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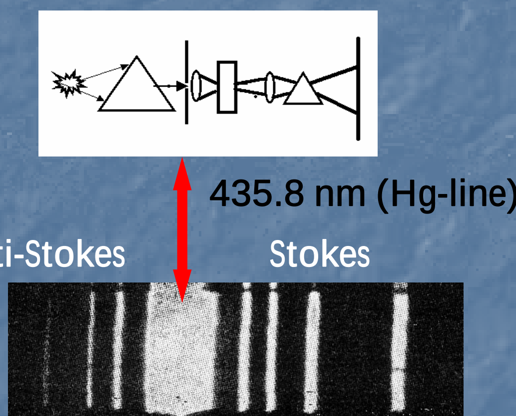
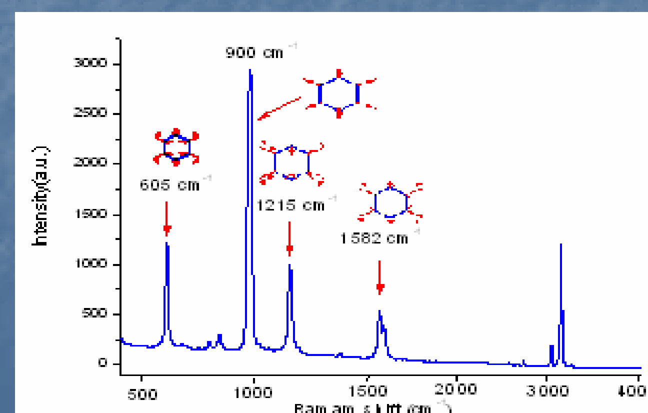


Resolution ca. 10 cm−1
Sample Volume: ca. 1 liter
Exposure time: ca. 40 hours



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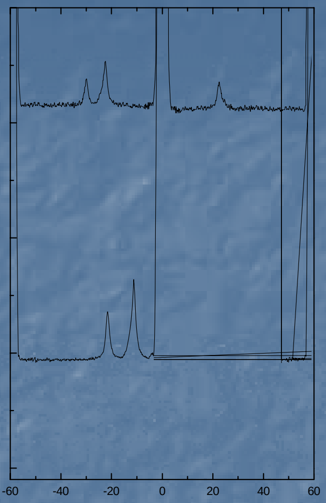
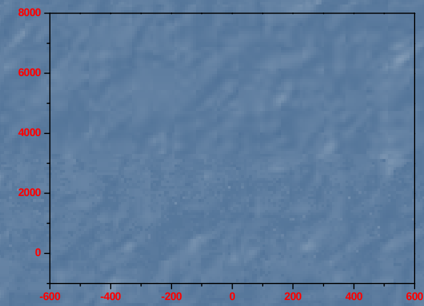
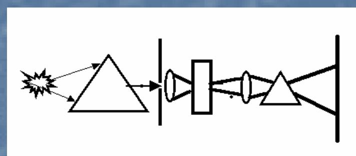
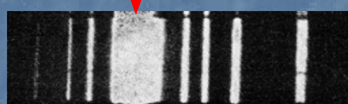






435.8 nm (Hg-line)

anti-Stokes Stokes



Resolution ca. 10 cm-1
Sample Volume: ca. 1 liter
Exposure time: ca. 40 hours

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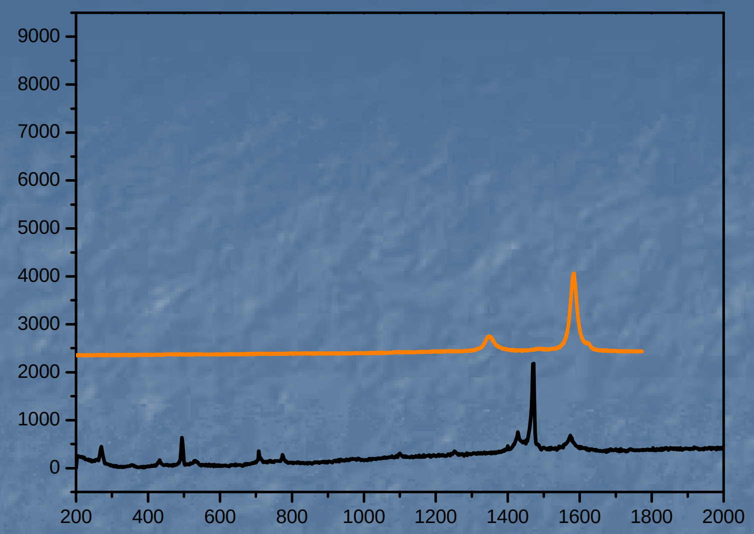

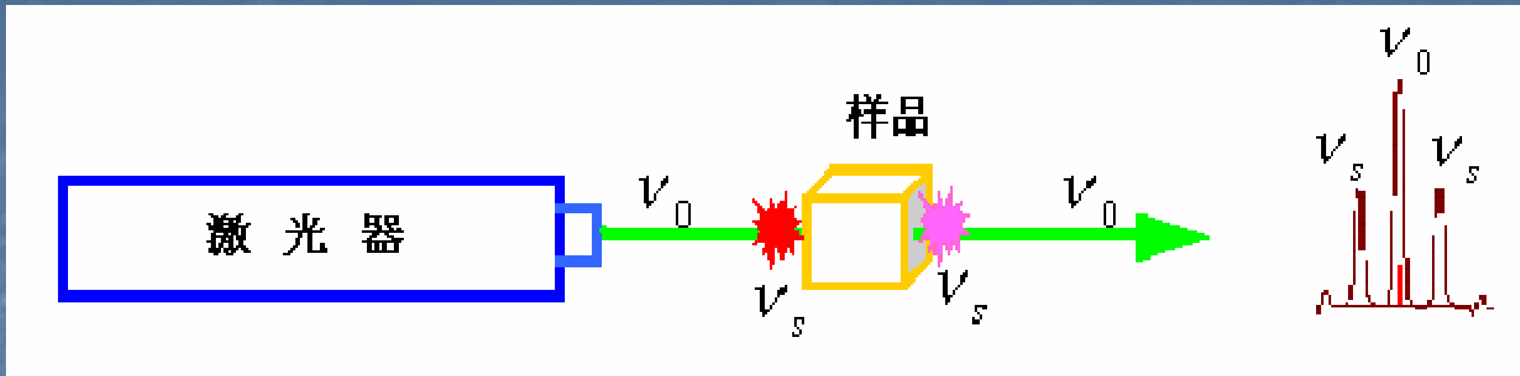
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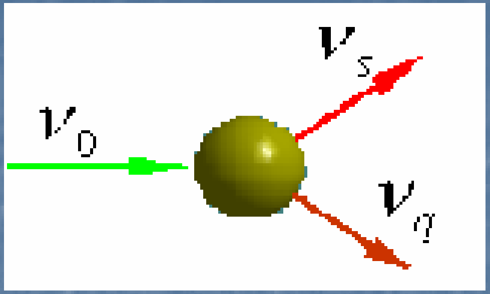
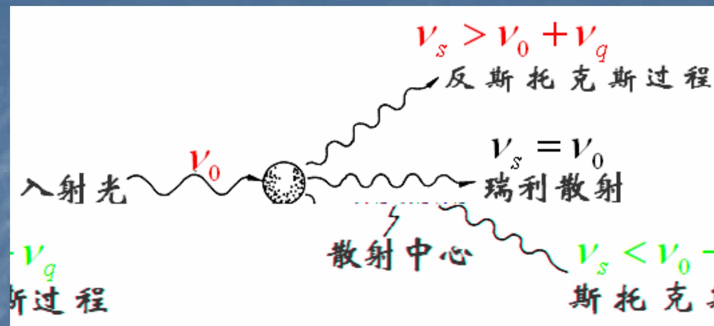


$h\nu_0$ hk_0



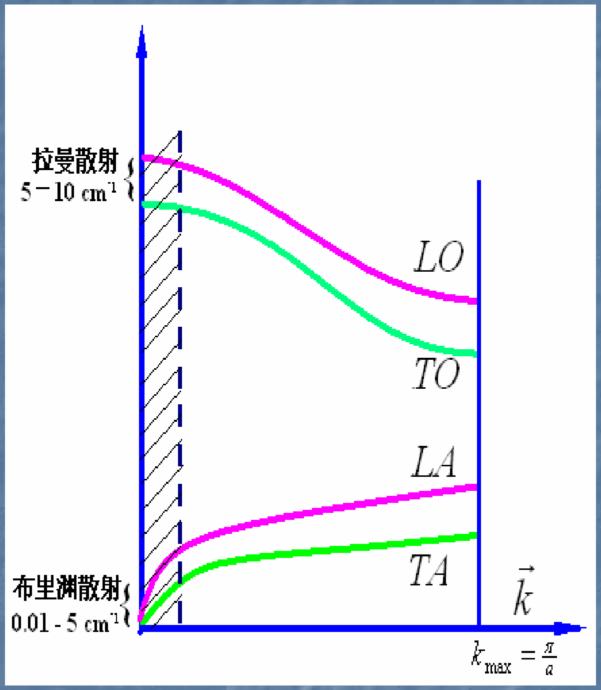
Rayleigh s 0

$s < 0$

Stokes

$s > 0$

Stokes



- $10－5000\ cm^{-1}$
- $0.01－2cm^{-1}$

$10^5\ cm^{-1}$, $(10^8\ cm^{-1})$

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(3.1)

$$E = E_0 \cos \ _{0}t$$

E_0 №

$$P =$$ (3-2)

№ №

$$q = q_0 \cos \ _{q}t$$ (3-3)

q_0 ≠ g ≠

3-4 3-2

$P =$

$=$

$=$ 3-5

$= \frac{}{2}(\ldots(\ _0 + \ _q)t + \cos 2\ (\ _0 - \ _q)t]$

(3-5)

3

2 3

($_0$ - $_q$) 3-5

g

(3-5)

$$\vec{k}_s = \vec{k}_0 - \vec{k}_q$$

$$\Delta\vec{k} = \vec{k}_0 - \vec{k}_q$$

3-6

Stokes

(3-5)

$$\vec{k}_s = \vec{k}_0 + \vec{k}_q$$

$$\Delta\vec{k} = \vec{k}_0 - \vec{k}_q$$

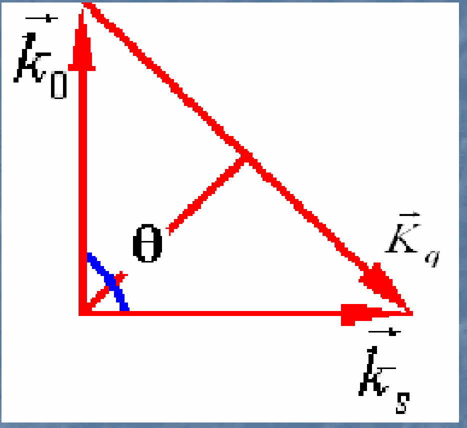
3-7

Stokes

3-6 3-7 Stokes

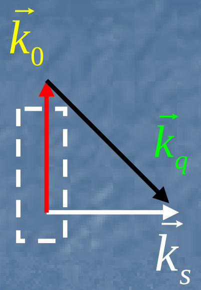
3.2

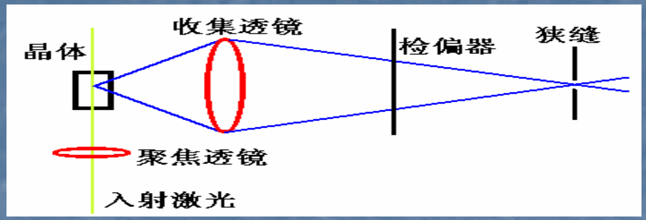
$|\vec{K}_s| \approx |\vec{K}_0|$



$$|k_q| = 2\,|k_0|\,n\,\sin\frac{\;}{2} \qquad 3\text{-}8$$

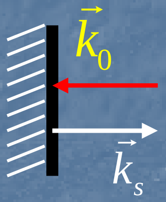
: $k_0(e_i^s e_j^0)k_s$

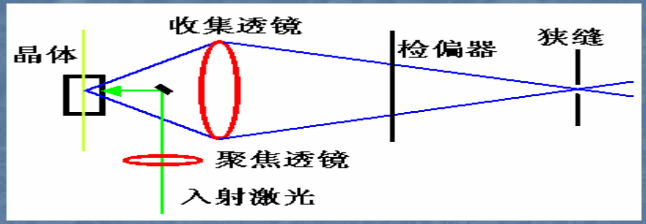




90 °

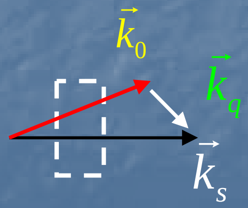
$$x(zz)y; x(zx)y; x(xx)y; x(yx)y$$

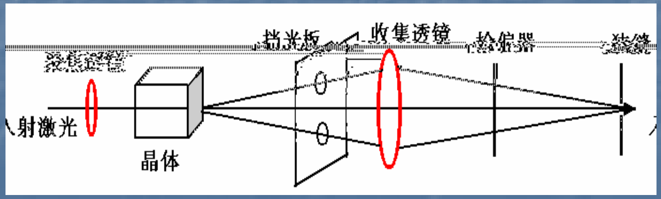




180 °

$$x(zz)\bar{x}; x(zy)\bar{x}; x(yy)\bar{x}$$





0 °

$$y(zz)y; y(zx)y; y(xx)y$$

3.3

a: 7

$\omega_s < \omega_0$

$$\omega_s = \omega_0 - \omega_q$$

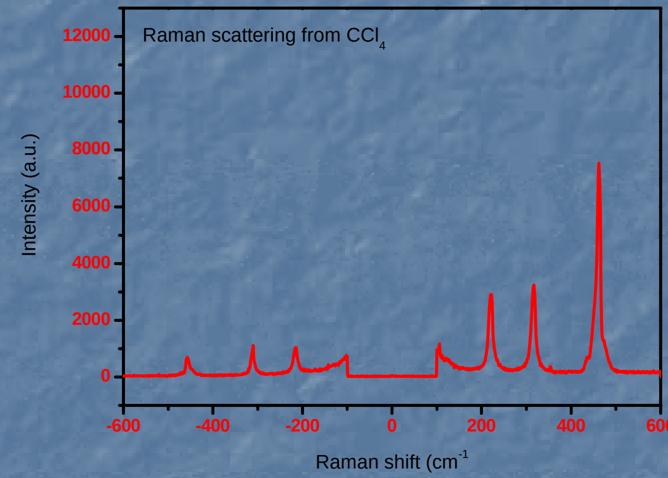
$$\vec{k}_s = \vec{k}_0 - \vec{k}_q$$

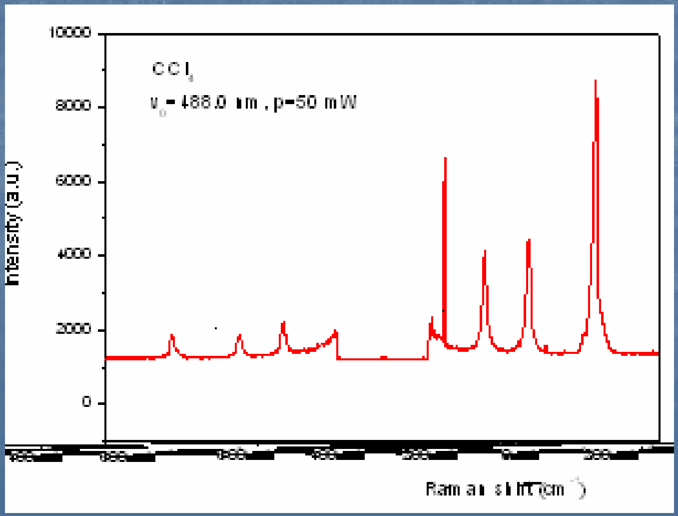
7

$\omega_s > \omega_0$

$$\omega_s = \omega_0 + \omega_q$$

$$\vec{k}_s = \vec{k}_0 + \vec{k}_q$$





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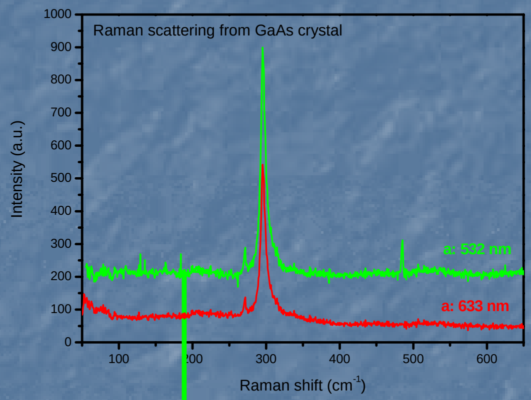

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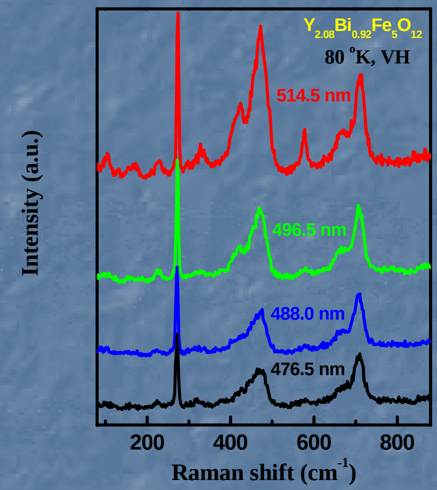

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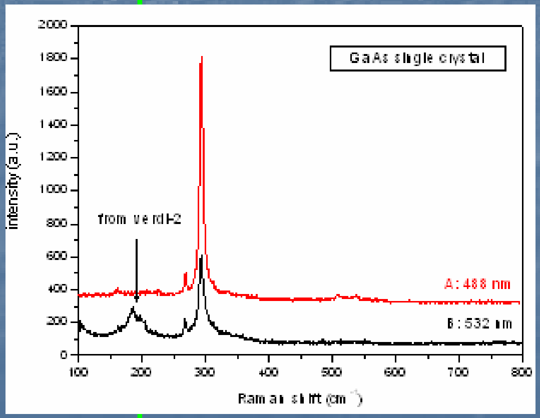
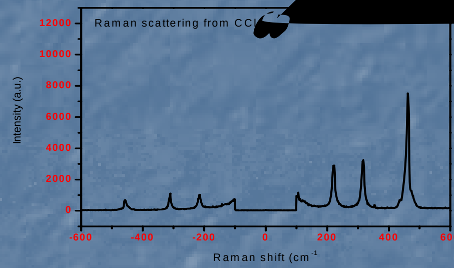


c. Boltzman



Stokes

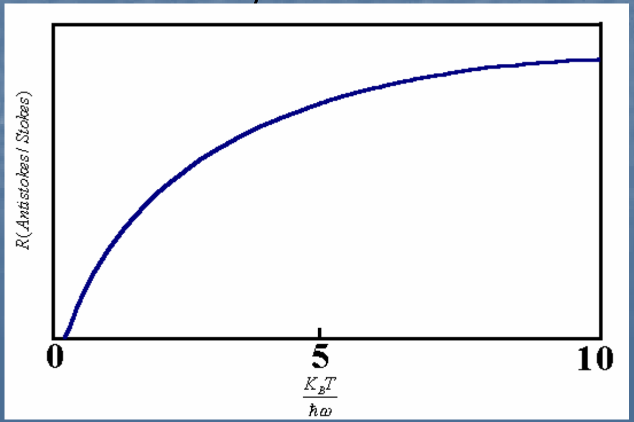
$$R = \frac{d}{d\Omega}\Big|_{A_s} \Big/ \frac{d}{d\Omega}\Big|_{S} = \frac{n(\ )}{n(\ )+1} = \frac{1}{e^{h\ /kT}}$$

$$n(\ ) = \frac{1}{\exp\frac{h}{k_B T} - 1}$$

Stokes

№

R



CCl_4)

100 mW , CCl_4 460 cm^{-1}

Stokes 2063522 counts. 250368 counts

$$R=\frac{d}{d\Omega}\Big|_{A_S}\Big/\frac{d}{d\Omega}\Big|_{S}=\frac{n(\ )}{n(\ )+1}=\frac{1}{e^{h\ /kT}}$$

$$T=-\frac{h}{k_B\ln(I_{AS}/I_s)}$$

$$=-\{(6.63x10^{-34}x4.6x10^{2}x30x10^{9})/[1.38x10^{-23}x(-2.11)]\}$$

$$=914.94/2.91$$

$$=314.4(K)$$

$$h=6.63x10^{-34}JS;k_B=1.38x10^{-23}J/K$$

3.4

$$I(\ ) \propto \int_0^1 \exp\left(-\frac{k^2L^2}{4}\right)\frac{dk^2}{[\ -\ (k)]^2+[\Gamma_0/2]}$$

3-9

k L

L Γ_0

$k \neq 0$

$$(k) = A + B\cos(\ k)$$

3-10

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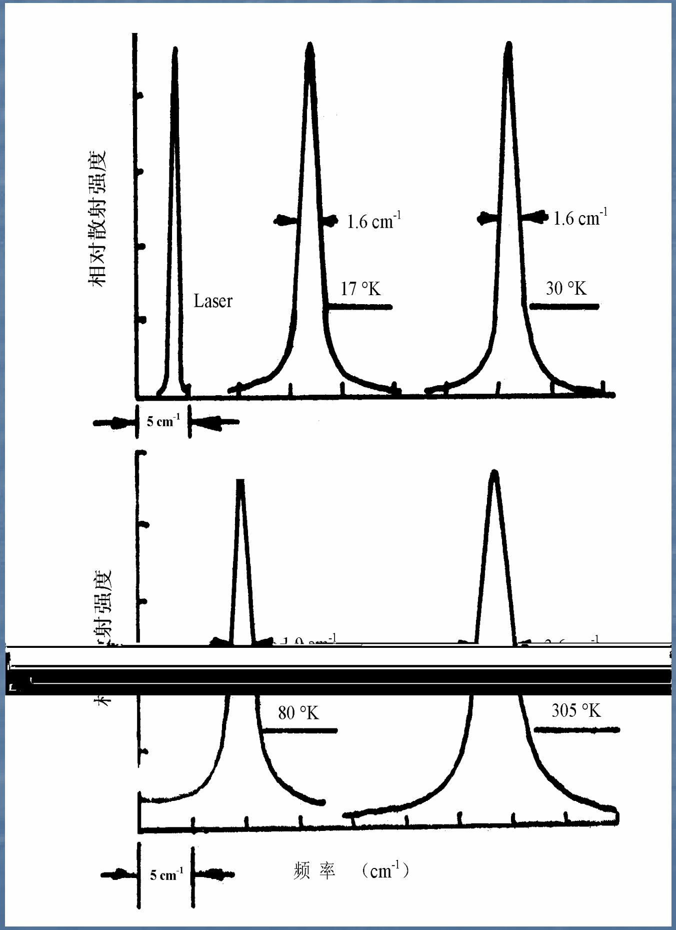

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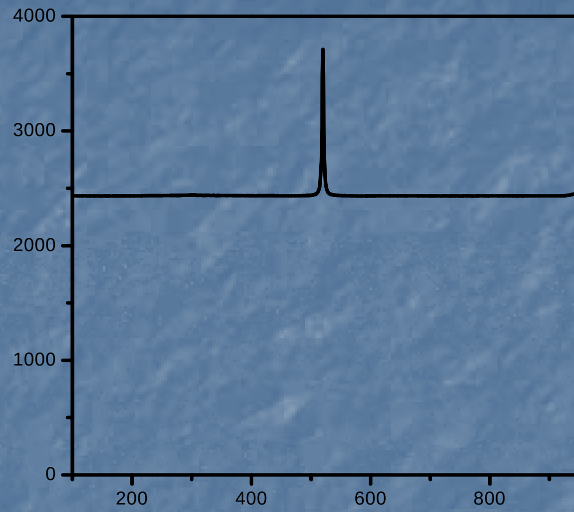

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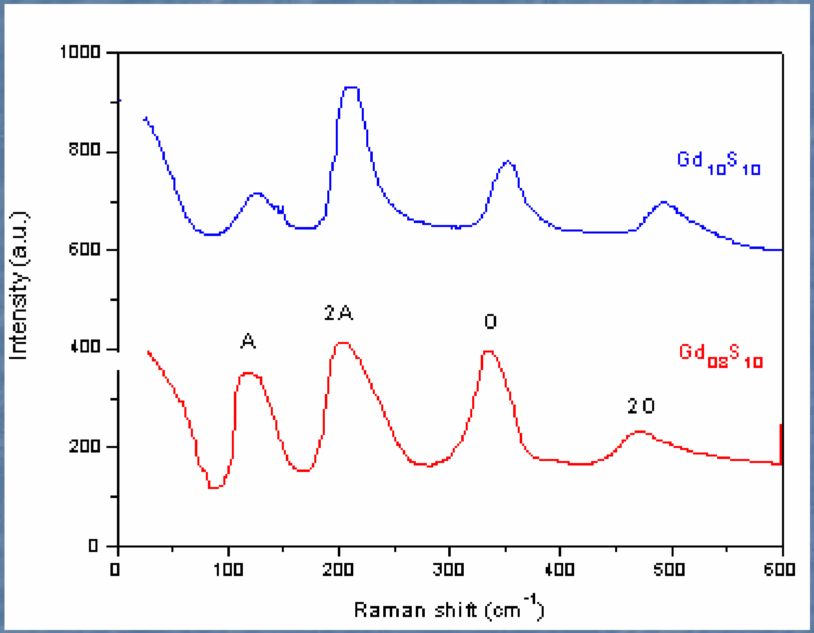
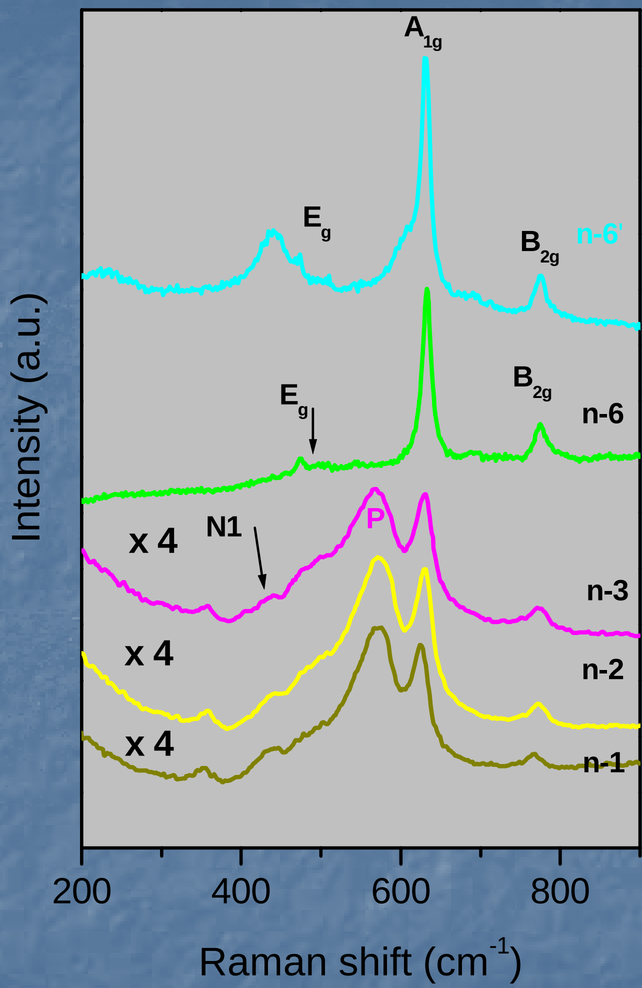
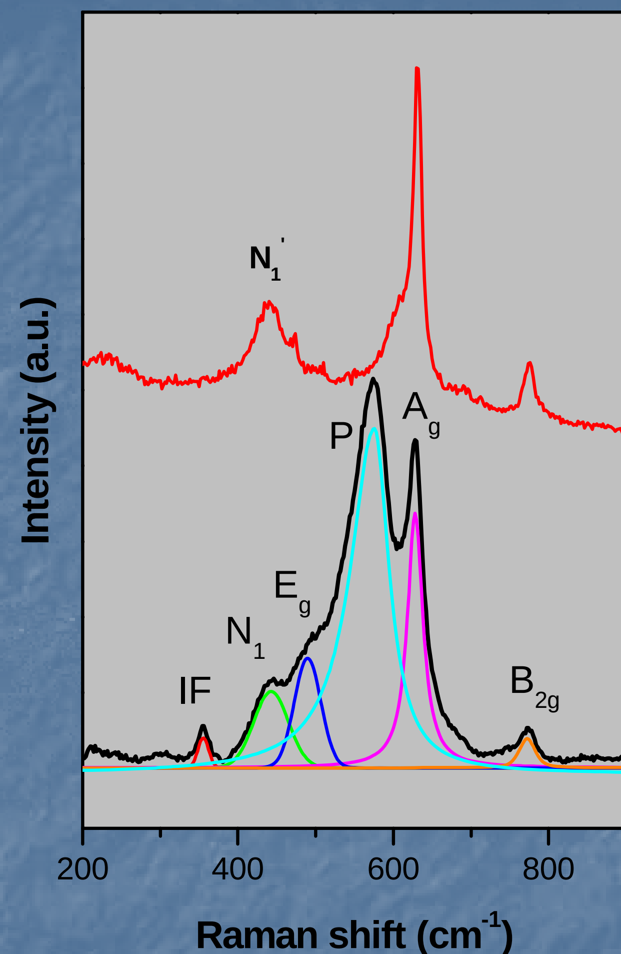


GdS ⅓ ڈ ה

ش SnO$_2$ في ڑ ↑ P ڭ ر °

ש SnO_2 ي ف ≠ ڑ ↑ ، Ni)


A1g
Eg
B2g
n-6'
Eg
B2g
n-6
x 4
N1
P
n-3
x 4
n-2
x 4
n-1
Intensity (a.u.)
200
400
600
800
Raman shift (cm-1)


N1'
P
Ag
Eg
N1
IF
B2g
Intensity (a.u.)
200
400
600
800
Raman shift (cm-1)

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4 NH_4Br

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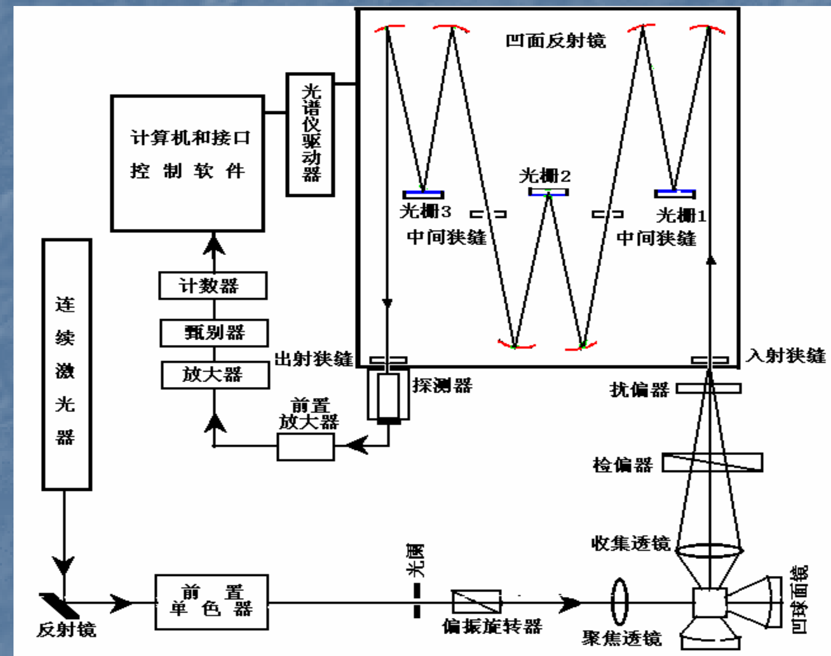

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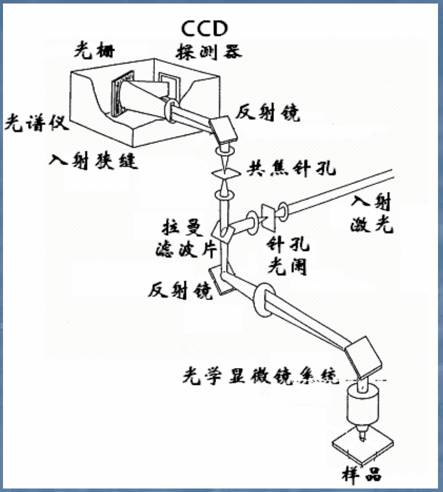
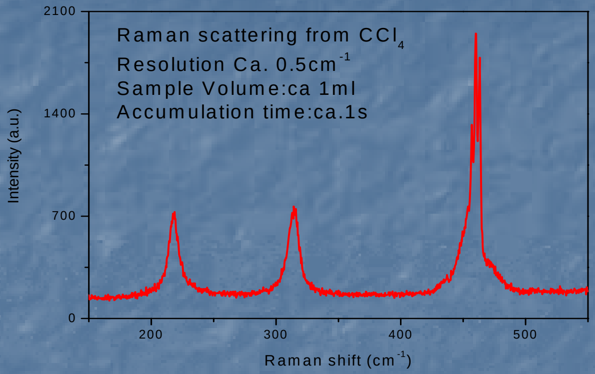
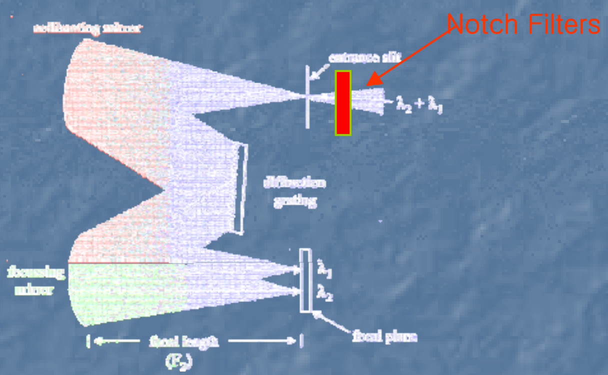
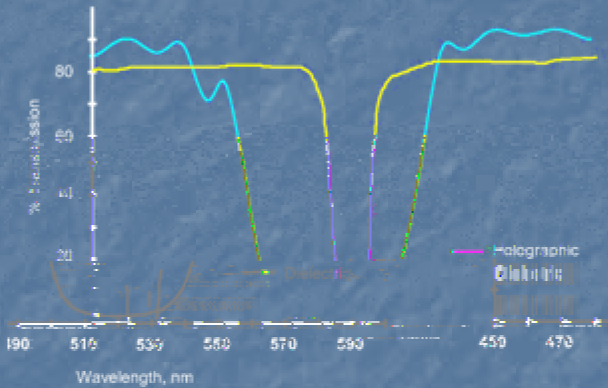
Laser line rejection – Notch Filters

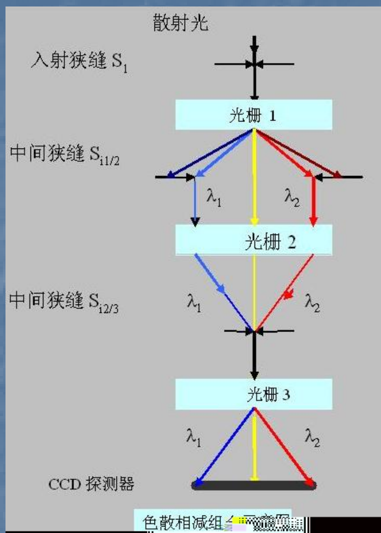


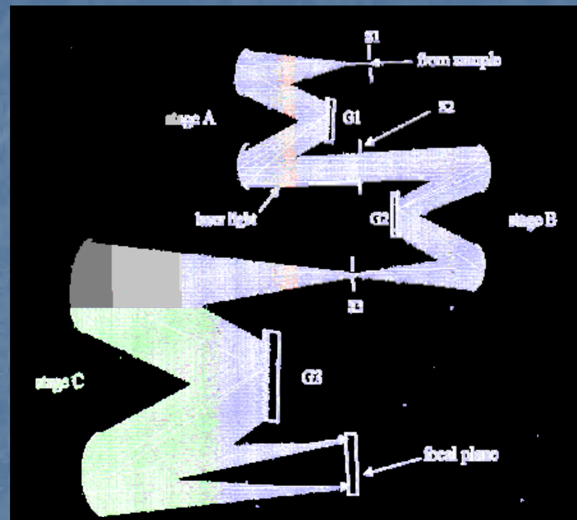






Spectrometer – Triplemonochromator





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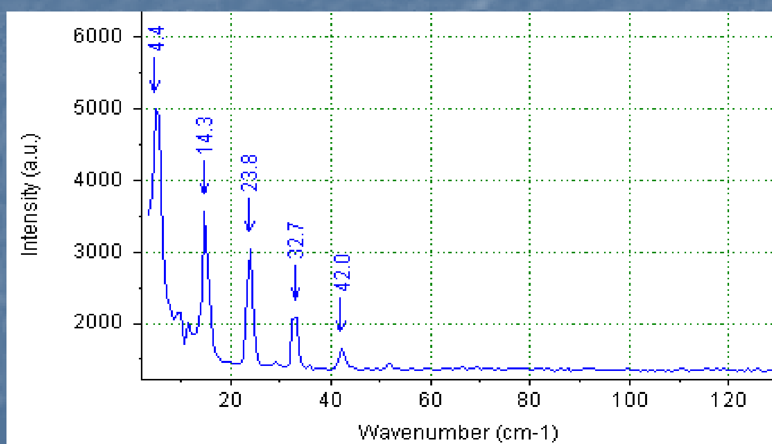
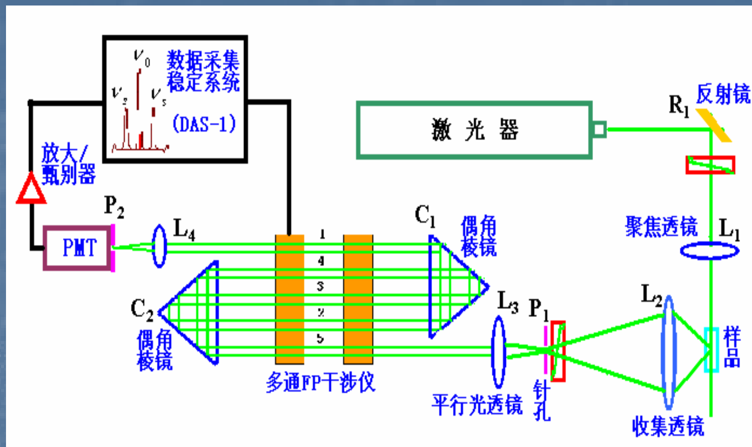
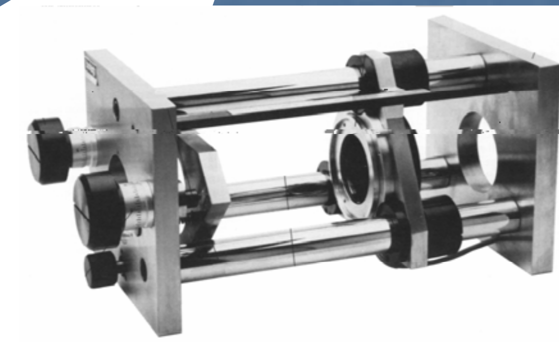
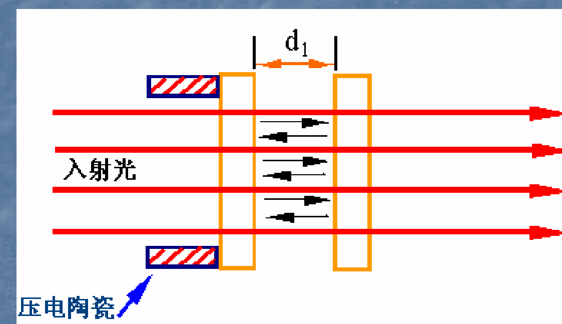


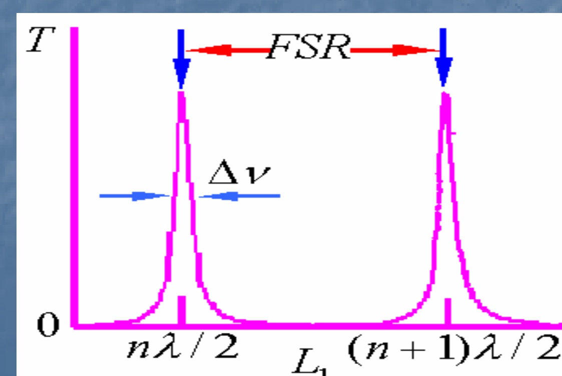
SiGe

Fabry, Perot, FP









m

(FSR)

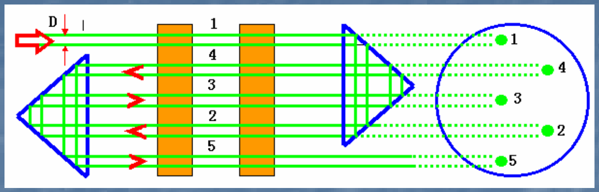
$$FSR = C \quad /2d_1$$

(F,

$$F = FSR / \Delta$$

$$C = I_{max.} / I_{min.} \approx 4F^2 / \quad ^2 \le 10^5$$

Dr. J.R.Sandercoker F-P ╪ ☿ ☿



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$$C_p = C_1^p$$

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$$F_p = (2^{\frac{1}{p}} - 1)^{-\frac{1}{2}} F_1$$

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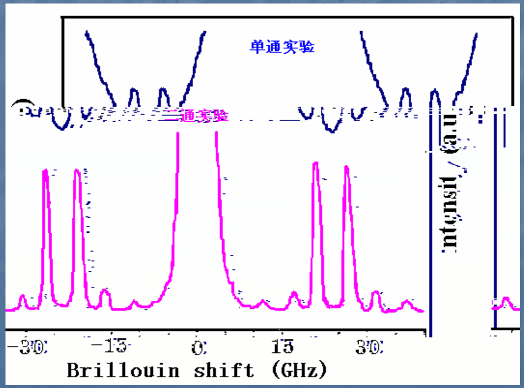
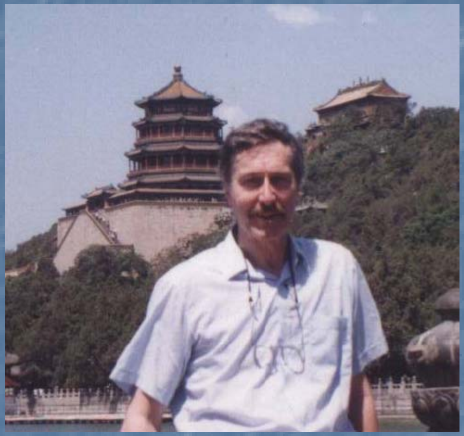
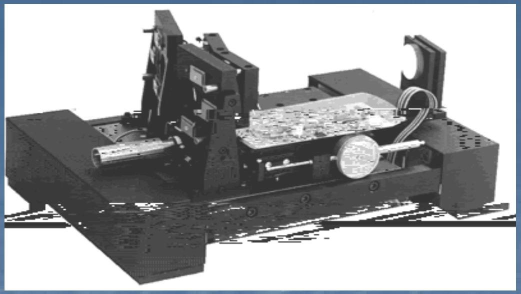
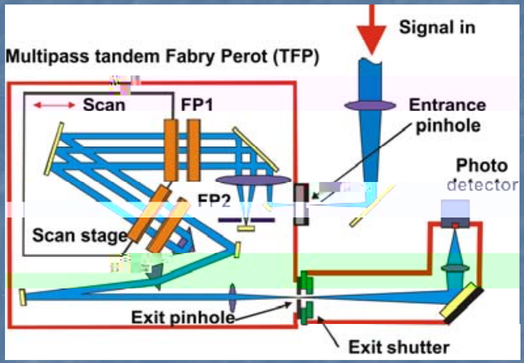


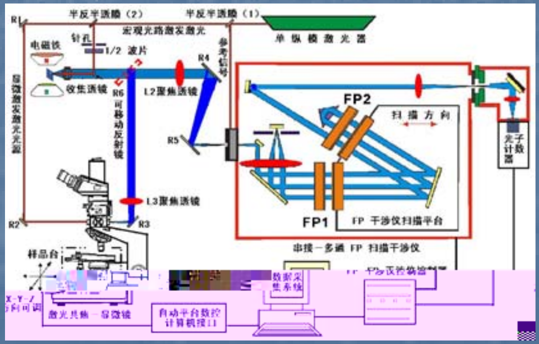




Φ ǁ FP



Φ ǁ FP ڎ



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$d < 30$ nm) ,

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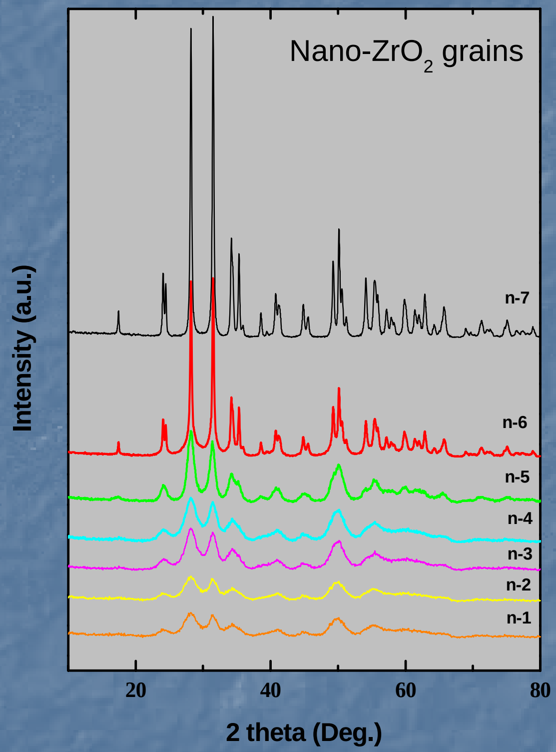

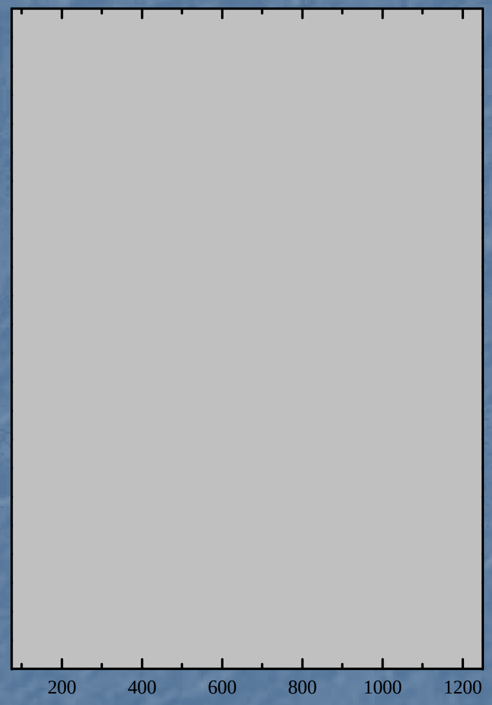

SnO_2

- 3.89 ev)
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- SnO_2

SnO_2

SnO

SnO_2

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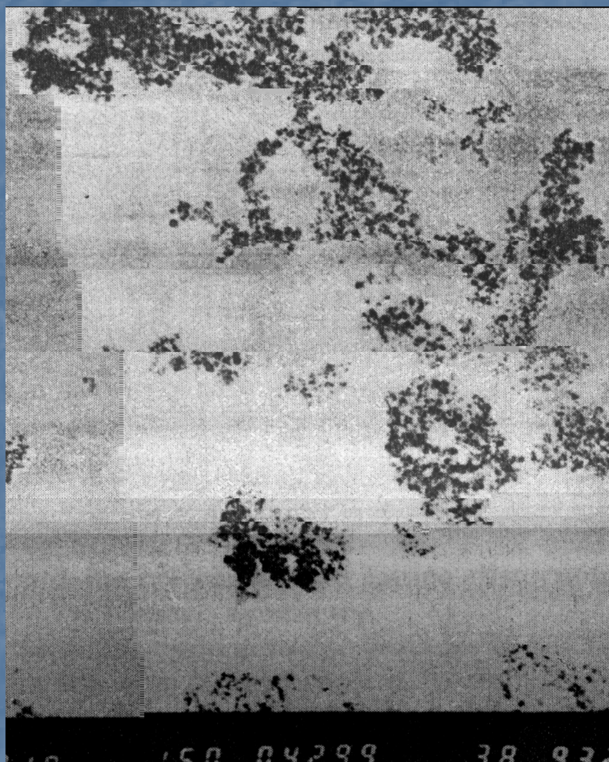

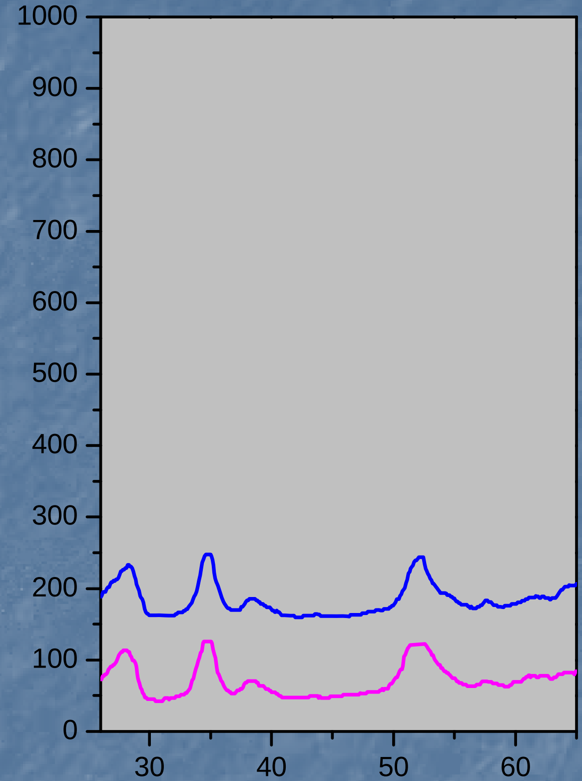

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SnO_2 ف ي ک ɺ ق ں [redacted]

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1. ، ძ . ً [redacted]

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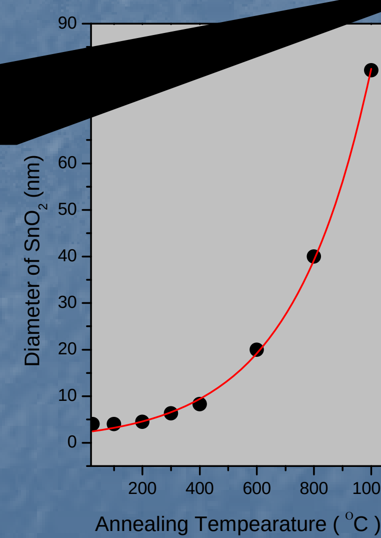
$T_a \le 500$ °C 1̧ [redacted]

ک ɧ [redacted]

$D = K$ [redacted] (β cos θ)

D : ي , K ر , [redacted] , β , g

	n-1	n-2	n-3	n-4	n-5	n-6	n-7	n-8
T_a								



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Yulong Liu et al. Phys. Rev B55, 2666(1997)

SnO_2

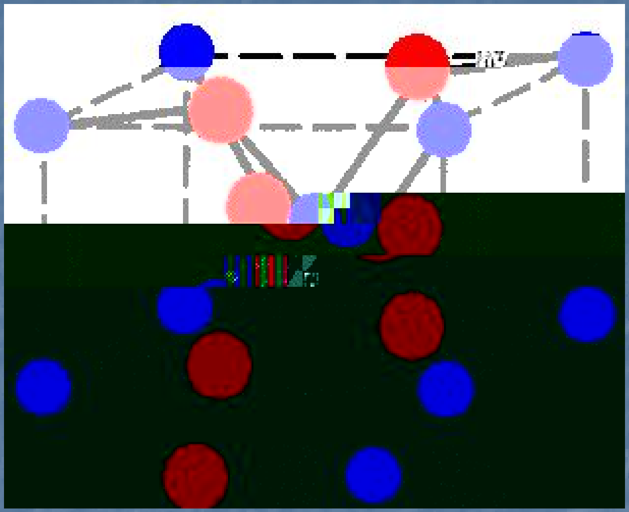


表 二、 点群 D_{4h} 的特征标表

D_{4h}	E	$2C_4$	C_2	$2C'_2$	$2C''_2$	I	$2S_4$	σ_h	$2\sigma_v$	$2\sigma_d$		
A_{1g}	1	1	1	1	1	1	1	1	1	1		$x^2+y^2+z^2$
A_{2g}	1	1	-1	-1	-1	1	1	1	-1	-1	R_z	
B_{1g}	1	-1	1	1	-1	1	1	1	1	-1		$x^2+y^2+z^2$
B_{2g}	1	-1	1	-1	1	1	1	1	-1	1		xy
E_g	2	0	-2	0	0	2	0	-2	0	0	R_x, R_y	xz, yz
A_{1u}	1	1	1	1	1	-1	-1	-1	-1	1		
A_{2u}	1	1	1	-1	-1	-1	-1	-1	1	1	T_z	
B_{1u}	1	-1	1	1	-1	-1	1	-1	-1	1		
B_{2u}	1	-1	1	-1	1	-1	1	-1	1	-1		
E_u	2	0	-2	0	0	-1	0	2	0	0	T_x, T_y	
$\pm1+2\cos\theta$:	3	1	-1	-1	-1	-3	-1	1	1	1		
U_R :	6	0	2	0	0	4	2	0	0	4		
χ_R :	18	0	-2	0	-4	-6	0	6	0	4		

SnO_2 2 Sn 4 O

D_{4h} 18

$$G = A_{1g} + A_{2g} + A_{2u} + B_{1g} + B_{2g} + 2B_u + E_g + 3E_u$$

$$A_{1g} + B_{1g} + B_{2g} + E_g$$

ﮋ SnO$_2$:

$$\frac{d}{d\Omega} = \frac{{}^4_0}{C^4} \left| e^s X_{ij} e^i \right|^2 < {}^*(k)\ (k) >$$

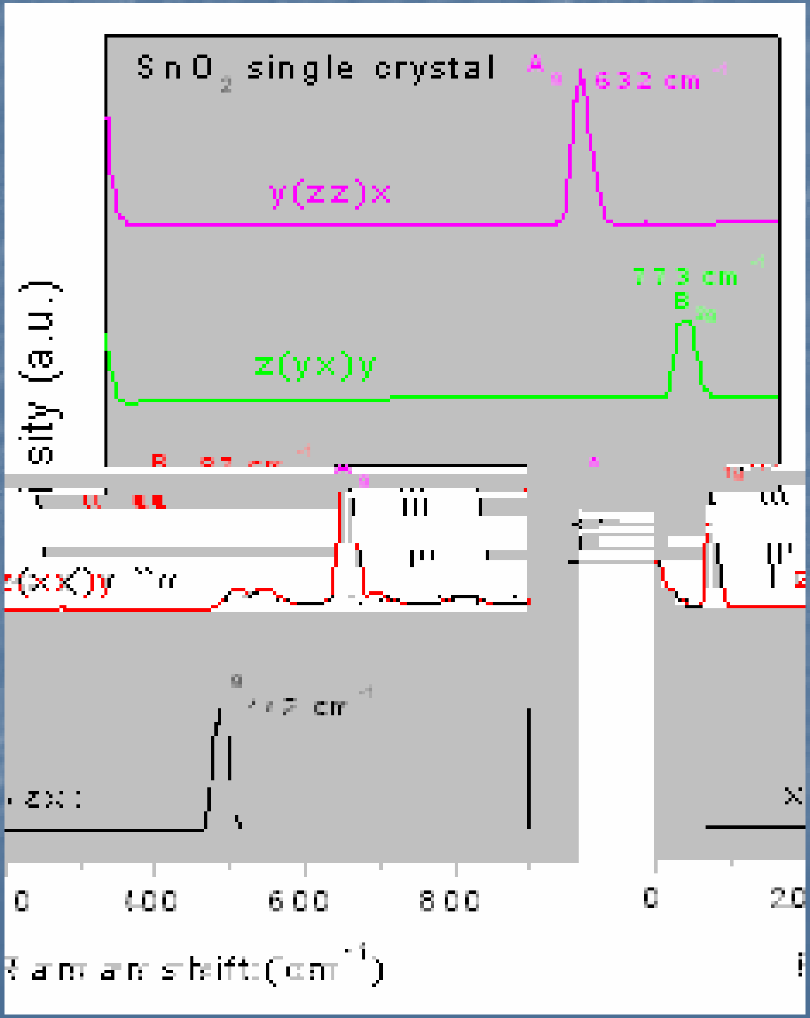
y (z z) x $\quad A_{1g}: \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \begin{pmatrix} a & 0 & 0 \\ 0 & a & 0 \\ 0 & 0 & b \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = b^2$

z (x x) y $\quad A_{1g}: \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} a & 0 & 0 \\ 0 & a & 0 \\ 0 & 0 & b \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = a^2$

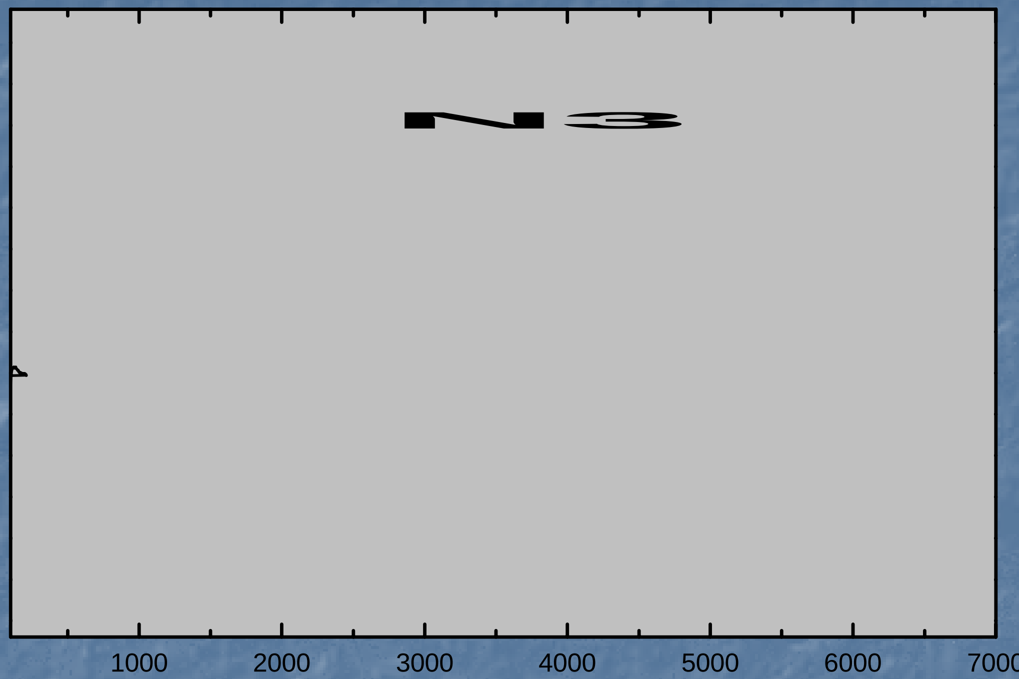
z (x x) y $\quad B_{1g}: \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} d & 0 & 0 \\ 0 & -d & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = d^2$

z (y x) y $\quad B_{2g}: \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \begin{pmatrix} 0 & e & 0 \\ e & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = e^2$

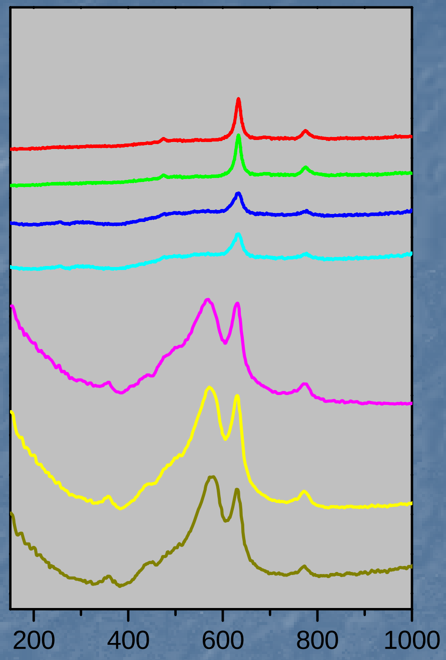
x (z x) y $\quad E_g: \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \begin{pmatrix} 0 & 0 & f \\ 0 & 0 & 0 \\ g & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = g^2$



SnO_2



SnO_2



SnO SnO

q≠

0

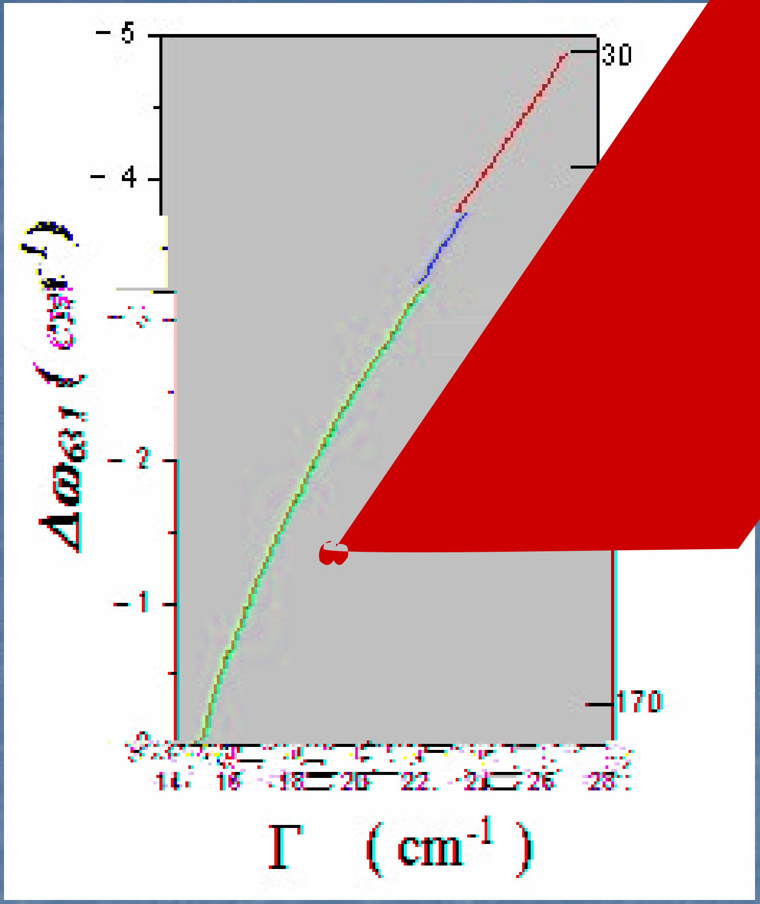
$\frac{1}{0}$ $\frac{2 \quad 2}{}$ $\frac{2}{2}$ 0 **1**

q L

L Γ_0

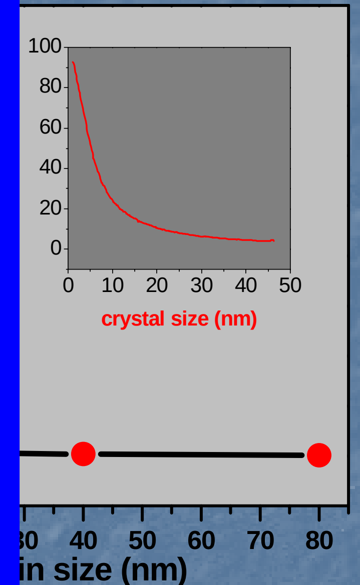
$$(q) = A + B\cos(\quad q)$$ **2**

(1) (2) SnO_2 L Γ



A_{1g} Δ 631 L A_{1g}

Γ


100
80
60
40
20
0
0 10 20 30 40 50
crystal size (nm)
30 40 50 60 70 80
in size (nm)

/ $N_{T(663)}$

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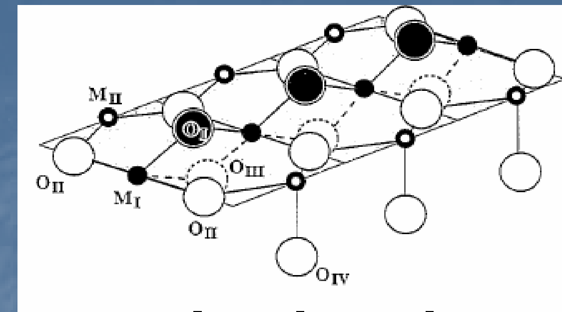
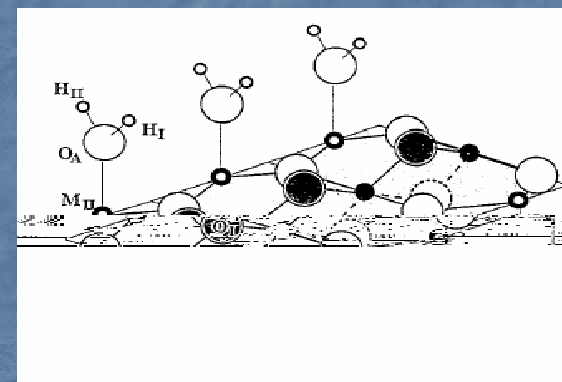
1~ № ╞
(molecular adsorption)

2~ ۿ ե ╞, ˝ ╞OH♣ H♣
(dissociative adsorption)

ה ╞ ୨



unabsorb surface

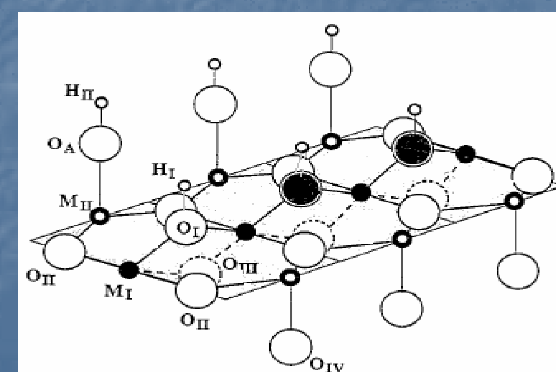


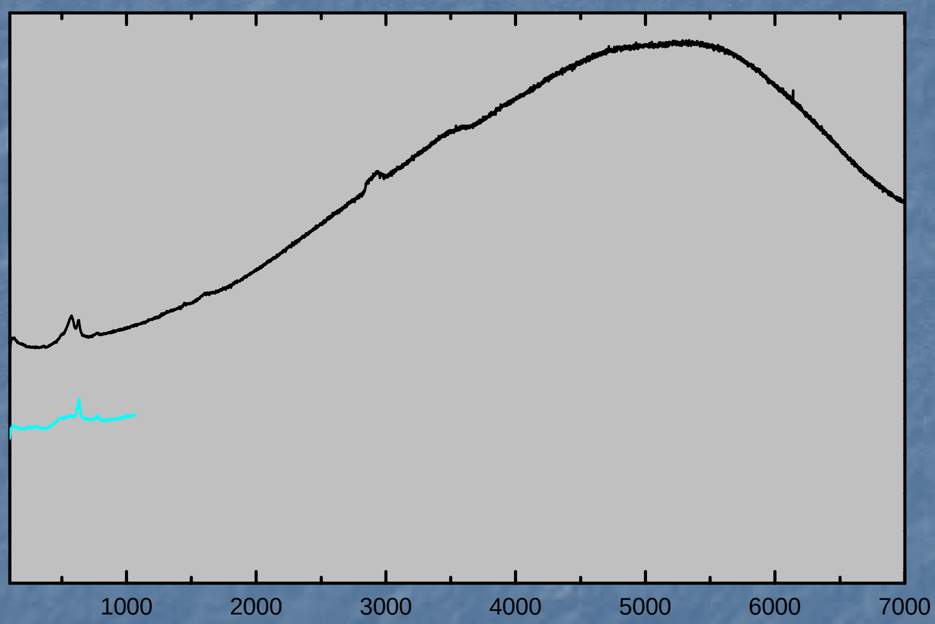
frustrated translations: $200\text{-}500\ cm^{-1}$

liberation mode: $500\text{-}1000\ cm^{-1}$

OH bending: $1500\text{-}1650\ cm^{-1}$

OH stretching: $2500\text{-}4000\ cm^{-1}$




1000
2000
3000
4000
5000
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7000

1. SnO_2

15 nm.

2. 15 571 cm^{-1}

SnO_2

3.

SnO_2 OH

Light Scattering from Magnons and Phonons in $Y_{3-x}Bi_xFe_5O_{12}$ (Bi-YIG) Single Crystals

1. ***Bi-YIG structure and their applications***
2. ***Brillouin light scattering from Bi-YIG crystals***
3. ***Raman scattering from Bi-YIG crystals***
4. ***summary***

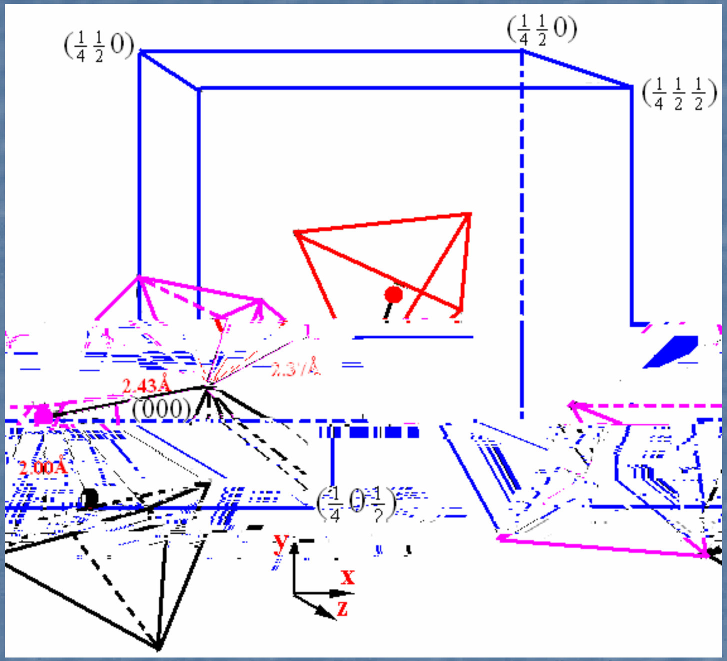
The crystal structure of $Y_{3-x}Bi_xFe_5O_{12}$

Yttrium iron garnets of the composition $Y_3Fe_5O_{12}$ (YIG), which is a typical ferrimagnet, have been important to microwave and magneto-optic technology.

$\{Y_3\}^c[Fe_2]^a(Fe_3)^d\,O_{12}$ (YIG)

doping Bi^{3+}

$\{Y_{3-x}Bi_x\}^c[Fe_2]^a(Fe_3)^d\,O_{12}$ (Bi-YIG)

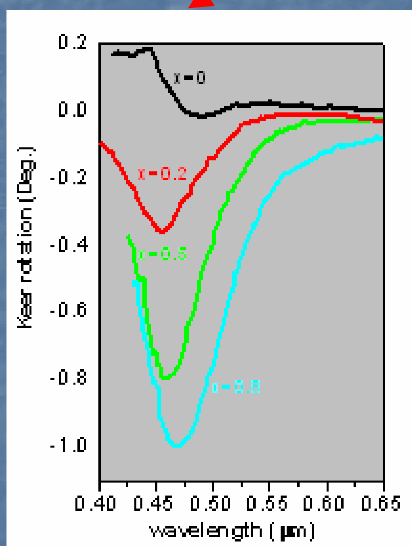


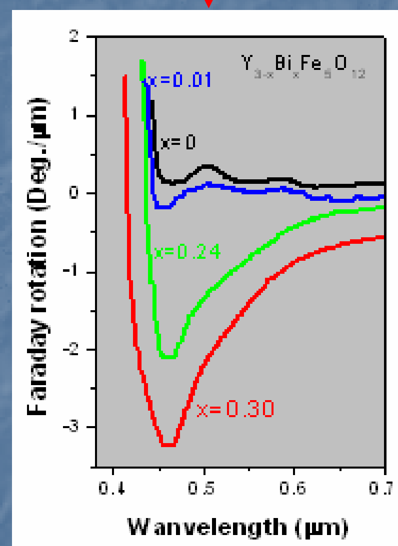
The structure of $Y_3Fe_5O_{12}$

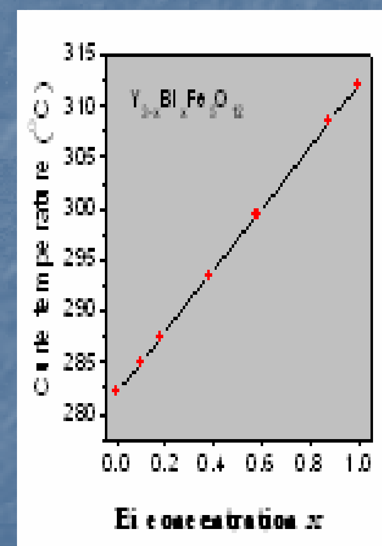
- Fe^{3+} (octahedral, a sites)
- Fe^{3+} (tetrahedral, d sites)
- Y^{3+} (dodecahedral, c sites)

The Faraday rotation $_F$ and Keer rotation $_K$, as well as the Curie temperature,of Bi-YIG increase with the Bi concentration.

Bi-YIG







The magneto optic –enhanced effects on Bi-YIG have attracted considerable experimental and theoretical interest in the past, various mechanism of the effects proposed. The physical origins of these effects are not clear so far. Thorough theoretical and experimental description to their origins is still needed.

Mainly different opinions:

1. *New type of transitions in Bi-YIG have been appeared*

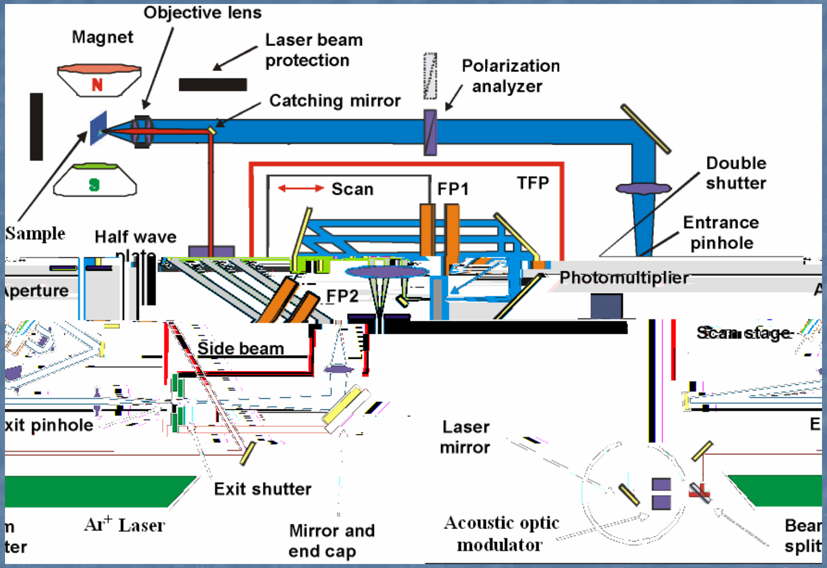
2. *The substitution of Y with Bi in YIG may relax the selection, initially forbidden transitions in YIG are possible or allowed transitions are srengthened.*

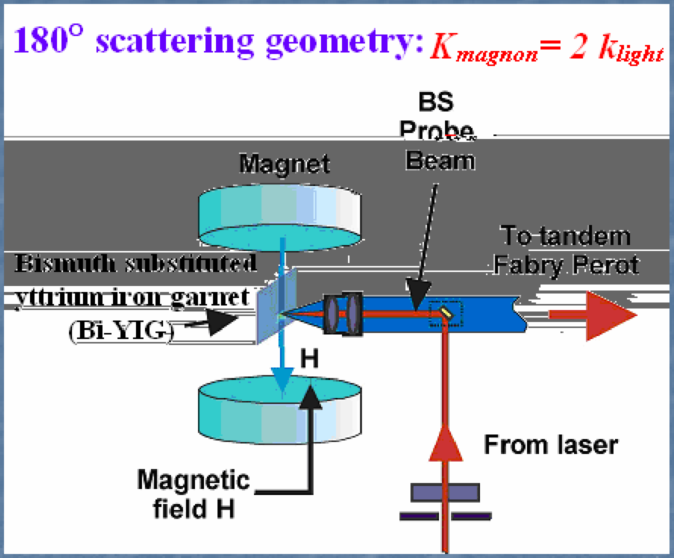
Experiment: samples and their compositions

Bi-YIG single crystals were grown by the flux method. The melt of constituent oxides with Bi_2O_3-PbO-B_2O_3 as flux was slowly cooled in Pt crucible.

Five slab samples cutting from bulk crystals with x=0, 0.14, 0.36, 0.54 and 0.92, respectively, all of size ~ 2x 2 x 1 mm^3, are selected for Brillouin light scattering.

Experiment: equipments and scattering geometry





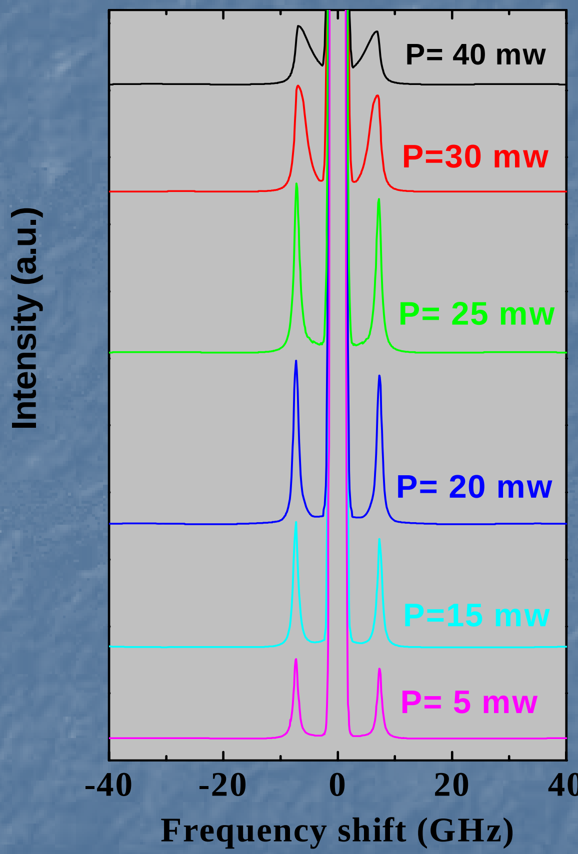
A JRS tandem Fabry-Perot interferometer (3+3 systems) for BLS

Back scattering: The optic axis of a focusing and collecting lens is taken to be the x axis. The sample slab stands vertically on the holder in the gap of a magnet and its surface normal coincides with the axis.

The broadening and downshift effect of laser power on magnon

When laser power exceeds 25 mW, the spectra deteriorate drastically: the peaks weaken and widen markedly with decreasing frequency shift and intensifying anti-symmetry. It shows that large-power excitation could affect the magnetic order of the crystal Bi-YIG and produce widening of spectral lines.

Low power of 5 mW, the lowest in BLS for Bi-YIG, was used and the results were good, showing development in interferometer.



BLS spectra of single crystal Bi-YIG (x=0.14) at different excitation power

Effect of Bismuth concentration on sound velocity

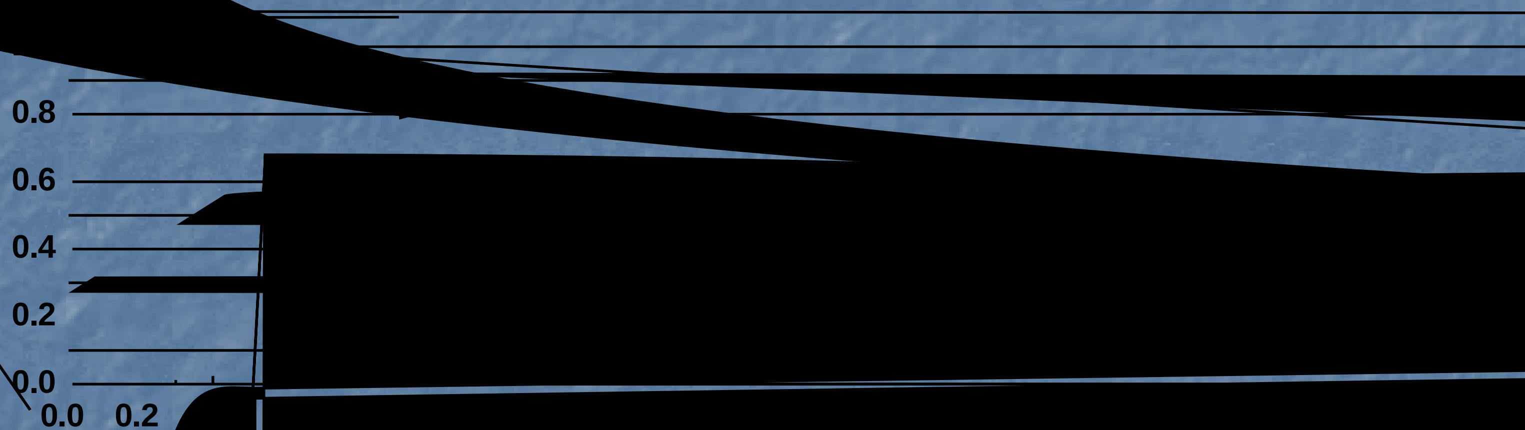
The LA sound velocity V_L:

;

V_L=7.18x10^5 cm/s for YIG

V_l =6.71x 10^5 cm/s for Bi-YIG (x=0.54)

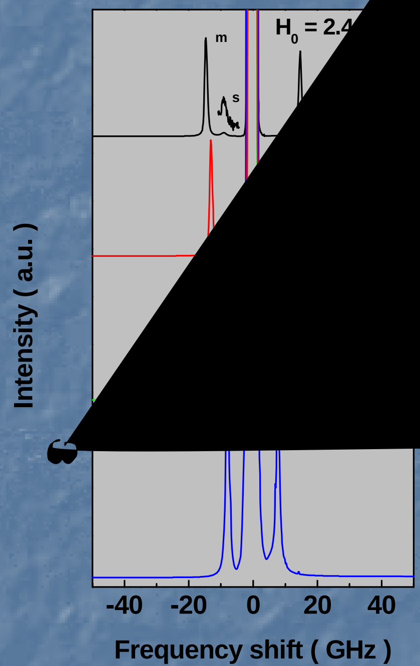
...and the band width of bulk magnons

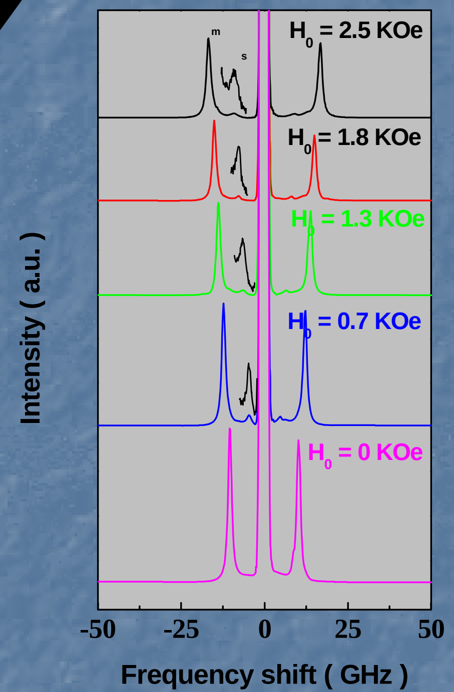


Bi-concentrat
bulk-magnon
linewidth (tr

Polarized BLS spectr[redacted]*YIG as*[redacted] *external magnetic fi*[redacted]

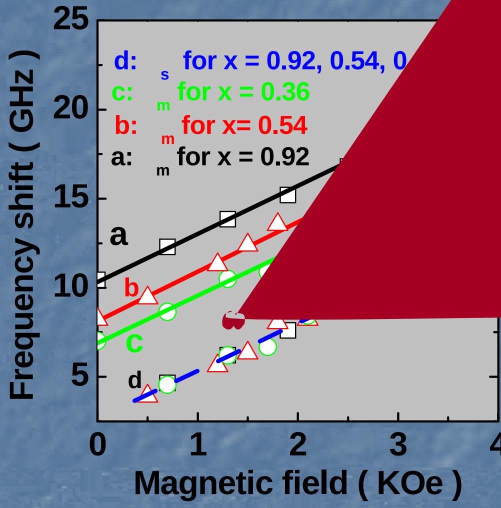
(a) Bi-YIG (x=0.9[redacted] **(b) Bi-YIG (x=0.54)**





$_s$ is determined to be scattering from magnon too by varying external field and scattering polariztion.

The stiffness co[redacted]$_x$ in Bi



Magnetic-field dependence of the bulk magnons frequencies and the weak peaks in Bi-YIG at 514.5 nm excitation. The squares, triangles, circles are data for x=0.92, 0.54,and 0.36,respectively, the solid lines are fited from Eq.(2)

The magnon frequency $_m$ should [redacted] related to the effective magnetic fi[redacted] and the magnon wavevector k_m, fo[redacted] by the dispersion relation:

$$_m = \gamma^2\sqrt{(H_0 + D_{ex}K_m^2)(H_0 + D} \text{[redacted]}$$

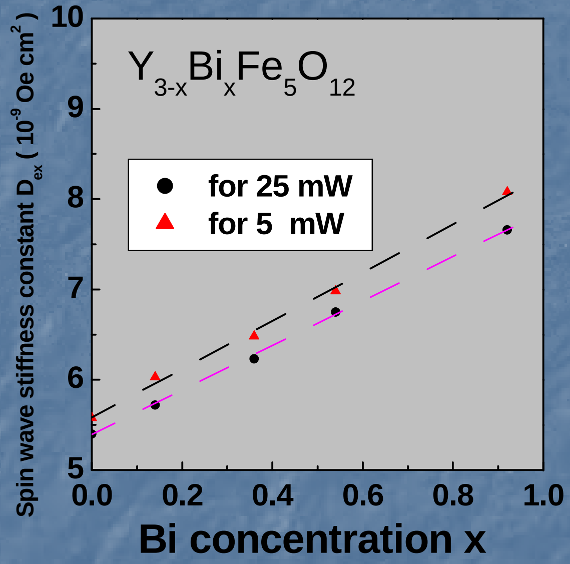
γ is the gyromagne[redacted]he external field a[redacted]tropic field and d[redacted] (H_0 = $H_{appl.}$+H_a[redacted]$_{demag.}$)[redacted]$_{ex}$[redacted] spin wave exchange stiffness constant and $4\ M_s$ is the saturation magnetization. D_{ex} and $4\ M_s$ are taken as parameters fitted to the experimental data.

The dispersion relation for our experiment:

$$_m \approx \gamma[H_0 + D_{ex}K^2 + (1-2N)2\ M_s] \quad \textbf{(2)}$$

TABLE 1. The stiffness constant D_{ex} and saturation magnetation 4 M_s in Bi-YIG

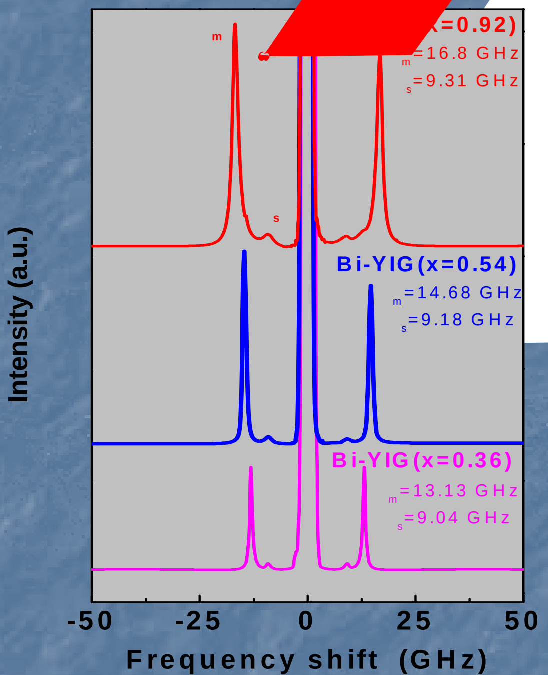
Concentration	Stiffness Constant $D_{ex}/10^{-9}$ Oe cm^{-2}			Saturation Magnetization $4\pi M_s/G$	
x	5 mW	25 mW	30 mW *	5 and 25 mW	30 mW *
0.00	5.58	5.40	5.4	1753	1750
0.14	6.03	5.87	5.9	1760	1756
0.36	6.48	6.23	6.2	1766	1762
0.54	6.98	6.75	6.7	1773	1770
0.92	8.06	7.66		1792	



Bi-concentration dependence of the spin-wave stiffeness constant D_{ex} under 5 and 25 mW, respectively.

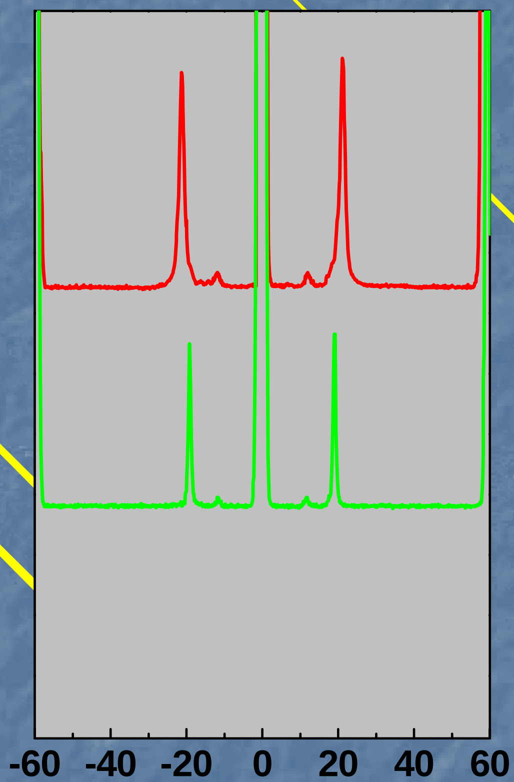
New weak peak $_s$ in Bi-YIG

1. Could it be a surface magnon? 2. Could it be a l… density-states effects of magnon ?



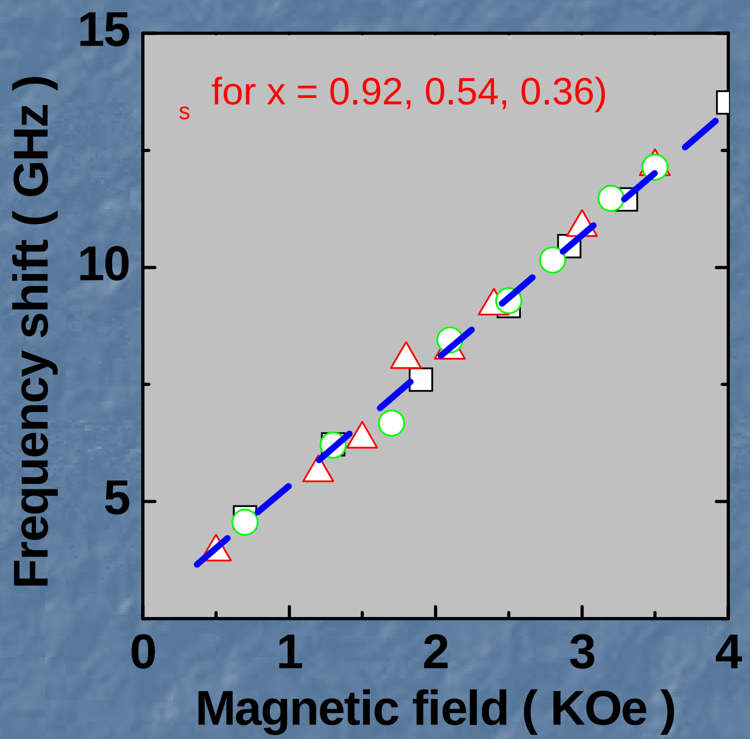
BLS spectra of the bulk magnon $_m$ and weak peak $_s$ for different Bi concentration in exteral magnetic field of 2.5 kOe.

BLS spectra of magnons of Bi-YIG (x=0.92) at 457.9 nm ($_i$=2 kOe) and 514.5 nm ($_i$=20 , 60 ; H =3.3 kOe) excitations,



The frequency of surface magnon $_s$ could be determinted according to the theory of surface magnon.

Magnetic-field [illegible] of the weak peaks in the [redacted] nm. The squares, triangles, and circles are data for x= 0.92, 0.54,and 0.36 . The dash line is fitted from the formula.



$$_s = \gamma\sqrt{H_0(H_0 + 4\ \ M_s)}$$

3. Raman scattering from Bi-YIG crystals

The enhancement of the magneto-optic coupling owing to The Bi-doping makes an opportunity of optic magnon in the magnetic materials.

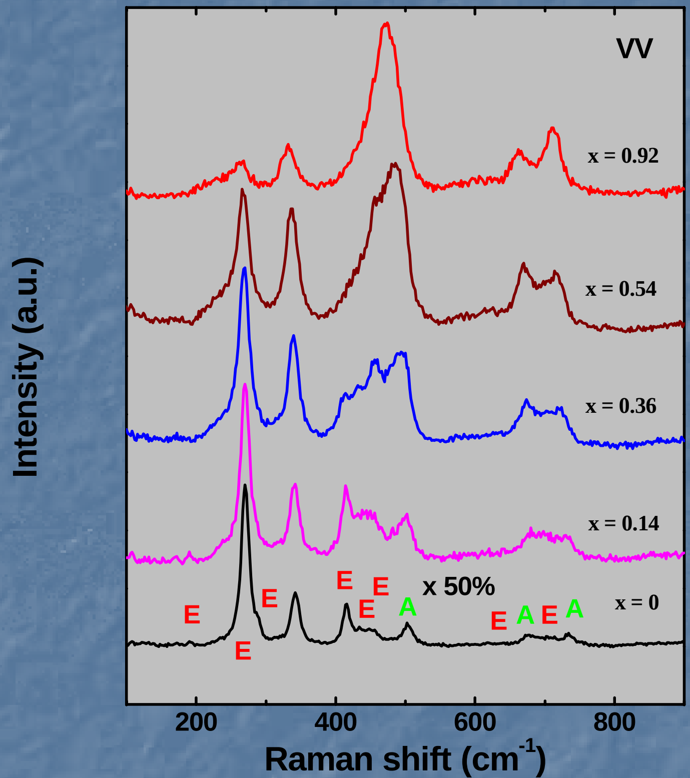
The result will provide useful information for studying the relationship between the Bi concentration, the microstructure of Bi-YIG crystals, and their magnetic and mechanical properties if the magnon is found.

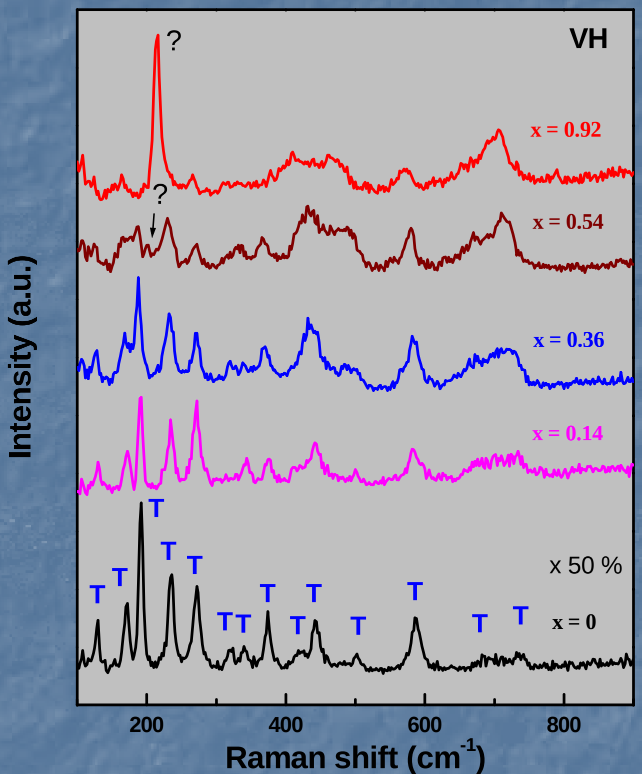
The crystal structure of Bi-YIG and Raman active phonons:

The crystal structure of Bi-YIG belong to the space group O_h^{10} (Ia3d), isomorphic to that of YIG. Since contains the inversion operator, the K = 0 phonons are either infrared active ,Raman active, or silent. There are 25 Raman active phonons which can be classified as 3A1g + 8Eg + 14T2g

Crystal orientation and selection rules

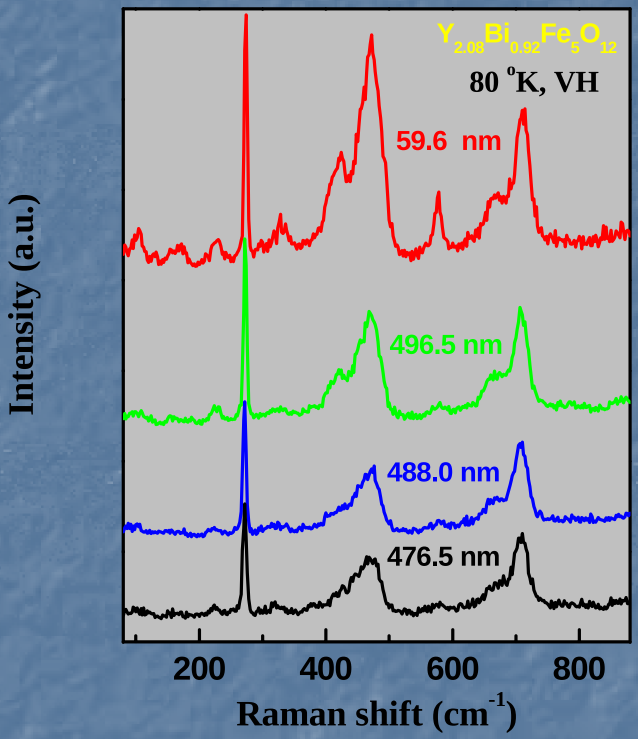
Polarized Raman spectra of Bi-YIG with Bi-concentrations x = 0, 0.14, 0.36,0.54 and 0.92 at room temperature using 514.5 nm argon emission





What is the new peak in Bi-YIG(x= 0.54, 0.92) ?

Raman spectra of Bi-YIG (x=0.92)with four different laser lines at 100 ° K

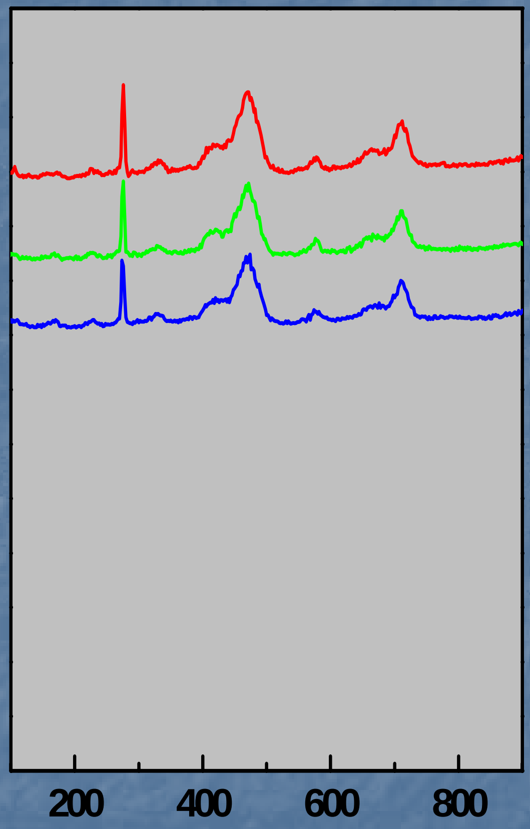


Raman data were taken with four different laser lines from argon laser, in order to eliminate misidentification of our Raman data duo to possible fluorescence from trace impurities.

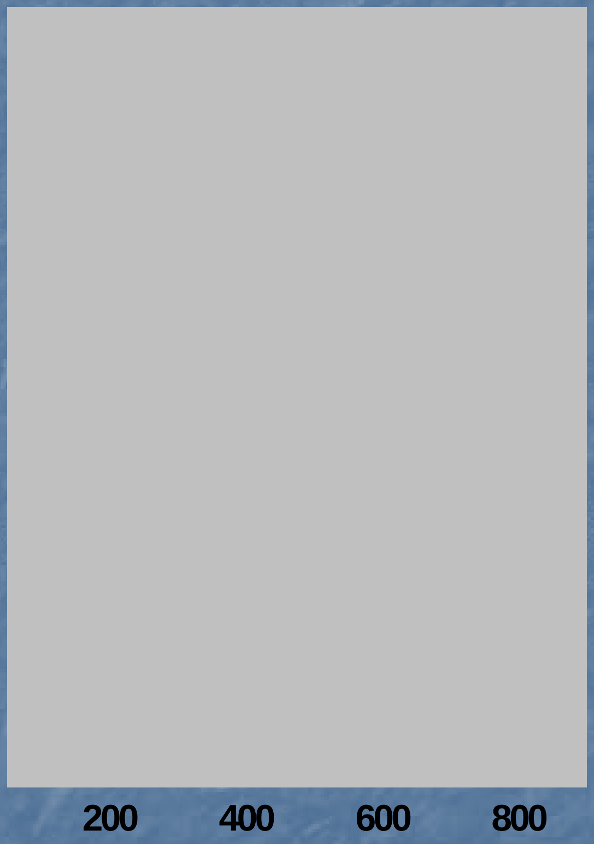
Finally, the observed process is indeed a first order scattering rather than a fluorescence was confirmed by observing the anti-Stokes line at 40 ° K, where $\hbar \quad / kT \approx 2$.

Could it be a electronic Raman scattering or optical magnon?

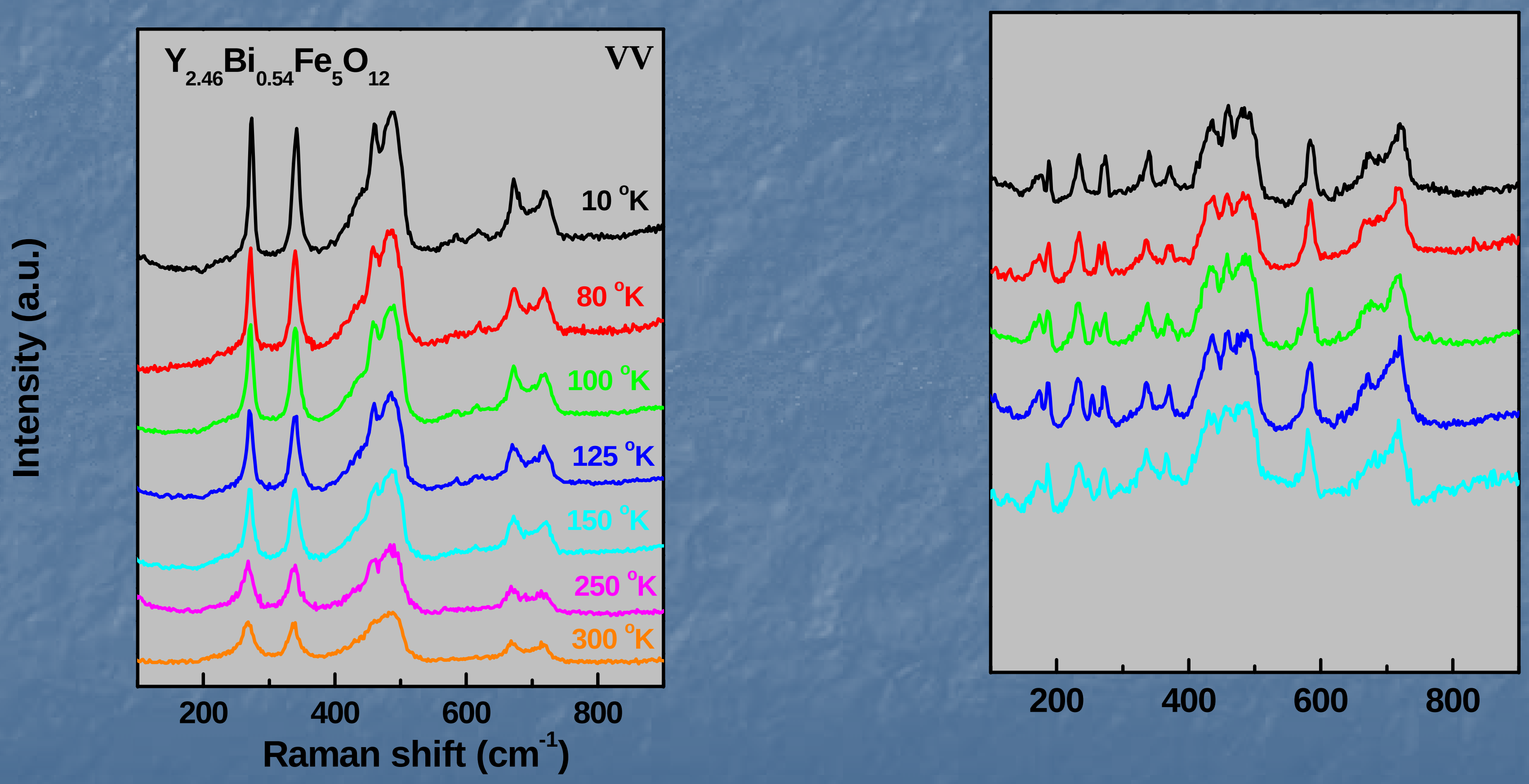
Polarized Raman spectra of Bi-YIG (x=0.92)measured at various temperatures between RT and 10 ºK in VV and VH scattering geometry



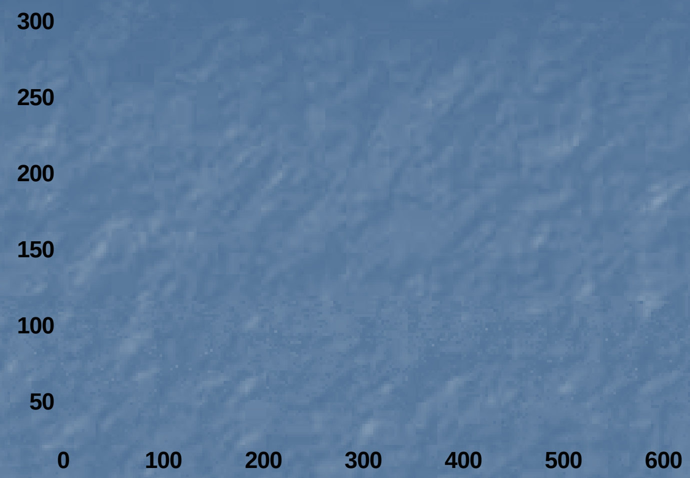
Polarized Raman spectra of Bi-YIG(x=0.92) measured at higher temperatures in VH scattering geometry



Polarized Raman spectra of Bi-YIG (x=0.54)measured at various temperatures between RT and 10 ^{0}K in VV and VH scattering geometry



Temperature dependence of Stokes frequency shifts in Bi-YIG (x=0.92)



Approximative c... esonance magnon

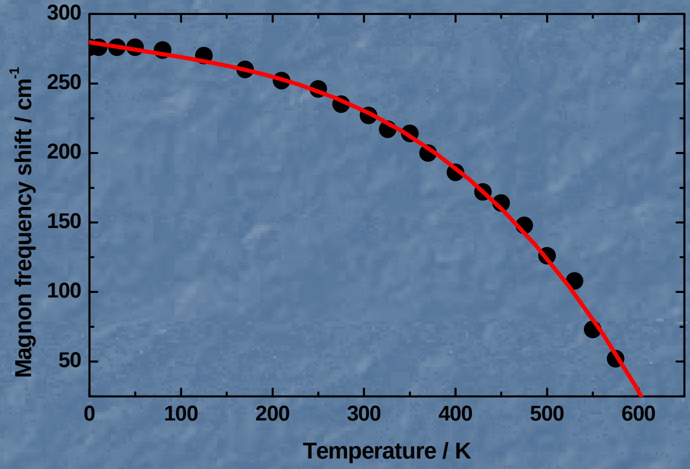
The ... betw... Kaplan a...

$_m = ... (\gamma_2 M ...$

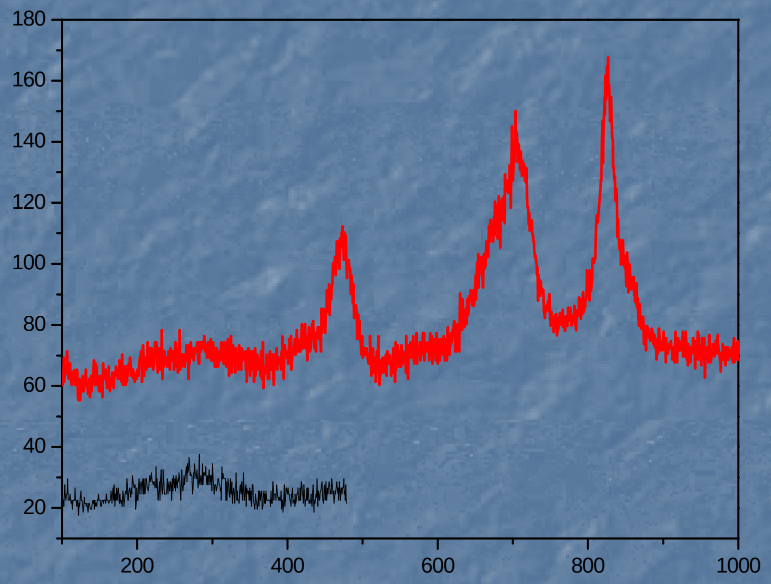
where is ... constant ... gyro... $_1, M_{2;}$ th... s.

(2)

g ... exchange field . M is ... blattice magneization. ... can be calculated from the experimentally measured quantities.



Raman scattering from {$Bi_{1.4}Ca_{1.6}$}[Fe_2]($Fe_{2.2}V_{0.8}$) single crystal



The substitution Y with Bi decreases the intensity of Raman shift in the range of the lower frequency .

The appearance of the exchange resonance magnon not only depends on the Bi concentrations in the crystal but also on the exchange interaction between the octahedral sites and tetrahedral sites.

Summary

1. In BLS, the spin wave exchange stiffeness constant $D_{ex}$is very sensitive the excitation power so that low power should used.
2. The behavior of the bulk magnon is opposite to LA phonons.
3. Not only the spin wave exchange stiffness constant, but also the relative intensity and the bandwidth of bulk magnon increase linearly with x.
4. The substitution Y with Bi softens the crystals and the measured sound velocities of the acoustic phonons decrease linearly with x.
5. As an external field is applied, the uniform magnetostatic mode appears.
6. In Raman scattering, the exchange resonance magnons are firstly observed in Bi-YIG($x > 0.54$).

Summary

7. The appearance of the exchange resonance magnon not only depends on the Bi concentrations in the crystal but also on the exchange interaction between the octahedral sites and tetrahedral sites.

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