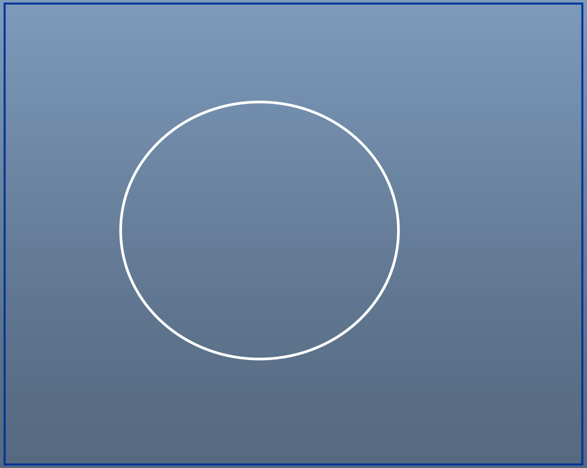
Separation of variables gives mode numbers *n*, *l* and *m*

n –described by modified Bessel functions, *n* = 1,2,3, …

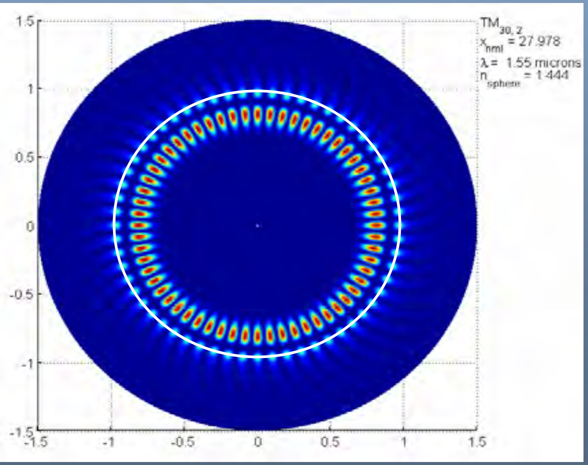
l – described my spherical harmonics, *l* = 0,1,2, …

m –described by sinusoidal variation, *m* = -*l*, … 0, …, *l*

View from sphere pole

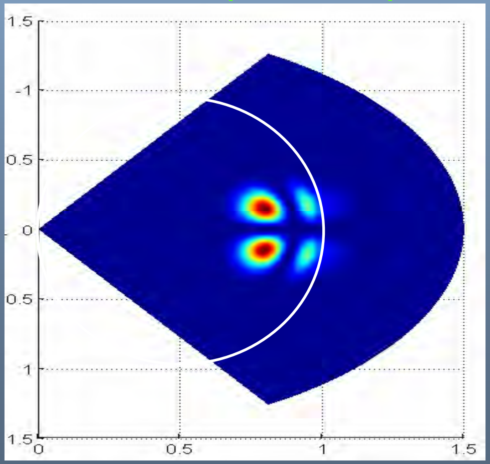


n = 1, *l* = 30



n = 2, *l* = 30

View from sphere equator



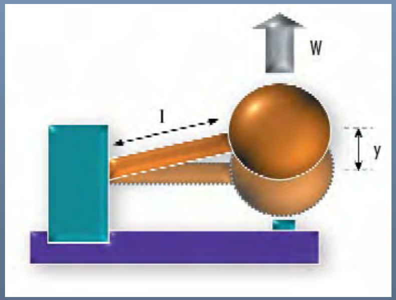
n = 2, *l*-|*m*| = 2

Applications

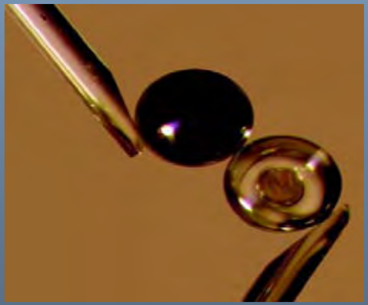
Active microspheres to realise miniature laser sources: erbium is gain material

Long photon storage times coupled with small mode volumes → very high intensities e.g. 1 mW coupled into cavity with Q ~ 10^8 and mode volume V ~ 1000 μm^3 yields circulating intensity of ~ 1 GW/cm^2

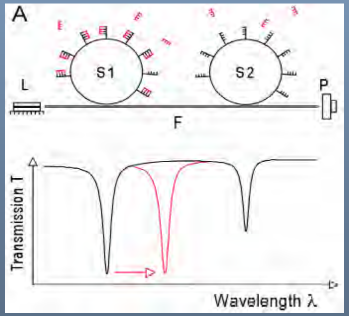
Of interest for fundamental studies e.g. cavity quantum electrodynamics and quantum information processing and applied research e.g. optical communications and trace species detection



Acceleration sensor, gas detection, temperature sensor



Optical and photonic filters, electro-optic modulators and photonic storage



Bio sensor – DNA detection and identification

Microsphere fabrication

Microspherical lasers fabricated from two different erbium doped glasses:

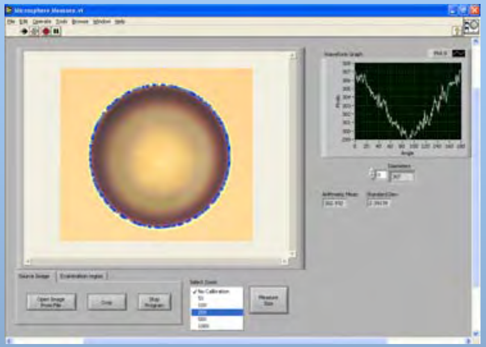
- ZBLALiP – novel heavy metal fluoride glass – 0.1% Er
- Schott IOG-2 – phosphate glass – 2% Er and 3% Yb

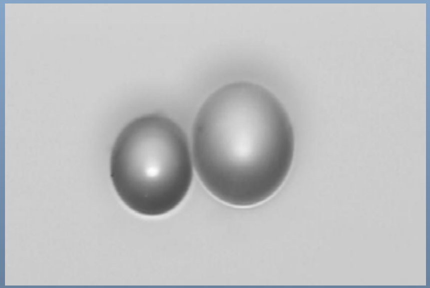
Bulk glass sample ground to powder

Powder dropped through microwave plasma torch

Surface tension forces yields sphere sizes in the 10-200 μm diameter range and ellipticity ~ 10^{-3}

Select defect free microspheres





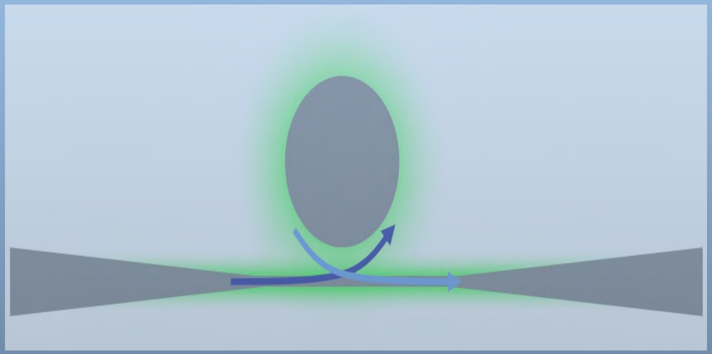
Software used to monitor sphere quality

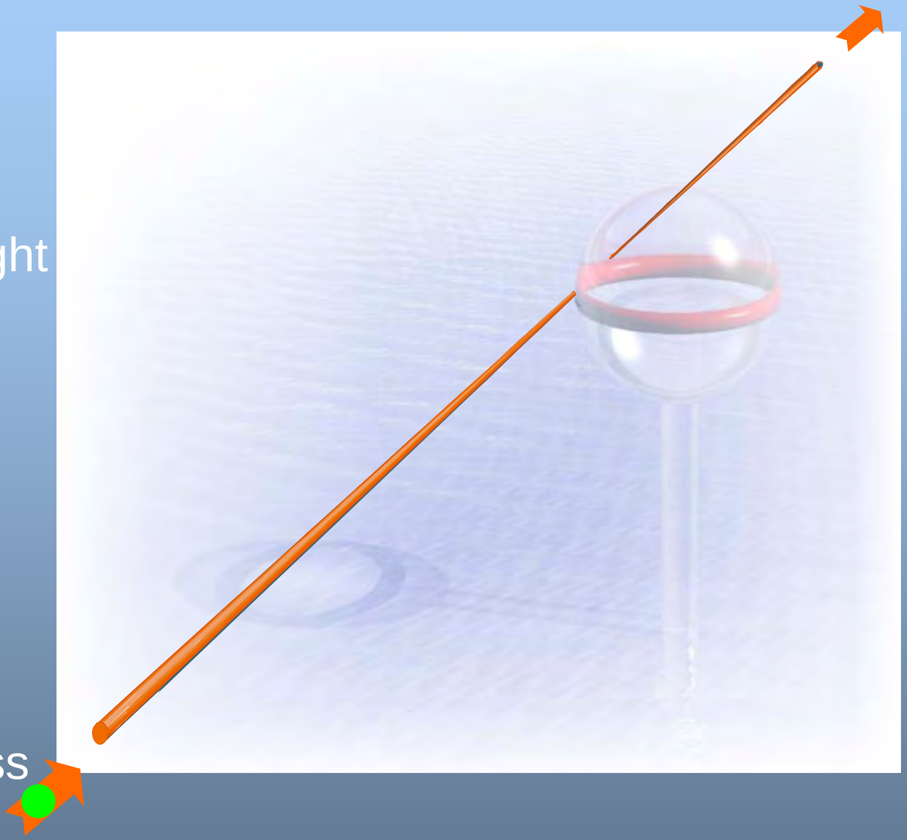
Microsphere-taper coupling

Realisation of useful device requires efficient in/out coupling of light

Achieved via overlap of evanescent fields

Evanescent field occur at surfaces where light undergoes TIR



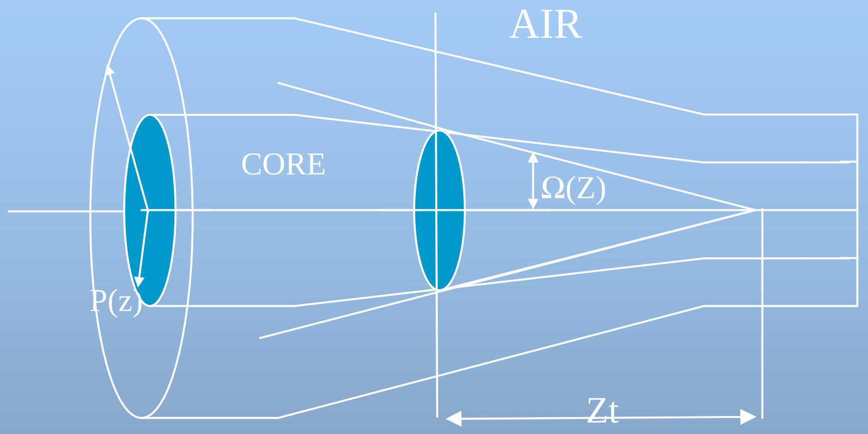


Even under TIR some light can tunnel across boundary

Light decays exponentially with distance from surface

Evanescent field couplers: prism, polished fibre blocks and tips, tapered optical fibre

Adiabatic length-scale criterion



local taper angle $\Omega(z) = \tan^{-1} |d\rho/dz|$

$\Omega(z) << 1$ *so* $Zt \sim \rho / \Omega$

Local coupling length

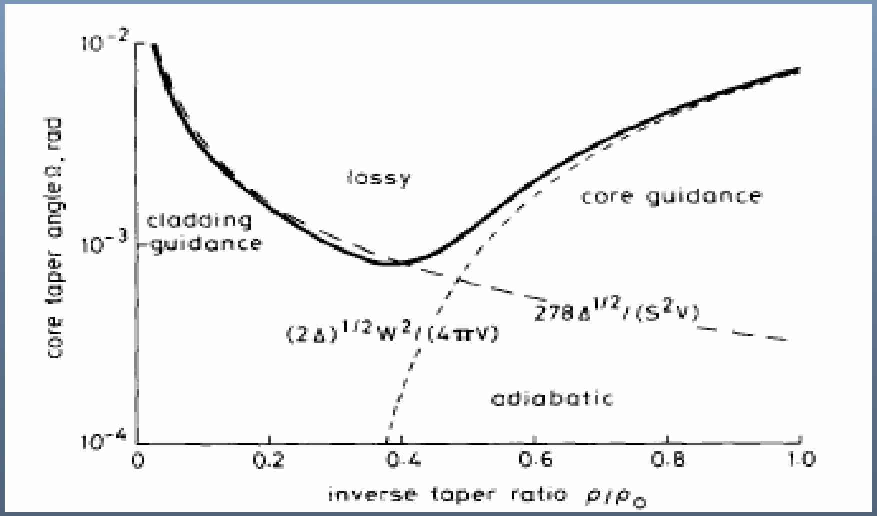
$Z_b = 2\pi / \beta 1 - \beta 2$

If $Z_t >> Z_b$ *negligible coupling will occur*

If $Z_t << Z_b$ *coupling will occur*

$Z_t = Z_b$ *is delineation*

$\Omega = \rho (\beta 1 - \beta 2) / 2\pi$



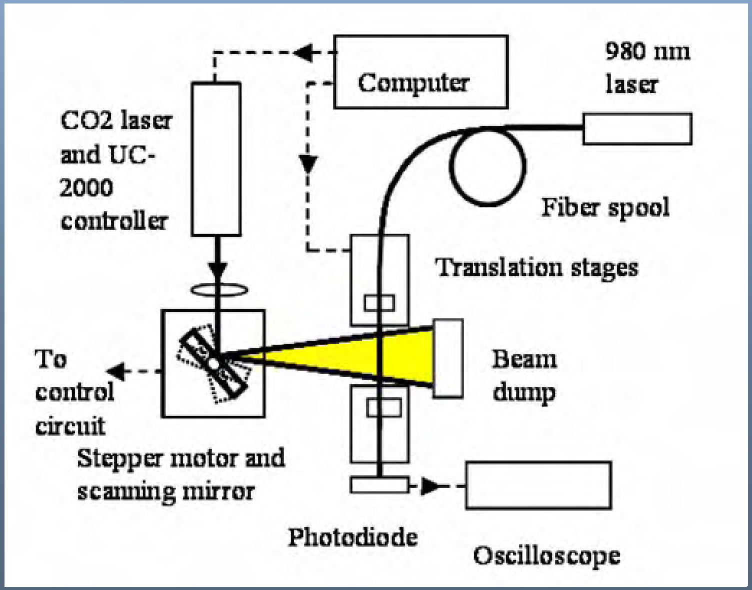
J.D. Love, Optical Sciences Centre, Canberra, Australia

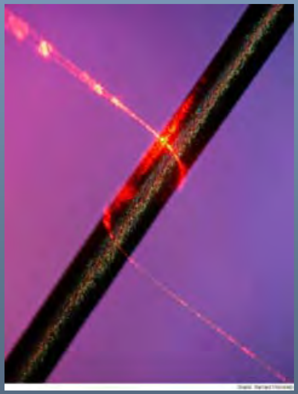
Fibre taper fabrication

- CO_2 laser: scan beam along fibre: 3 µm T = 90%

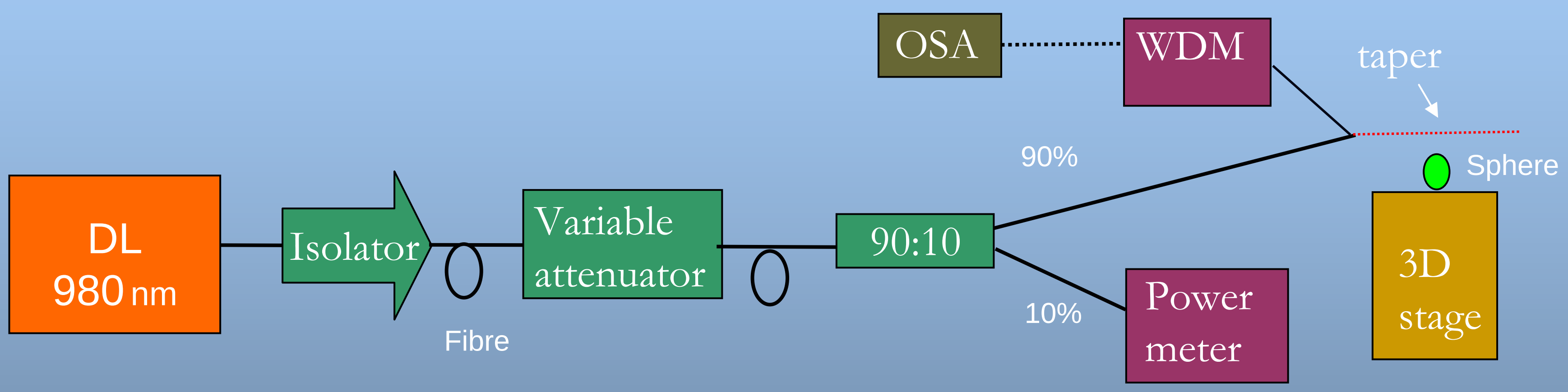
  Rev. Sci. Instrum. **77**, 083105 2006
- Micro furnace: sapphire tubes: 1 µm T = 50%
- Butane torch: static flame and flame brush: 1 µm T = 60%
- Electric heater: disilicate element: 1 µm 75% - 90%

  Length of fibre depends on size of hot-zone





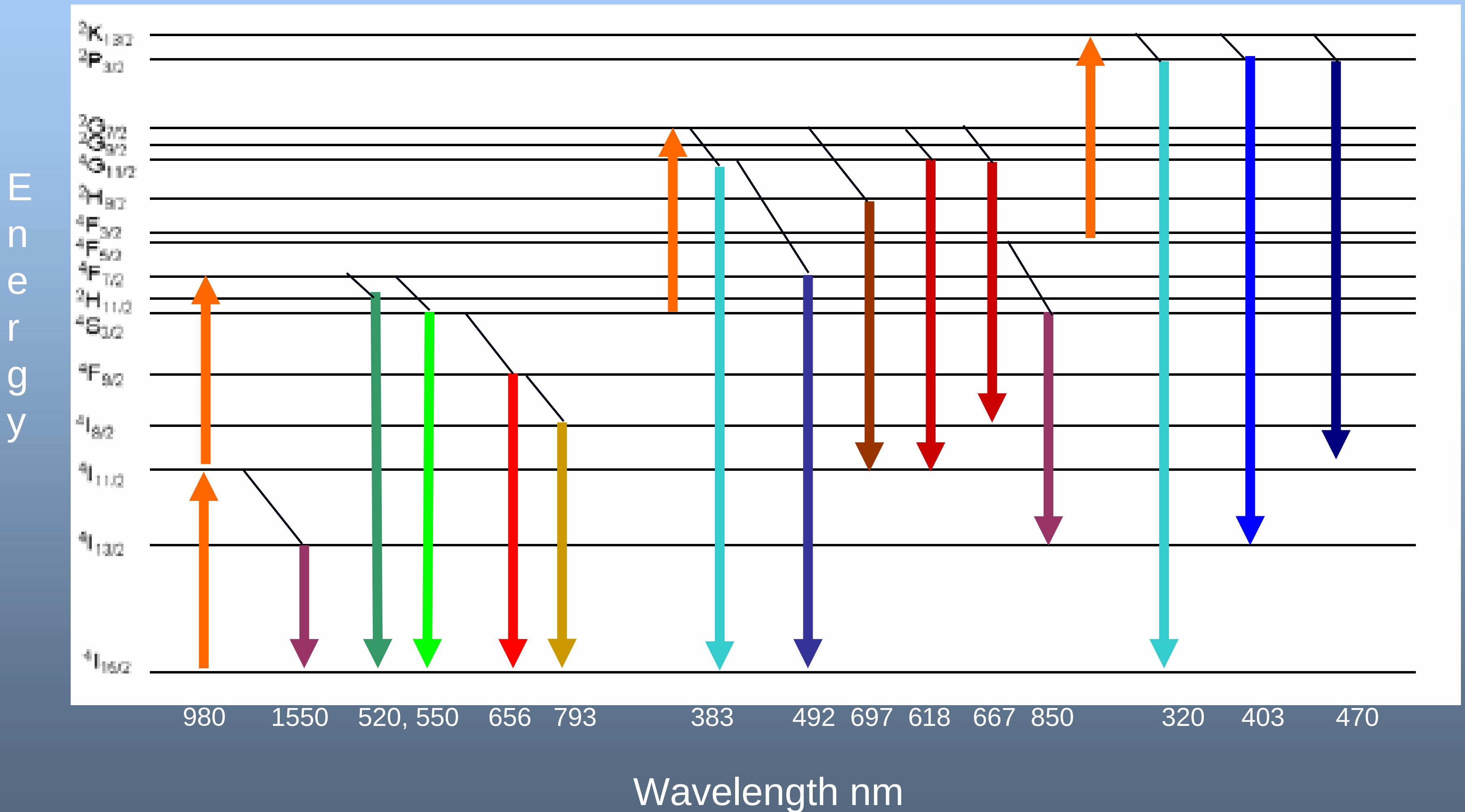
Experimental setup



Current multimode pump source linewidth: ~ 17 GHz. The same taper is used to probe for 1.55 μm radiation by evanescent out-coupling, through a WDM and into an optical spectrum analyser.

WGM movie

Erbium



${}^2K_{13/2}$
${}^2P_{3/2}$
${}^2G_{7/2}$
${}^2G_{9/2}$
${}^4G_{11/2}$
${}^2H_{9/2}$
${}^4F_{3/2}$
${}^4F_{5/2}$
${}^4F_{7/2}$
${}^2H_{11/2}$
${}^4S_{3/2}$
${}^4F_{9/2}$
${}^4I_{9/2}$
${}^4I_{11/2}$
${}^4I_{13/2}$
${}^4I_{15/2}$
Energy
980
1550
520, 550
656
793
383
492
697
618
667
850
320
403
470
Wavelength nm

ZBLALiP

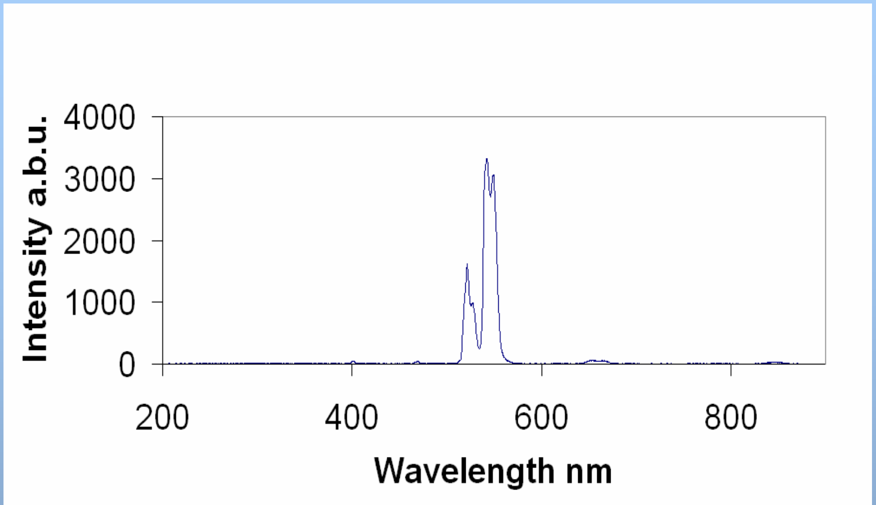
13 separate upconversion signals

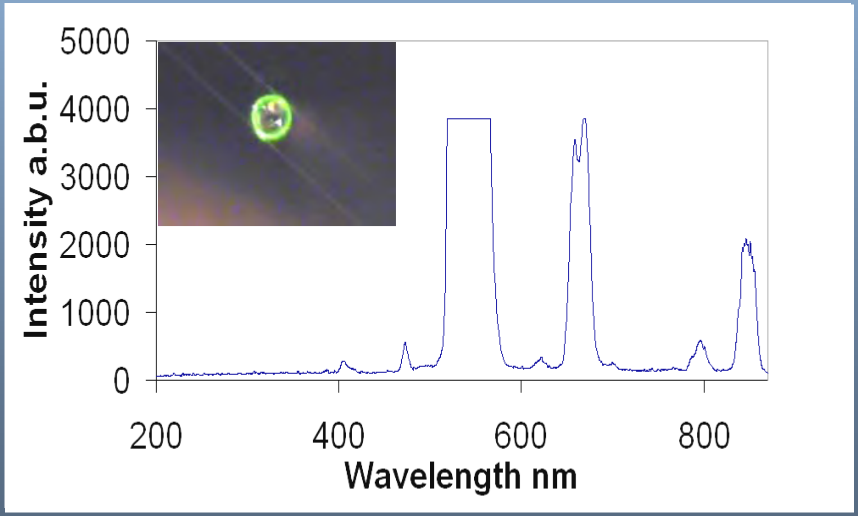
320 nm – 850 nm.

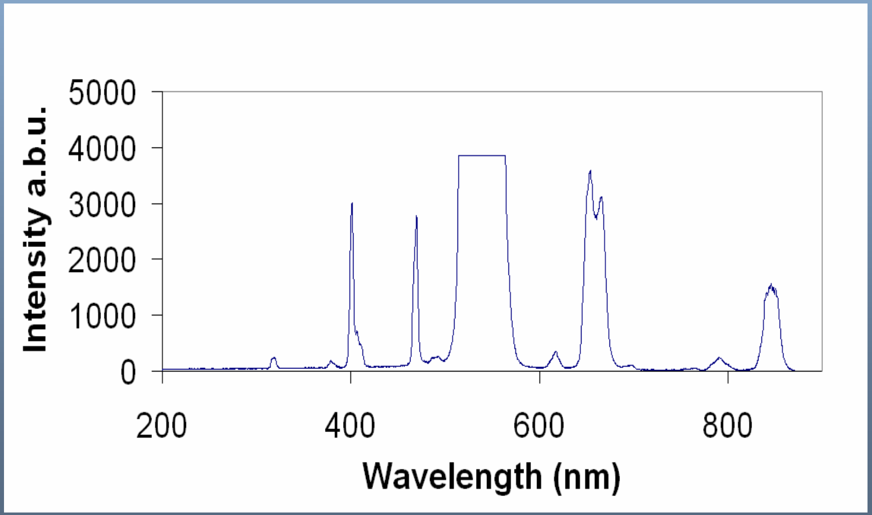
IR lasing at 1550 nm.

Lifetime of $^4F_{3,5/2}$ greater than other fluoride glasses.

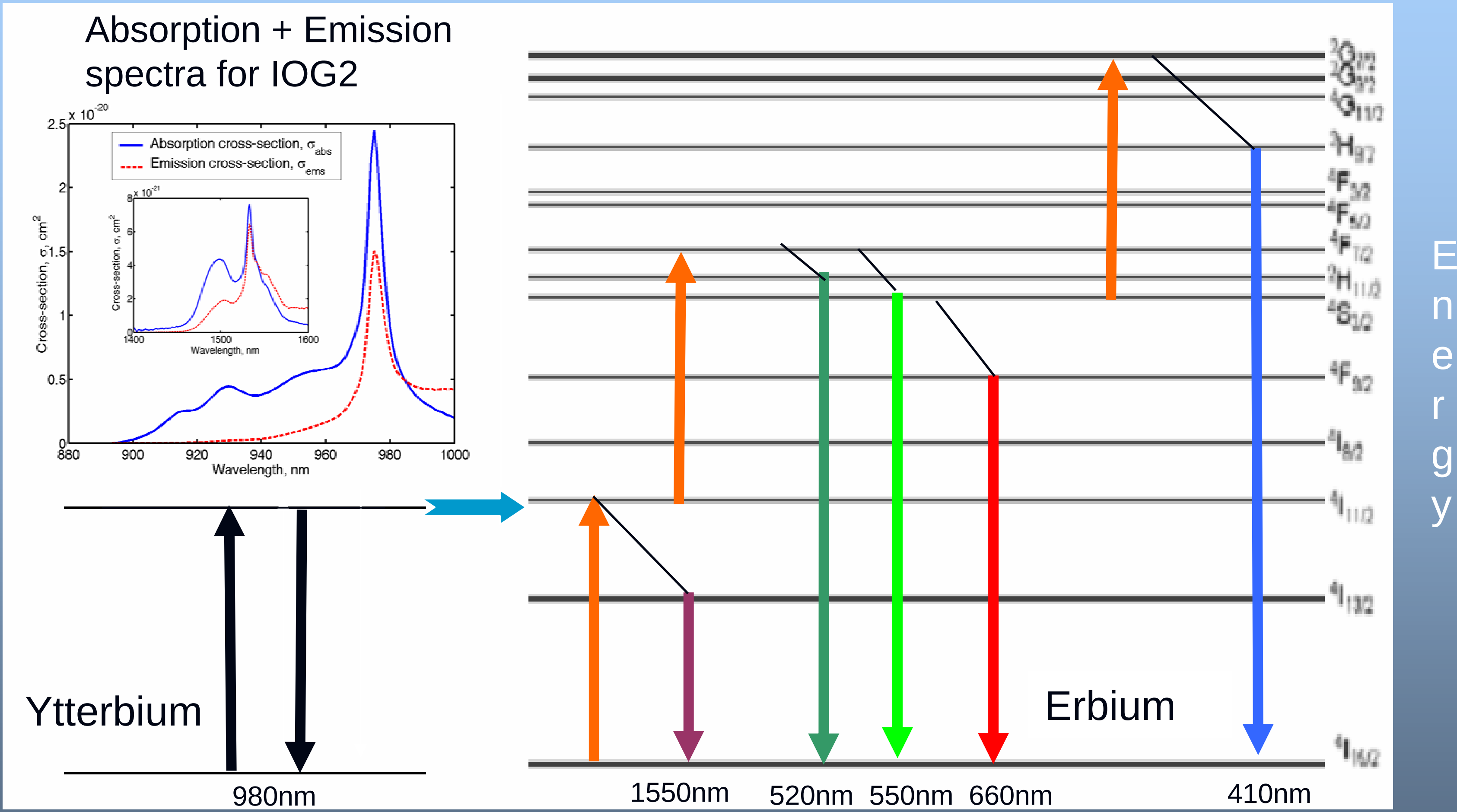
Intensity ratios agree with calculated branching ratios.







IOG2


Absorption + Emission spectra for IOG2
x 10^-20
Absorption cross-section, σ_abs
Emission cross-section, σ_ems
Cross-section, σ, cm^2
Wavelength, nm
880
900
920
940
960
980
1000
Ytterbium
980nm
Erbium
1550nm
520nm
550nm
660nm
410nm
Energy

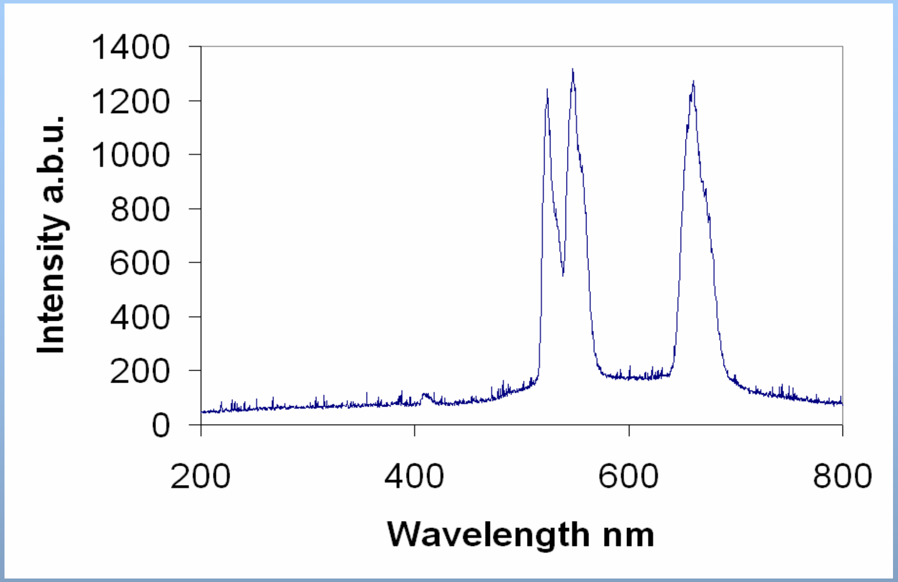
IOG2 Emission spectra

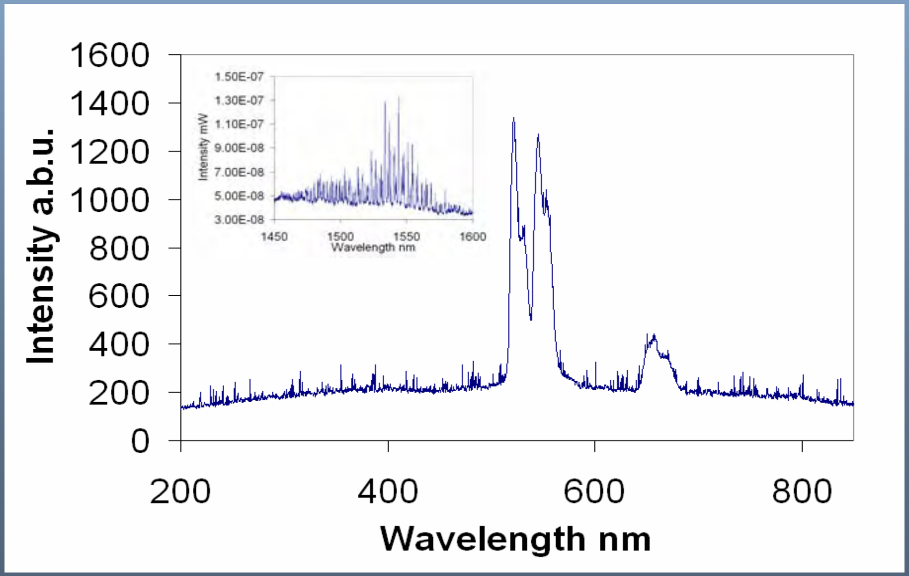
3 distinct spectra obtained.

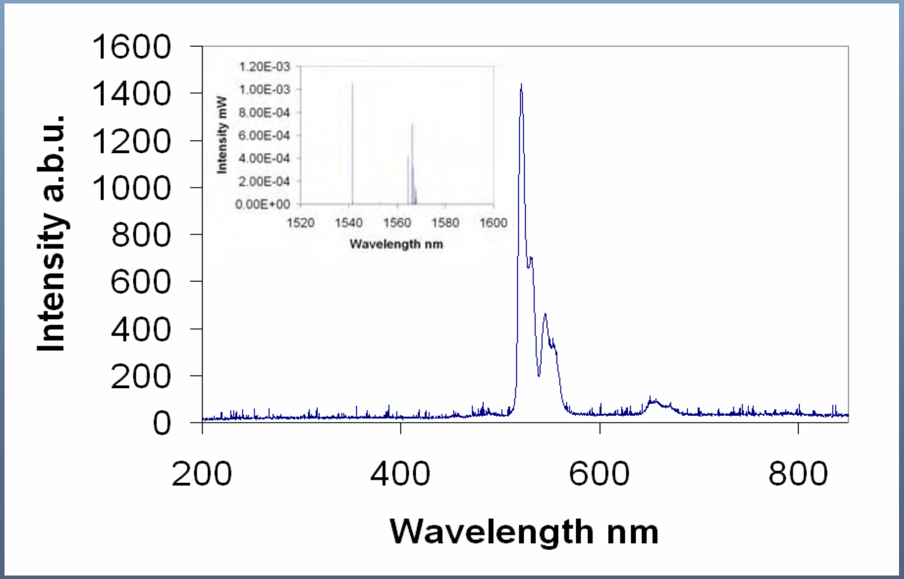
660 nm emission in competition with 1.5 µm emission.

Only ever see RGB emission with spheres < 40 µm diameter.

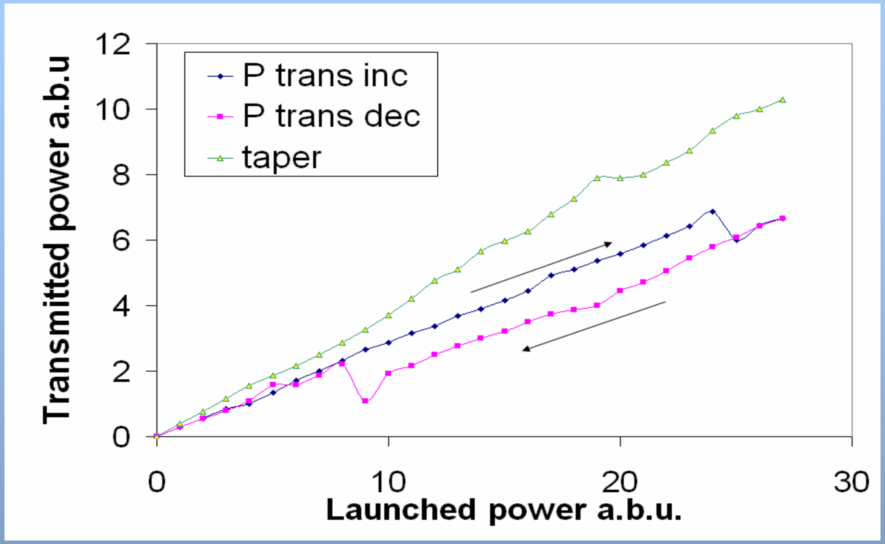
Increased emission at 520 nm due to thermalisation.

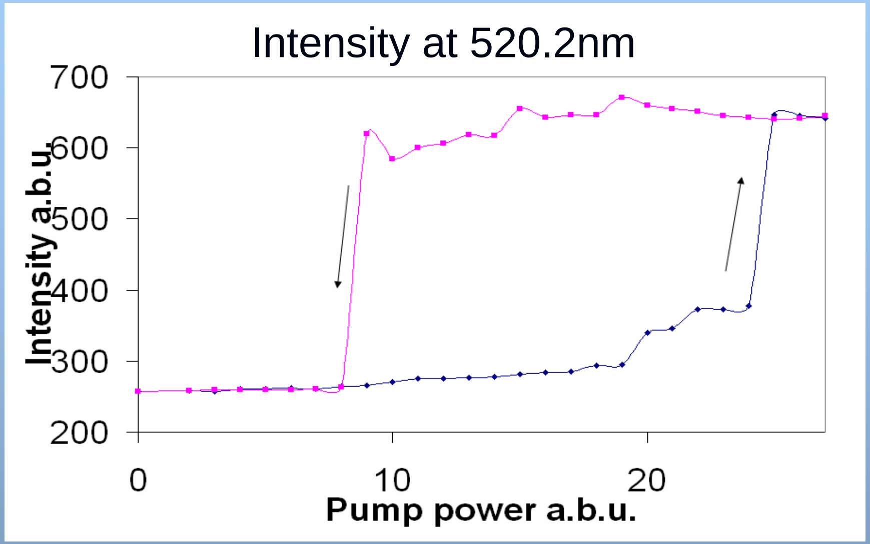


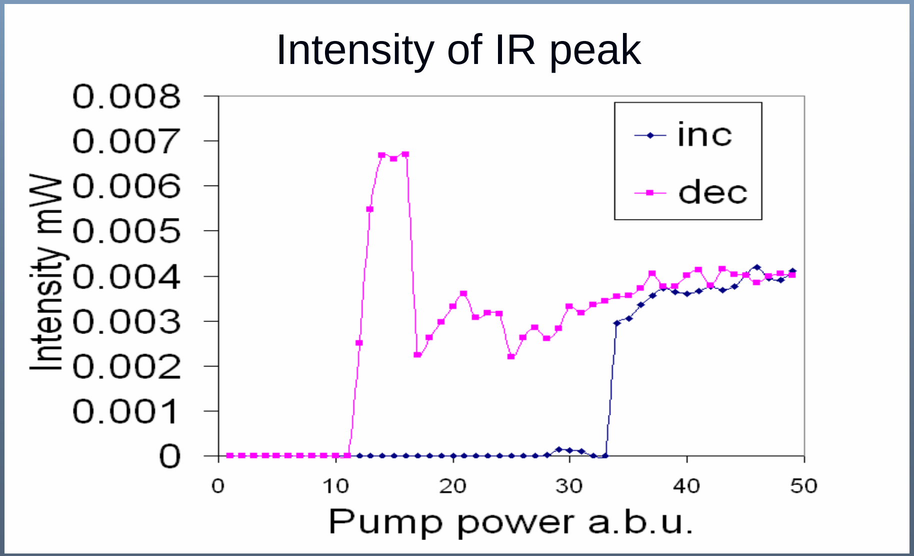




Optical bistability







Optical bistability

Possible mechanisms?

- Temperature dependent absorption cross section of Yb ion

Temperature increase due to pump.

- Dispersive/ absorptive bistability

Non linear change in refractive index due to increase in temperature.

- Non linear energy transfer

Temperature dependent energy transfer between Yb-Er or Yb-Yb.

- Photon avalanche

Sudden increase in ESA absorption due to intermediate state saturation.

Future work

Bistability - characterisation, temperature dependence

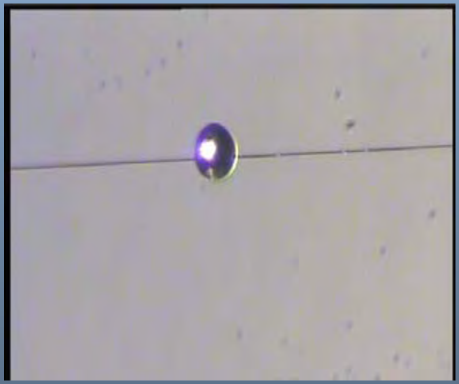
Photonic molecule - effect on lasing and bistability

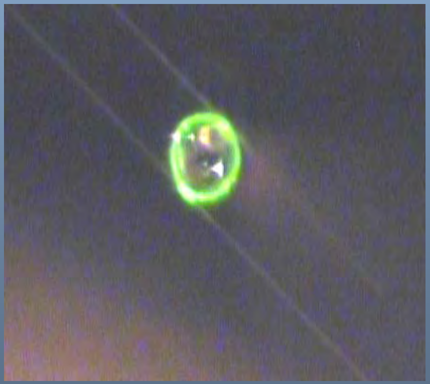
Integrated devices - microsphere fused to taper

Taper / MOT experiment

Photonic molecule

Integrated devices





Conclusion

Microsphere useful tools for studying light-matter interactions.

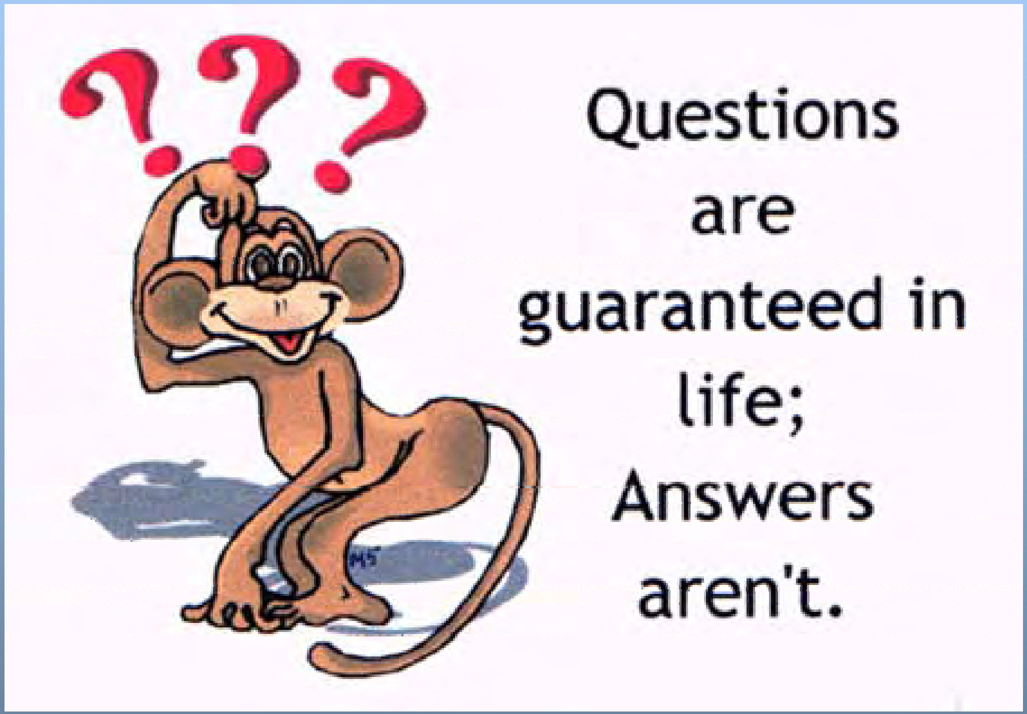
Enhanced probability of 3 and 4 photon ESA.

ZBLALiP broad emission spectra for sensing applications.

IOG2 Optical bistability over multiple wavelengths.

IOG2 Good candidate for optical switch.

THANKS FOR YOUR ATTENTION



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