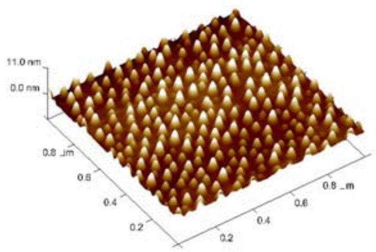
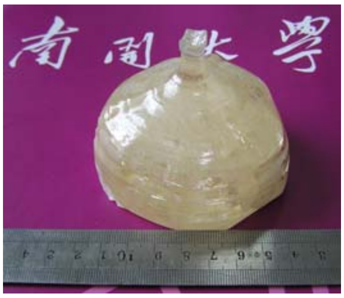
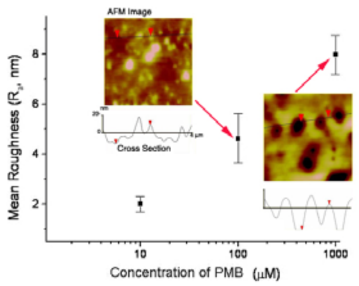
# The Key Laboratory of Advanced Technique and Fabrication for Weak-Light Nonlinear Photonics Materials, Ministry of Education

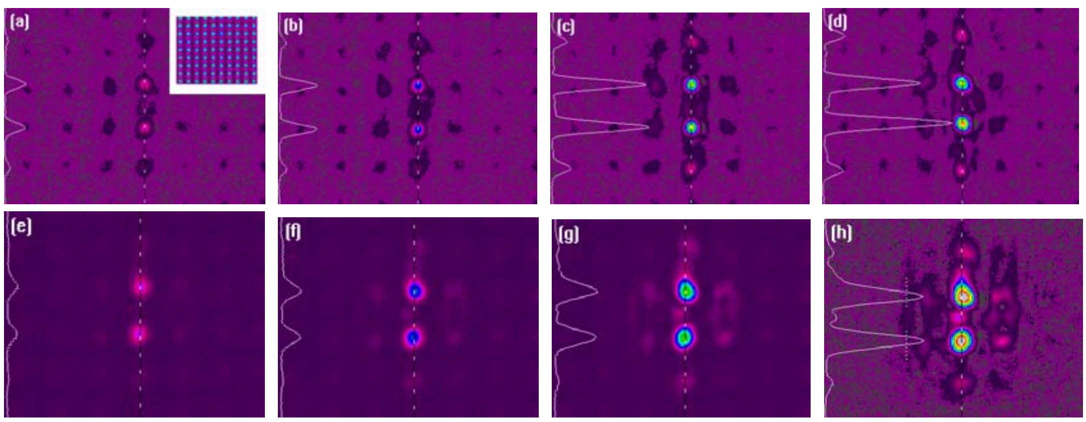
# *Annual Report*

# 2004



# Preface

This annual report summarizes the main research activities performed within the Key Laboratory of Advanced Technique and Fabrication for Weak-Light Nonlinear Photonics Materials, Ministry of Education of China in 2004. Our Laboratory was active in the following fields:

a) Nonlinear Physics and Materials
b) Photonics Material and Advanced Fabrication Technique
c) Nonlinear Optics at Weak Light and Quantum Coherent Optics
d) Spectral Characterization and Sensor Techniques
e) Design of Tunable Laser Cavity
f) Growth Techniques of Semiconductor and Semiconductor Devices

The research topics and achievements in these areas are described briefly in this report. These researches are supported by the National Natural Science Foundation of China, the "973" Project, the National Advanced Materials Committee of China ("863" Project), the Ministry of Education of China, the Natural Science Foundation of Tianjin and Nankai University.

In 2004, more than 80 papers were published in international pre-reviewed academic Journals, two national patents were issued, and one academic book was published. Mr. Kun Wang et al. (totally ten) completed their Master thesis and Dr. Zhiyong Jiao and Dr. Tang Xu completed their PhD thesis. 42 ones were enrolled as Master students and 8 ones joined the Laboratory as PhD candidates. This year Mr. Feng Gao, Cibo Lou and Zhibo Liu joined the Laboratory as Lecturers. Prof. Jianguo Tian has been selected as national talents by the Personnel Ministry of China, Prof. Jingjun Xu and Jianguo Tian have been selected as conferred specialists of Tianjin. Prof. Feng Song and Guoquan Zhang were granted by Program for New Century Excellent Talents in University, Ministry of Education. And the group lead by Prof. Jingjun Xu was selected as the Cheung Kong Scholar and Innovation Group by the Ministry of Education. It is my pleasure to thank all scientific, technical and administrative members of the Key Laboratory for their active collaboration.

Prof. Guoquan Zhang<br>
Nankai University, Tianjin<br>
2005-4-23

# Analytic solutions to z-scan characteristics of thick media with nonlinear refraction and nonlinear absorption

Wei-Ping Zang, Jian-Guo Tian, Zhi-Bo Liu, Wen-Yuan Zhou, Feng Song, Chun-Ping Zhang

The Z-scan technique is popular [1] for measurements of nonlinear index and nonlinear absorption because of its simplicity and accuracy. The propagation of a Gaussian beam in a system with thin nonlinear elements is readily modeled. But beam propagation in thick nonlinear media is usually complicated. Various analytic approaches to such measurements have been used [2-4]. Most of them involve an aberrationless approximation, and the results are correct to first order for irradiance. For higher-power regimes, numerical techniques are usually applied [5].

We give a theoretical analysis of the Z-scan characteristics of thick media with nonlinear refraction as well as nonlinear absorption by the combination of a Gaussian decomposition method and a distributed lens model. By the introduction of correction functions, the effects of saturation of nonlinear refraction and the effects of coupling between nonlinear refraction and nonlinear absorption in higher-power regimes are included, and analytic solutions are obtained. Comparisons of our analytic solutions with previous results and numerical solutions are made, and good agreement of the two kinds of solution is obtained, no matter how much nonlinear refraction or nonlinear absorption there is. To the best of our knowledge, our analytic solution reaches its best agreement with numerical simulation when an analytic analysis of the Z-scan characteristics of a thick medium with nonlinear refraction and nonlinear absorption is made.

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# Accurate determination of nonlinear refraction and nonlinear absorption by single z-scan method

Wei-Ping Zang, Jian-Guo Tian, Zhi-Bo Liu, Wen-Yuan Zhou, Feng Song,
Chun-Ping Zhang and Jing-Jun Xu

The *Z*-scan method proposed by Sheik-Bahae *et al* [1] has been widely used to determine the nonlinear characteristics, especially nonlinear refraction and nonlinear absorption, of a medium. Recently Boudebs pointed out that in a case with large nonlinear absorption and small nonlinear refraction the relative error of nonlinear refraction obtained by the above method can reach as high as 50% [2]. Yin *et al.* presented a method to obtain nonlinear refraction and nonlinear absorption simultaneously by a pinhole *Z*-scan curve [3], but it is suitable only for a case with a small nonlinearity. Liu *et al.* also analyzed *Z*-scan characteristics of a nonlinear medium with both nonlinear refraction and nonlinear absorption, but the results obtained are accurate only for a case with a small nonlinearity, too [4].

A theoretical model based on the Gaussian decomposition method and symmetric analysis is demonstrated to determine the nonlinear refraction and nonlinear absorption of a nonlinear medium accurately and simultaneously by a single *Z*-scan method. More accurate values of nonlinear refraction and nonlinear absorption can be obtained simultaneously by the model, no matter how much they are, if accurate experimental data are acquired. The treatment procedure of *Z*-scan experimental data is demonstrated. The effect of aperture size is also considered in our analysis. It will provide a solid theoretical foundation for determination of nonlinearities by the *Z*-scan method.

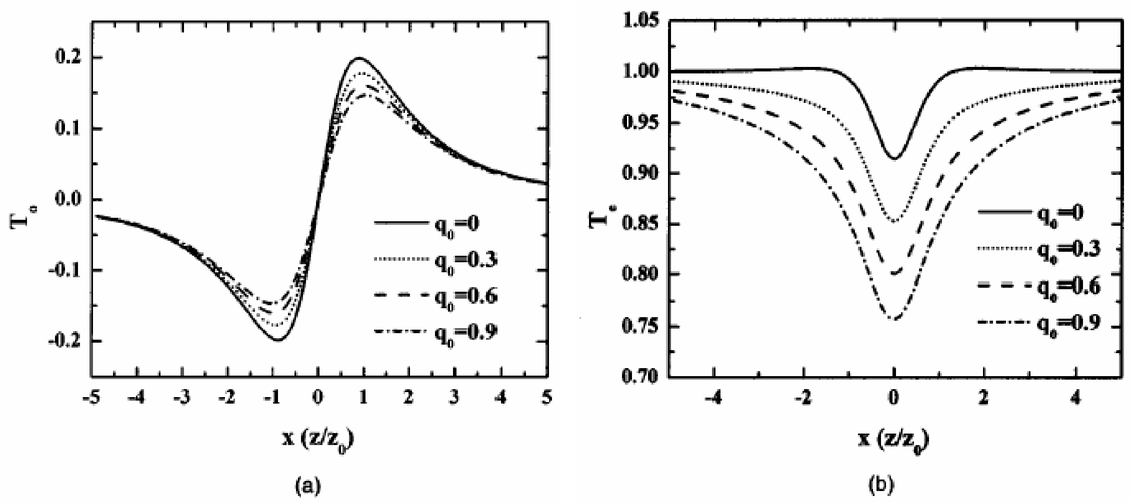


**Fig. 1** (a) Group of curves of odd function *To*, (b) A group of curves of even function *Te*

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# Local one-dimensional approximation for fast simulation of Z-scan measurements with an arbitrary beam

Wei-Ping Zang, Jian-Guo Tian, Zhi-Bo Liu, Wen-Yuan Zhou, Feng Song, Chun-Ping Zhang

Some authors analyzed the elliptic Gaussian beam propagation in a Kerr medium by the fast-Fouriertransform beam-propagation-method algorithm [1-3], but this algorithm has the following disadvantages owing to the nature of the fast Fourier transform [4]: (1) It requires a long computation time, (2) the propagation step has to be small, and (3) the number of sampling points must be a power of 2.

We analyzed the elliptic Gaussian beam propagation in a Kerr medium by a combination of the local one-dimensional (LOD) approximation and the Crank–Nicholson scheme. This scheme uses a tridiagonal solution of a one-dimensional situation, which is unconditionally stable and accurate to second order because it uses the Crank–Nicolson algorithm.18 For the situation in this paper, the LOD algorithm is the same as the alternating direction implicit and can be applied more easily. A detailed comparison between the LOD algorithm and the alternating direction implicit has been given in Ref. [5]. The accuracy of the LOD algorithm, the error tolerance, and the step sizes in transverse and longitudinal coordinates were tested by a comparison of the numerical predictions of the algorithm with the known analytic solutions.

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# Analysis of z-scan of thick media with nonlinear refraction and absorption for elliptic Gaussian beam by variational approach

Wei-Ping Zang, Jian-Guo Tian, Zhi-Bo Liu, Wen-Yuan Zhou, Feng Song, Jing-Jun Xu

Variational method has been widely used to obtain approximate solutions to the nonlinear Schrödinger equation (NLSE) for problems concerning laser pulse and/or nonlinear beam propagation in nonlinear media, involving one or more transverse dimensions besides the propagating direction [1]. The total Lagrangian of the system consists of a conservative term and a nonconservative term. Variational method has been successfully applied to nonconservative optical system [2].

We combine variational method and nonlinear absorption equation to obtain a group of ordinary differential equations, which describes elliptic Gaussian beam propagation in a thick medium with nonlinear absorption as well as nonlinear refraction. They can be solved by Runge–Kutta algorithm. Results show that the computation time taken by the variational method is much less than that required by numerical simulation using a combination of local one-dimensional (LOD) approximation and Crank-Nicholson implicit (CNI) approximation algorithms. Meanwhile, the validity of the variational method is checked by comparing it with numerical simulations, and the results show that this method provides a fast and accurate way to solve this type of nonlinear problems. In our analysis the normalized transmittance in open aperture Z-scans for different values of the beam ellipticity and astigmatism is given.

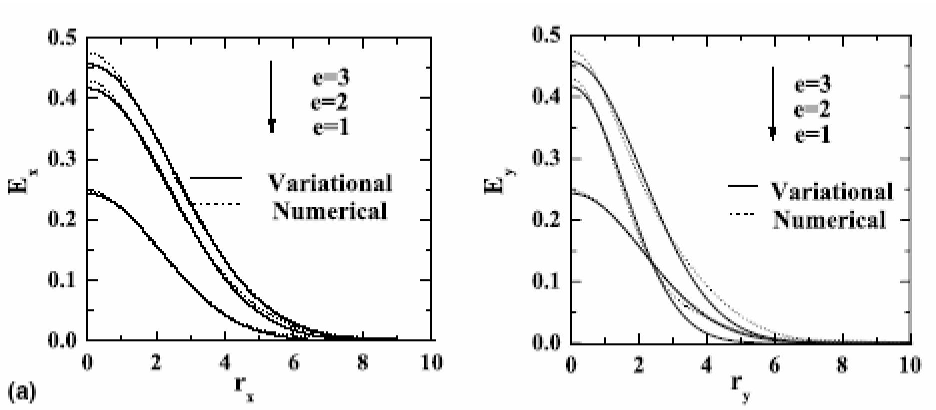


**Fig.1** Beam transverse profiles as a function of $r_x$ and $r_y$ at the exit plane of medium for ellipticity e=1, 2, 3, respectively.


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# Flexible alteration of optical nonlinearities of iodine charge-transfer complexes in solutions

Zhi-Bo Liu, Jian-Guo Tian, Wei-Ping Zang, Wen-Yuan Zhou, Feng Song, Chun-Ping Zhang

Materials with large optical nonlinearities are required for photonic applications such as all-optical switching, data processing, and eye or sensor protection. Recently, large enhanced optical nonlinearities caused by intramolecular and intermolecular charge-transfer (CT) transition have been reported [1, 2]. For iodine CT complexes with organic solvents there are intermolecular CT interactions between the acceptor iodine and the donor solvent molecules [3, 4]. Hyperpolarizability of the pyridine–iodine CT complex was reported by Levine and Bethea. The charge separation in CT complexes may lead to an enhancement of optical third-order nonlinearities because of its large dipole moment. For molecular iodine vapor there exists a saturable absorption (SA) and self-focusing effect.. We report the magnitude and sign change of large optical nonlinearities of iodine CT complexes with different solvents at 532 nm. The type of donor used is found to influence greatly the optical nonlinearities of iodine CT complexes in solutions for several solvents. The magnitude and sign changes of nonlinear absorption of iodine CT complexes for different solvents as donors are observed, which implies the transition from saturable absorption to reverse saturable absorption. Compared with C60 in toluene, iodine CT complexes with toluene and benzene demonstrate larger reverse saturable absorption. Meanwhile, f lexible alteration of optical nonlinearities is easily obtained by adjusting the mixture ratio of different solvents, yielding a prospective means of constructing a nonlinear medium with a large nonlinear coefficient.

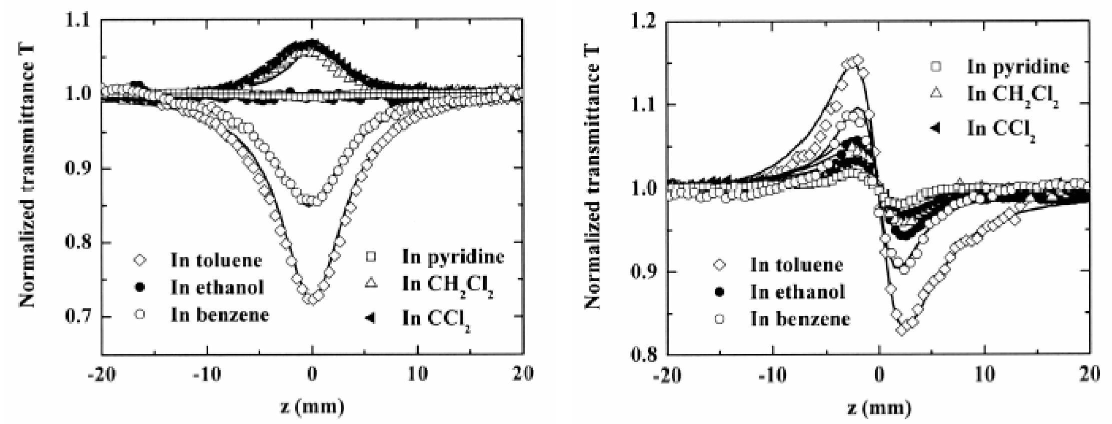


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**Fig.1** *Z*-scan curves of iodine CT complexes for nonlinear absorption and nonlinear refraction.

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# The influence of pulse width on transient thermally induced optical nonlinearities in a Kerr nonlinear medium

Shu-Qi Chen, Zhi-Bo Liu, Wen-Yuan Zhou, Jian-Guo Tian, Wei-Ping Zang,
Feng Song, Chun-Ping Zhang

We report the experimental results on the effect of pulse width on transient thermally induced optical nonlinearities in the nanosecond regime. We have obtained the Z- scan curves of the CS2 solutions of nigrosine for different pulse widths , and analyzed the co-existence of third-order and transient thermally induced optical nonlinearities. The process of changing from transient state to steady- state thermal-induced optical nonlinearities was observed. Meanwhile , we have obtained the results of numerical simulation by solving simultaneously acoustic and electromagnetic wave equations , which agree well with the experimental results.

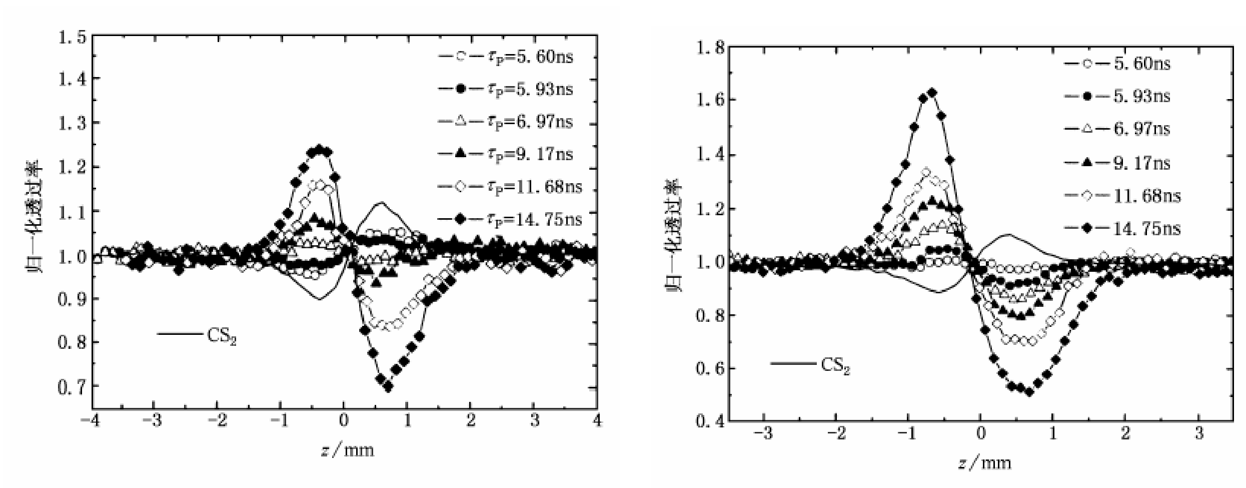


**Fig.1** *Z*-scan curves for thermal induced nonlinear refraction.

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# Research on Er/Yb codoped glass and fiber with high gain

Song Feng✉ , Fu Qiang, Yu Hua, Su Ruiyuan, Zhou Changguang, Tian Jianguo

Erbium-doped fiber (EDF) devices play important role nowadays. For commercial EDF, the lengths are usually longer, which are a shortcoming for many applications such as in integrated photonoics. We are trying to make fibers that have high gain (3-5dB/cm). The first step is to make glasses with high optical qualities.

Erbium ytterbium codoped phosphate and tellurite glass has high energy transfer efficiency between $Er^{3+}$ and $Yb^{3+}$ and can have good luminescence performance at 1.5μm. We have made several erbium-ytterbium-codoped phosphate glasses and telluride glasses. Absorption spectra, emission spectra and excitation spectra photoluminescence (PL) including the upconversion of these samples were measured at room temperature. Optical parameters are calculated from absorption spectra with Judd-Ofelt theory.

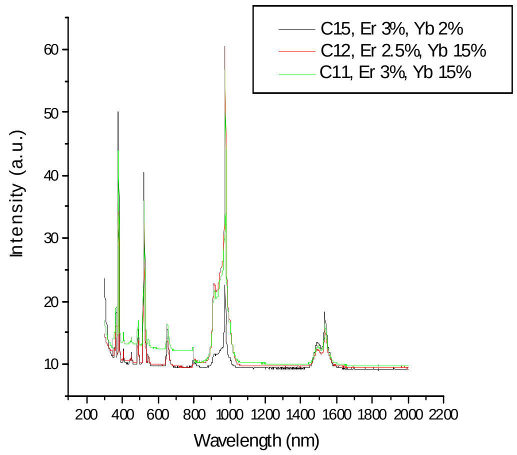


**Fig.1** The absorption spectra of the phosphate glasses

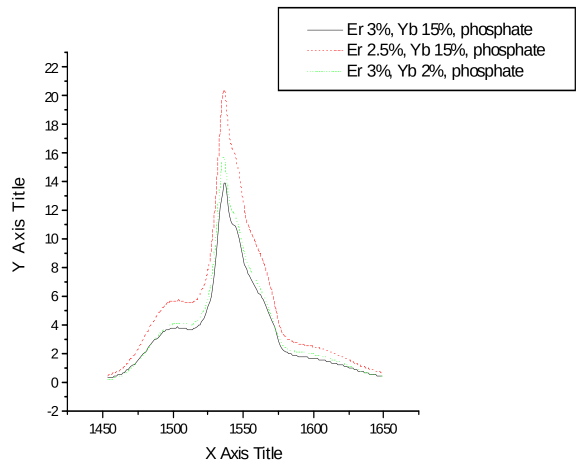


**Fig.2** Fluorescence spectra of the phosphate glasses

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# Research on Er/Yb codoped glass and fiber with high gain

Song Feng✉ , Fu Qiang, Yu Hua, Su Ruiyuan, Zhou Changguang, Tian Jianguo

The lifetime of $Er^{3+}$ upper level ($^4I_{13/2}$) is very important for optical performance of the erbium glasses. We have constructed a home-made device to measure lifetime. The lifetime for different glasses at different exciting powers were measured and analyzed.

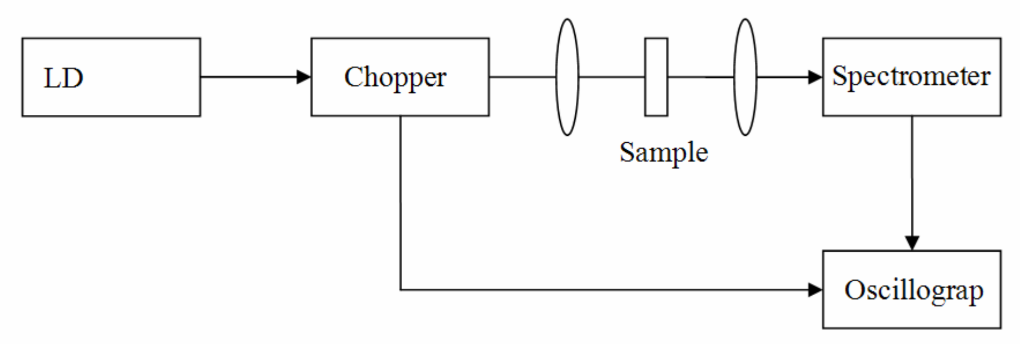


**Fig.1** Setup for lifetime measurement

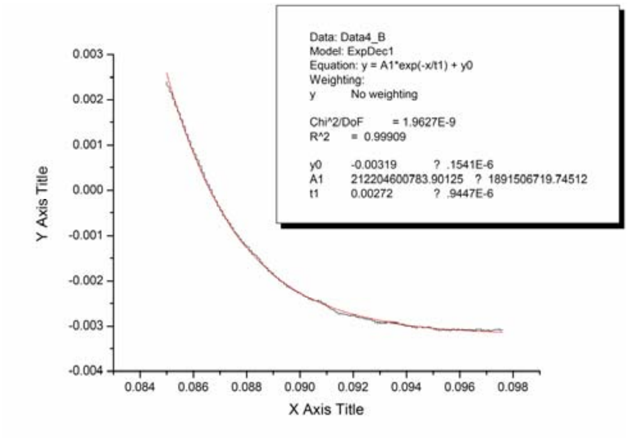


**Fig.2** decay curve of population (black) and fitting exponential decay curve (red).t1 is the lifetime

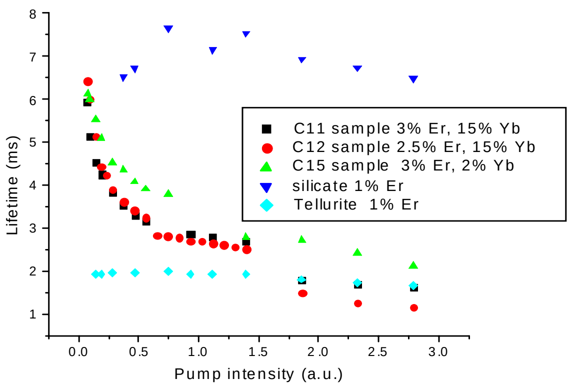


**Fig.3** Lifetime decreases with pump rate.

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# Research on Er/Yb codoped glass and fiber with high gain

Song Feng✉, Fu Qiang, Yu Hua, Su Ruiyuan, Zhou Changguang, Tian Jianguo

We have established a theoretic model for high gain fiber laser. With the rate equations and the propagation equation of $Er^{3+}/Yb^{3+}$-codoped phosphate fiber, we analyzed the effects of concentrations of erbium and ytterbium ions, pump power, signal power, fiber length on the gain characteristics of the co-doped fiber amplifier. Comparison with single erbium-doped fiber amplifier was also made. It can be shown that the sensitization of $Yb^{3+}$ decreases the cluster effect of erbium ions in the fiber and the gain and pump efficiency of $Er^{3+}/Yb^{3+}$ co-doped fiber are apparently higher than that of single erbium-doped fiber. Numerical results also demonstrate that considerable signal gain, 10dB, can be achieved in a 3.2cm-long fiber amplifier with 20dBm(100mW) pumping power at 980 nm. Our data are very close to results of wave-guide amplifier[5-7] and Er/Yb codoped fiber amplifier[8-9].

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# Design for LD pumped solid state laser adaptive to the change of the thermal focal length*

Song Feng, Qin Bin, Wang Zhijun, Wu Yanxiong, Xu Jingjun, Zhang Guangyin

In LD (Laser Diode ) pumped solid state lasers, thermal length acts an important role in design of laser resonator. When pump power increase, the focal length of thermal lens will decrease apparently. We have experimentally researched the thermal effect of a LD pumped Nd:YVO4 laser and given an resonator design, which can automatically adapt to the change of the thermal focal length.

The experiment set-up is as follow:

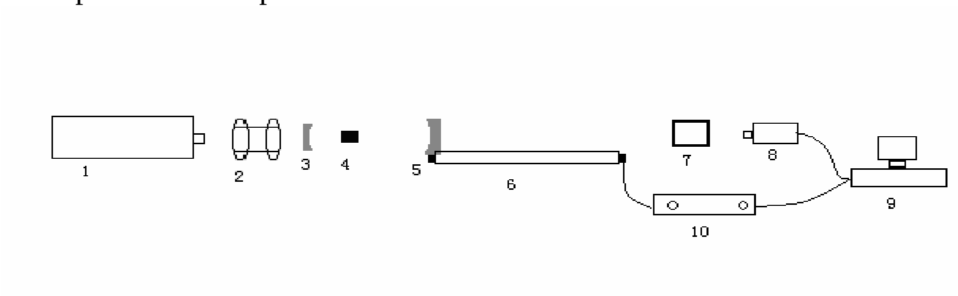


**Fig.1** The experiment set-up:
1.LD; 2.coupling system; 3.concave mirror(808nm HT, 1064nmHR, R=150mm); 4.Nd:$YVO_4$ crystal, size:3×3×5mm; 5.output coupler (1064nm T=5.3%, R=150mm); 6.step motor; 7.attenuation plate; 8. detector; 9.computer; 10. controller of step motor

When pump power increases, the focal length of thermal lens changes, which will influence the resonator parameters and thus the output. We detect and measure the beam profile on-line and send the signal to the computer. Athe computer will analyze the data and give an order to the step motor to adjust the cavity length to adapt the changes due to the thermal length.

In the next work we will choose a CCD whose dynamic range of light intensity is more appropriate to detect thebeam profile, as well as improve the program and develop a three-dimentional self-adapting system to control the laser cavity.

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# The study of luminescent properties of materials doped by rare-earth ions *

Song Feng, Su Jing, Han Lin, Tian Jianguo, Zhang Guangyin

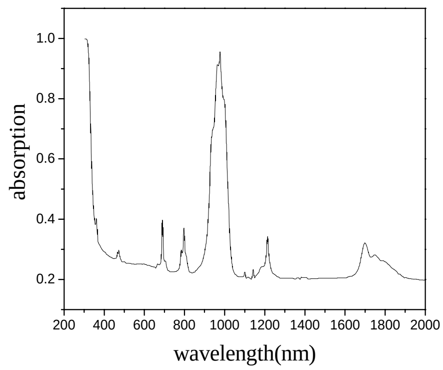
The absorption spectra, emission spectra, excitation spectra, and the upconversion luminescence of the materials with different doping contents were collected. Fluorescent lifetime and saturation absorption characteristics were measured with the commercial spectra-meter and home-made device. Experimental results were analyzed according to some theory models, such as Judd-Ofelt theory, McCumber theory, and rate equation theory. Several papers were published on the authority journals.

In our work, one of the the hosts is NaY(WO4)2 crystal (NYW), which not only has good mechanical and chemical stability, but also has wider absorption bands. NYW crystals were grown by the Czochralski method. It's Tetragonal uni-axial crystal, and its space group is C4h6. The rare-earth ions include Er, Yb, Tm and so on

The room-temperature absorption spectrum of the crystal was measured with the Hitachi UV-365 spectrophotometer. With the absorption spectra, the main optical parameters of the samples, such as effective intensity parameters, oscillator intensity, experimental oscillator intensity, fluorescence branching ratio, spontaneous emission rate, lifetime and the integrated emission cross section were calculated according to the Judd-Ofelt theory.

The emission spectra, excitation spectra, and the upconversion luminescence of the sample also were measured with the SPEC Model F111AI Fluorescence meter.

The figure shows the room-temperature absorption spectra of Tm:NYW crystal; and the photo shows that the intensity blue upconversion luminescence of our sample:

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# Influence of upconversion effects on $Er^{3+}$, $Yb^{3+}$ co-doped phosphate glass laser*

Song Feng, Wu Zhao-Hui, Liu shu-jing, Qing Bin, Su Jing, Tian Jianguo

An analytical model of CW longitudinally diode-pumped $Er^{3+}$,$Yb^{3+}$ co-doped phosphate glass laser that includes the influence of cooperative up-conversion(CUC) and cumulative energy-transfer(CET) effects has been developed, which is put forward for the first time to our best knowledge. The results of general output modeling were applied to a laser with Gaussian beams, and rigorous numerical calculations has been made to study the influence of CUC and CET, where the dependence of laser output on the influence of CUC and CET was investigated in particular. We have found that the influence of CUC on the threshold could be up to 22%. The model is in good agreement with experiments of the Er/Yb phosphate glass laser. Further numerical analysis will be developed and it is useful to optimize these kind of lasers.Fig 1 shows the calculated and experimental results.

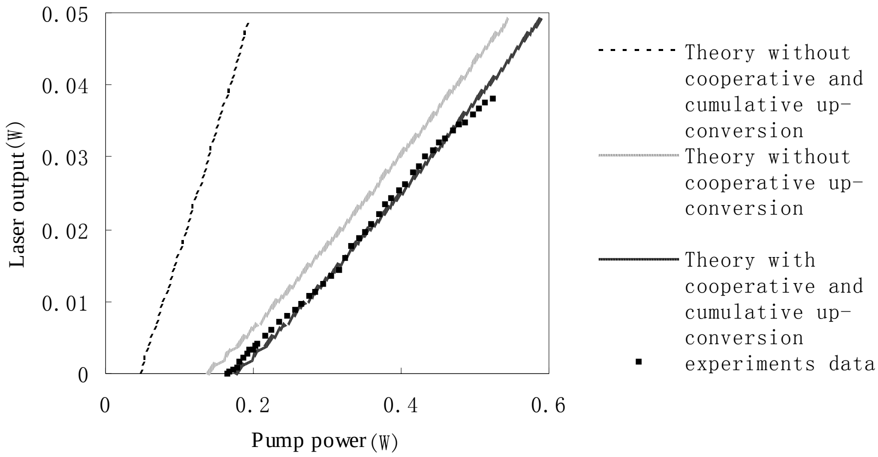


**Fig.1** Theory and experiments comparison

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*Project supported by NSFC 60377033, and 60025512 and Creastin Funding from Nankai-Tianjin Coco-Cola Drink Inc.

# PMB Molecular Kinetics at the Polyurethane Surfacial Interfaces

Lee I and Shin HY

Membrane mimetic polymer PMB(2-methacryloyloxyethyl phosphorylchroline- co-n-butyl methacrylate) polymer was designed in maximize biocompatibility. To understand the physiobsorption mechanism of a membrane mimetic polymers on the hydrophilic and heterogeneous polyurethane surfaces (PU), interfacial morphology was studied at real-time and molecular level. It seemed that PMB polymers were absorbed at hard segment areas of the PU surfaces, which appears as hydrophobic surface, and then progressively the coated PMB islands formed the networks. Finally holes were appeared on the PMB coated PU surface. The holes indicated the hydrophilic soft segments of the PU surfaces. The absorption kinetic was proportional to Ln([PMB]).

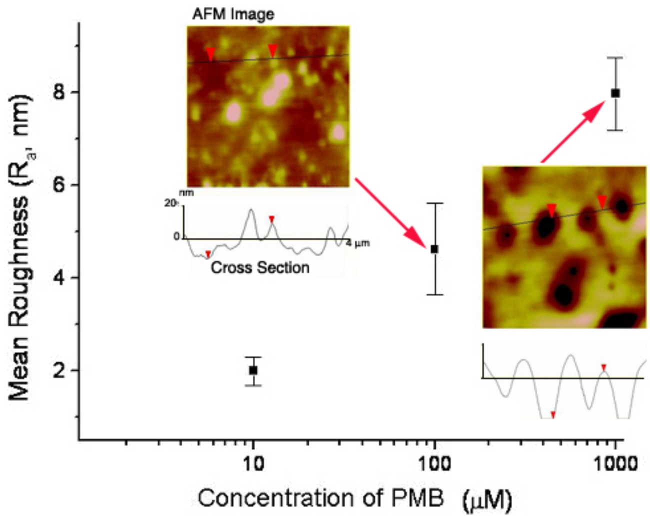


**Fig. 1**: Morphology and section analysis of different concentration PMB-coated PU surfaces. All AFM images were obtained after 30 min incubation time that was after saturation time. The isolated PMB adsorption for 100 μM PMB observed, while the networked and layered PMB adsorption for 1 mM PMB for 30 min did. Roughness of the PMB-coated PU surfaces was proportion to Ln[PMB].

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Supported by the outstanding program of Nankai University

# Analysis of Capillary Interferometry for Measuring Refractive Indices of Minute Samples

Shengwen Qi, Xiuqin Yang, Chunping Zhang, Lianshun Zhang, Xinyu Wang, Tang Xu

A method of measuring the refractive indices of minute samples by analyzing capillary interferometry is introduced. With the interference theory of light, the intensity distribution of an interference fringe pattern formed by a cylindrical tube of a capillary is obtained, and the influences of some parameters on the fringes are discussed. The measurement accuracy and its relative problems are analyzed.

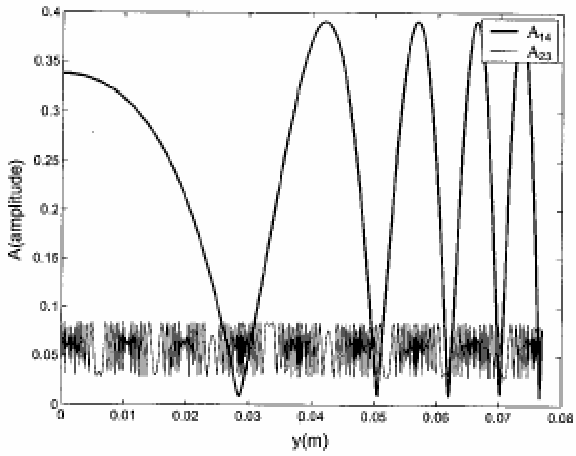


Fig. 1. Calculated amplitude distributions *A*14 and *A*23 of the interference field on the screen

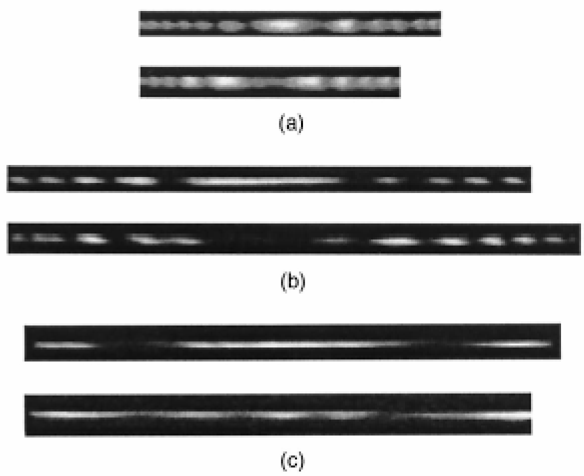


Fig. 2. Photographs of interference fringes (a) $d_0$= 0.4 m, (b) $d_0$ = 1.5 m, ( *d* ) $d_0$= 2.5 m

This work was supported by the National Natural Science Foundation of China under Grant No. 60278007 and 60025512.
published on Applied Optics.

# Nonlinear Optical Properties of Mercury Dithizonate in Polymer Film

Shengwen Qi, Xiuqin Yang, Rui Lu , Kuan Chen, Chunping Zhang, Jianguo Tian, and Jingjun Xu
Duo Wang , Qiang Wu, Zhengji Song, Wenqiang Huang, Binglin He

The absorption spectra of trans and cis isomers of mercury dithizonate in doped PMMA film were measured, and the optical properties of the two isomers were analyzed. The properties indicate that the different isomers of mercury dithizonate can convert into each other irradiated by proper wavelength light. With Z-scan method, the nonlinear optical properties of mercury dithizonate are investigated, and the experimental data of nonlinear refractive index and the change of refractive index are obtained. The changes of refractive index as a function of wavelength are obtained by Kramers-Kronig transformation.

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published on J.Modern Optics.

# Determination of the waist position of a Gaussian beam by enhanced chemically bacteriorhodopsin film

Zhang Chunping, Chen Guiying, Guo Zongxia, Tian Jianguo,
Qiwang Song, and Mingchien Huang

The waist position is an important optical parameter of a Gaussian beam. The waist position of a Gaussian beam passing an optical system is different from the focal position of an optical system, so the methods of the measuring focal length of an optical system can't be used for determining the waist position of a Gaussian beam. Here we present the properties of bR film and measure the transmitted intensity of bR film as a function of the incident intensity. A new method of determining waist position of a Gaussian beam passing an optical system by using enhanced chemically bacteriorhodopsin film is proposed. The measured results are in agreement with the calculated results based on the parameters of the Guassian beam. This new method is simple and easy to perform.

This work was supported by the National Natural Science Foundation of China under Grant No. 60078012 and 60278007.
published on Journal of Optoelectronics Laser.

# Analysis of higher order self-diffraction of low power continuous wave based on nonlinear transmission of bR film

Chunping Zhang, Guiying Chen, Q.Wang Song , Zongxia Guo, Gang Fu

Higher order self-diffraction in bacteriorhodopisn (bR) film has been investigated.The diffraction efficiencies of higher order self-diffraction as a function of incident intensity and order are analyzed theoretically. The increase of the diffraction efficiency of higher order is due to the nonlinear transmission property of bR film that leads to the non-sinusoidal grating in shape and induces an increase of the harmonic components, the calculated results taking into account of the contribution of the harmonic components for diffraction efficiencies are in agreement with the measured results.

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This work was supported by the National Natural Science Foundation of China under Grant No. 60278007 and 60025512)
published on J. Modern Optics.

# The dynamic characters of self-diffraction in bacteriorhodopsin film

GUO Zong-Xia, CHEN Gui-Ying, ZHANG Chun-Ping, TIAN Jian-Guo, Q. Wang Song,
SHEN Bin, FU Guang-Hua

The dependences of the diffraction efficiency of the first order self-diffracted beam in bacteriorhodopsin (bR) film on the illumination time, the intensity and wavelength of the incident light were measured. When the blue light ($\lambda = 488nm$) and low intensity red light ($\lambda = 632.8nm$) were incident on bR film respectively, the diffraction efficiencies increased from zero to a stable value with the illumination time. When the green light ($\lambda = 533nm$) and high intensity red light illuminated bR film respectively, the diffraction efficiencies increased from zero to the maximum and then decreased to a stable value with the illumination time. Rise and decay times were dependent on the intensity and wavelength of the incident light. The maximal diffraction efficiencies of the red and blue light were twice higher than that of the green light. The highest diffraction efficiency of 5.4% was obtained at 633nm. The diffraction efficiency change following the time for the green light was larger than that for the blue and red light.

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This work was supported by the National Natural Science Foundation of China under Grant No. 60278007 and the Natural Science Foundation of Tianjin under Grant No 033601311.
published on Chinese Physics Letters.

# Experimental study of photoinduced birefringence in azo-dye-doped polymer

Shengwen Qi, Chunping Zhang, Xiuqin Yang, Kuan Chen, Lianshun Zhang, Xinyu Wang, Tang Xu, Jianguo Tian, Guangyin Zhang

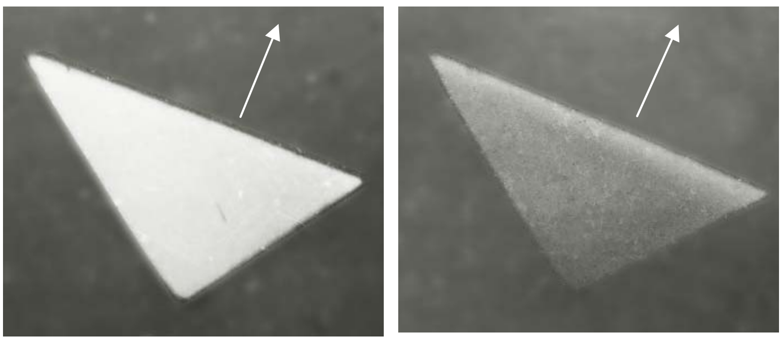
Under varying intensities and polarization of the exciting light respectively, the photoinduced birefringence of azo dye polymer film placed between a pair of orthogonal polarizers is studied by measuring the transmitted intensity. It is concluded that the saturation and stable values of the transmitted intensity are all proportional to the intensity of exciting light. Both values also relate to the polarization direction of the exciting light, and when the angle q between the polarization directions of the probe intensity and the exciting light is lager than 10_, the saturation and stable values of the transmitted light are all proportional to sin2 2q. In addition, the birefringence of the sample was measured accurately by using a compensator.

This work was supported by the National Natural Science Foundation of China Grant No. 60278007 and 60025512
published on Optik.

# A new kind of optical novelty filter using bacteriorhodopsin film

Chunping Zhang, Guiying Chen , Xuan Wei, Zongxia Guo,Jianguo Tian, Xingyu Wang, Guangyin Zhang and Q. Wang Song

A new kind of optical novelty filter is presented by incoherent light system, which is based on a special property of dynamic complementary suppression modulated transmission (DCSMT) in bacteriorhodopsin (bR) film. Through simplifying the energy system, we establish a theory model, the result obtained by experiment is compared with those reached by data simulation of the novelty filter. Figure shows the experimental demonstration of the novelty by bR film, a and b are the photographs of the input pattern and the output image respectively. The arrows in a and b are the moving directions of the inout pattern and the output image respectively.



a b

This work was supported by the National Natural Science Foundation of China under Grant No. 60278007 and the Natural Science Foundation of Tianjin, China under Grant No 033601311.
to be published on Optics Letters.

# Reusable Biological Film--A New Application of Blue Membrane

Tianhao Zhang, Guiying Chen, Zongxia Guo, Chunping Zhang, Liqun Gu,
Guangyin Zhang, Q.Wang Song

Red light can convert a blue membrane into a pink membrane, which has a good thermal stability and can be converted back by illumination of blue light. Taking advantage of this property, a reusable biological film based on the deionized blue membrane is demonstrated, which can be used to store and erase images conveniently. The device exhibits a resolution of～64 line pairs/mm. The MTF of the blue membrane system is presented.

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This work was supported by the National Natural Science Foundation of China under Grant No. 60078012 and 60278007.
published on Optical Engineering.

# Digital optical operation with multilateral system by bacteriorhodopsin film

Gu Li-Qun, Chen Gui-Ying, Guo Zong-Xia, Zhang Chun-Ping,
Tian Jian-Guo, Zhang Guang-Yin, Q.W.Song

Bacteriorhodopsin film has special property of complementary suppression modulated transmission of the yellow and blue beams. Resolved the transmission rate equations of the yellow and blue beams, the analytical formulae are obtained and graphic results are shown. We bring forward the multilateral system computational model of digital optical matrix addition and subtraction operation without carry and abdication respectively. The novel model and frame of basic optical computation are constructed, and the optimized project of digital optical matrix addition and subtraction operations are designed.

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This work was supported by the National Natural Science Foundation of China under Grant No. 60278007 and 60278007)
published on ACTA PHYSICA SINICA.

# The growth of large-diametered nearly stoichiometric lithium niobate crystals by double crucible technique

Yongfa Kong, Jun Sun, Ling Zhang, Bing Li, Shiguo Liu, Ziheng Huang, Shaolin Chen, Jingjun Xu, and Guangyin Zhang

Recently, nearly stoichiometric lithium niobate (NSLN) crystal has been paid much attention for its excellent physical properties as compared with congruent one (CLN). However, the growth of NSLN is more difficult than that of CLN. Among these methods for growing NSLN[1-3], double crucible technique is the most successful one for commercial purpose.

As shown in Fig. 1, a new double crucible method was designed, which is different from what is repeoted by Kitamura et al[3]. NSLN crystal (shown in Fig. 2) was grown in the lower crucible with a melt composition of $[Li_2O]/[Nb_2O_5]$ = 58/42, and it is the melt not the powder that was continuously added from the higher crucible. The composition of the adding melt is $[Li_2O]/[Nb_2O_5]$=36/64, far away from the stoichiomtric point of 50/50. 3 inch NSLN crystals were successfully grown with a radial composition deviation of ±0.02 mol% and a axial composition deviation less than ±0.03 mol%/cm.

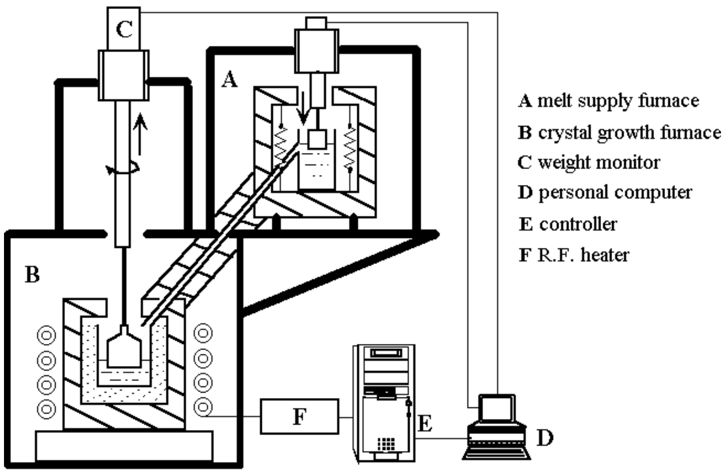


**Fig. 1**: A sketch of double crucible technique.

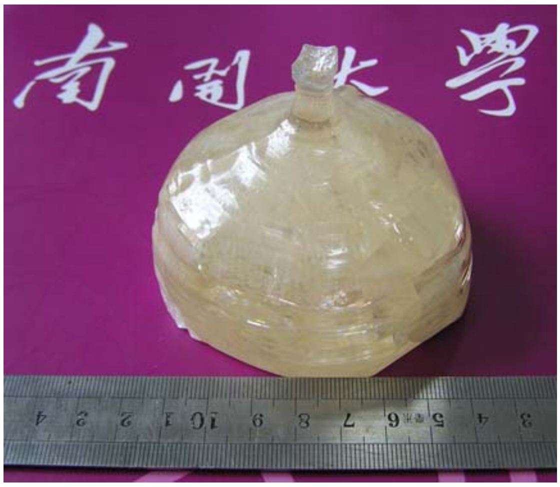

**Fig. 2** 3 inch NSLN crystal.

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Supported by the National Advanced Materials Committee of China (2001AA313020)
Two patents in application (200410019454.X and 200410019732.1).

# Optical Microstructure Materials and Applications

Chen Yunlin, Guo Juan, Yuan Jianwei, Luo Yongfen, Yan Weiguo, Zhou Binbin, Chen Shaolin, Huang Ziheng

Based on the theoretical analysis of cascading of sum frequency-generation and difference-frequency- generation processes ( $\chi^{(2)}:\chi^{(2)}$ ) under quasi-phase-matched conditions, we fabricated periodically poled lithium niobate (PPLN) and annealed-proton-exchanged waveguide (APE). Using the fabricated crystal of PPLN—APE, we carried out an all-optical switching experiment. The control pulse was generated by a Q-switched $Co^{2+}$ doped $MgAL_2O_4$ laser with a wavelength of 1.54μm. The CW signal beam was generated by a laser diode with a wavelength of 1.5μm. When the control pulse intensity reached 3KW and the CW signal intensity reached 1mW, the all-optical switching realized a switching efficiency of 13%.

Periodically poled $LiNbO_3$(PPLN) waveguide quasi-phase-matched all-optical for wavelength conversion was studied theoretically. The analysis suggests useful criteria for the optimization of the fabrication parameters in order to enhance the efficiency of quasi-phase-matched wavelength conversion processes

MgO-doped different compositions of $LiNbO_3$ crystals have been produced using vapor transport equilibration technique. The poling characteristics of the crystals with different Mg doping levels have been investigated. The switching field and the spontaneous polarization $P_s$ of the crystals were as a function of crystal stoichiometry and Mg content. The switching field for the domain reversal in the near stoichiometric crystal with [Li]/[Nb]=0.973 doped with 2.0mol.% MgO was 1.8KV/mm. This is about one twelfth of the switching field for the congruent crystal, and the pattern of the periodic domain in the crystal is better than in the congruent and stoichiometric crystal.

MgO-doped (6.5mol.%) congruent $LiNbO_3$ (MgO:LN) was periodically poled and its operation in a femtosecond second-harmonic generation at room temperature. Because the switching field of MgO:LN is ~5KV/mm, which is approximately one fourth that of the congruent LN field, periodic poling of thicker MgO:LN wafer was successfully performed by means of applying external field at room temperature. The performance of quasi-phase-matched second harmonic generation with a 1mm thick PP MgO:LN was compared with that of the second harmonic generation with the PP CLN at room temperature. The PP MgO:LN exhibited better performance.

# Submicron domain patterning in $LiNbO_3$ doped MgO

Yao Jiang-Hong, Yan Bo-Xia

By applying microsecond pulse field, We succeeded in fabricating a uniform submicron domain patterning with a period of 1.7 $\mu$m in $LiNbO_3$ doped 5mol.% MgO. And the depth of these domain strips is, typically, about 30 to 50 $\mu$m. When applying a poled field with a pulse width of 100 ms, the domain-inverted structure with a width of 0.5 $\mu$m was obtained. Using the spontaneous domains backswitching and domain side-grown effects, we explain the mechanism of the submicron domains evolution.

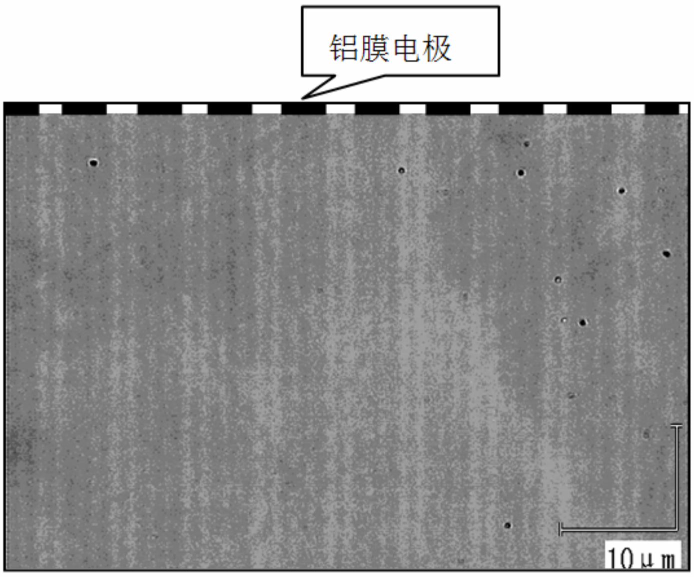


**Fig.1** submicron domain of periodically poled $LiNbO_3$ doped 5mol% MgO

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Published in Acta Physica Sinica (2004)

# Effect of vapor transport equilibration and Mg doped on the luminescence of Er:$LiNbO_3$

J.H. Yao, B.X. Yan

Luminescence properties of the congruent and vapor transport equilibration (VTE) treated Er:$LiNbO_3$ and Er:Mg:$LiNbO_3$ crystals were recorded at room temperature. It is observed that VTE treatment could enhance the emission intensity of $Er^{3+}$ ions and doping with MgO would weaken it in the visible spectra. As a result, the luminescence intensity of $Er^{3+}$ ions in the VTE treated Er:Mg:$LiNbO_3$ crystal increased up to 2.2 times than that in the congruent Er:$LiNbO_3$ crystal. In addition, both VTE treatment and doping with MgO result in some changes of the relative emission intensity of some peaks in the visible emission spectra. In the infrared emission spectra, the luminescence peak at 1540 nm of $Er^{3+}$ ions shifts towards the larger wavelength when the Er:$LiNbO_3$ crystals were treated using VTE or doped with MgO. The changes in crystalline environment of $Er^{3+}$ ions due to VTE treatment or doping with $Mg^{2+}$ play a key role in these phenomena.

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Supported by the national Natural Science foundation of China (Grant No: 90101022), the Natural Science Foundation of Tianjin and the foundation of National Laboratory for Infrared Physics.
Published in Optical Materials **27**, 373-376(2004)

# Nature of Nanocrystals Structure in Oxyfluoride Glass Ceramics*

YU Hua, ZHAO Lijuan, MENG Jie, LIANG Qin, TANG Liqin, YU Xuanyi, TANG Baiquan, and XU Jingjun

The up-conversion luminescent property of the oxyfluoride glass ceramics $30SiO_2 \bullet 15Al_2O_3 \bullet (50\text{-}x)PbF_2 \bullet xCdF_2 \bullet$doped with $4ErF_3 \bullet 1YbF_3$ has been investigated. Up-conversion luminescent intensity of $Er^{3+}$ ions increased obviously after heat-treatment due to co-doping with $CdF_2$. The structure model of nanocrystals $Pb_xCd_{1-x}F_2$ was determined and the effect of $CdF_2$ in oxyfluoride glass ceramics was explained by the analysis of XRD data. Different nucleation temperatures of samples with different compositions were obtained by DTA curves and the results showed the growth process of different nanocrystals in glass ceramics.

$Pb_xCd_{1-x}F_2$ nanocrystals phase could be formed in glass ceramics. Cd ions replace Pb ions to form $Pb_xCd_{1-x}F_2$ nanocrystals, and $Pb_xCd_{1-x}F_2$ structure keeps a face-centered-cubic (fcc) structure. The rare earth ions doped in $Pb_xCd_{1-x}F_2$ nanocrystals would enhance greatly the up-conversion luminescence. High nucleation temperature of $CdF_2$ makes $Pb_xCd_{1-x}F_2$ nanocrystals more difficult to be formed.

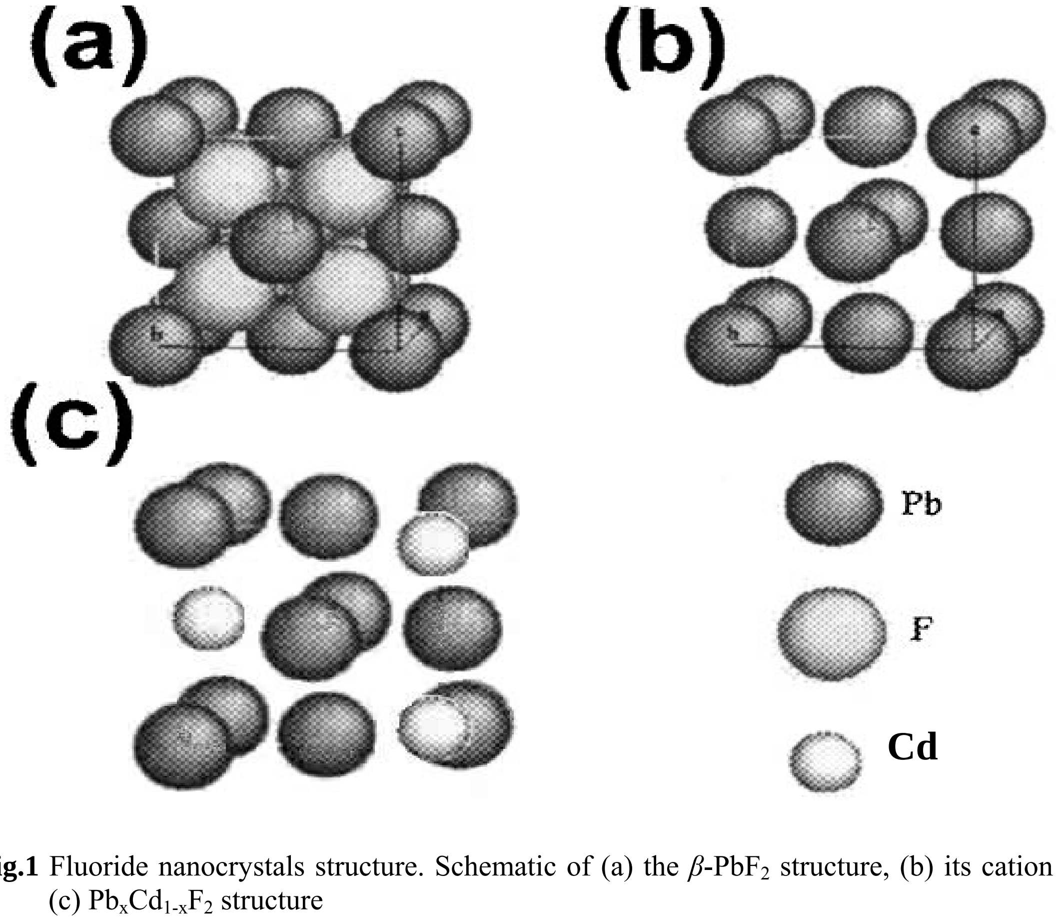


**Fig.1** Fluoride nanocrystals structure. Schematic of (a) the $\beta$-$PbF_2$ structure, (b) its cation sublattice and (c) $Pb_xCd_{1-x}F_2$ structure

The investigations were made within the frame of grant No. 60178024 financed by the National Natural Scientific foundation of China.
To be published on Jonal. Phys. 54(3) 2005

# Red up-conversion luminescent process in the oxyfluoride glass ceramics doped with $Er^{3+}/Yb^{3+}$ *

YU Hua, ZHAO Lijuan, MENG Jie, LIANG Qin, TANG Liqin, YU Xuanyi, TANG Baiquan, and XU Jingjun

The Phonon-assisted Energy Distribution (PED) model was presumed in order to clarify the process of the red up-conversion emission process in $Er^{3+}/Yb^{3+}$ co-doped glass ceramics by the excitation and emission spectra. The red up-conversion emission of $Er^{3+}$ ions mainly comes from three-photon absorption by Phonon-assisted Energy Distribution process when the rare earth ions was doped in the glass ceramics and excited by 980nm pumped-laser. $Er^{3+}$ ions absorb three-photons to transit to $^4G_{11/2}$ state and then emit the red up-conversion luminescence. The calibration coefficient for the relation of pump-laser power and up-conversion intensity (*P-I*) was found through the analysis of excitation spectra of the red luminescence, which was the main factor to understanding the true red up-conversion emission process. The new *P-I* relation was explained by the model of Phonon-assisted Energy Distribution.

In conclusion, phonon-assisted energy distribution (PED) model was presumed in order to explain the red up-conversion emission process by the measurements of excitation and emission spectra in oxyfluoride glass ceramics. The red up-conversion emission mainly comes from $^4G_{11/2}$ state by means of the PED process with three-photon absorption.

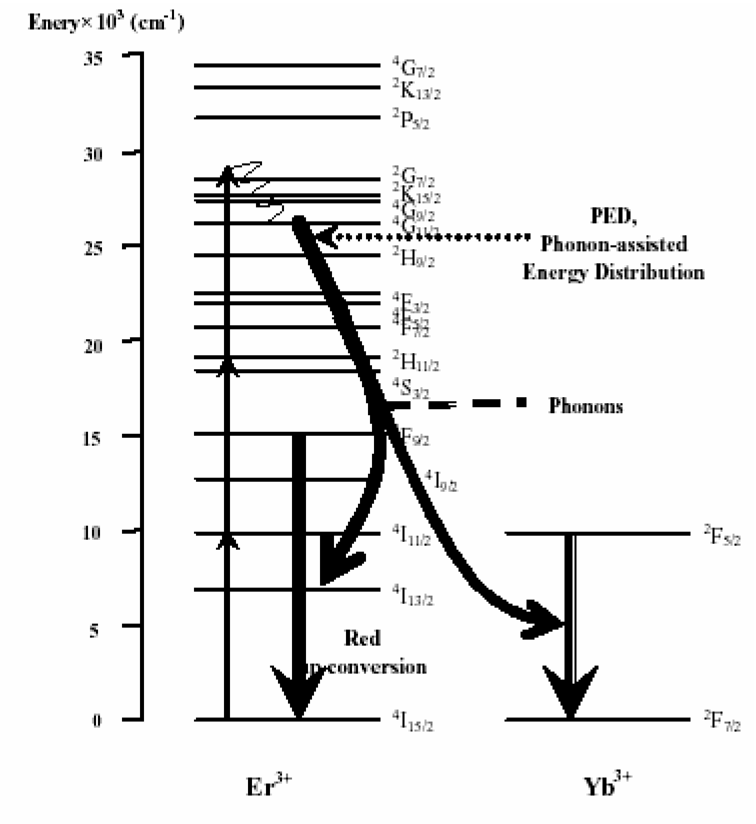


**Fig.1** Schematic energy state diagram and red up-conversion luminescent mechanism (Phonon-assisted Energy Distribution, PED) under 980 nm laser excitation

The investigations were made within the frame of grant No. 60178024 financed by the National Natural Scientific foundation of China.
Submitted to Chin. Phys. Lett.

# Luminescent Enhancement in Mg- and Er-Codoped $LiNbO_3$ Crystals

Tang Liqin, Zhao Lijuan, and Zhang Xinzheng

We investigate the MgO codoping-induced effect on the luminescent properties of $Er^{3+}$-doped and Er/Mg codoped $LiNbO_3$ crystals. The emission and excitation spectra and the absorption spectra are measured. The results show that the luminescent behaviour of $Er^{3+}$ ions is very sensitive to the codoping of $Mg^{2+}$ ions. According to the photorefractive level theory, we propose a quench model for the Er/Mg codoped lithium niobate crystal. The quench centres are suggested to be the bipolaron ($Nb_{Li}$-$Nb_{Nb}$), we attribute the luminescent enhancement to the decreasing concentration of these centres. The luminescent enhancement effect is successfully explained.

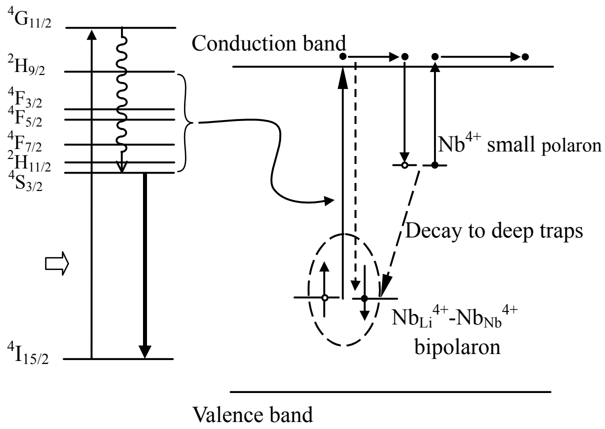


**Fig. 1**: Energy quench diagram in $LiNbO_3$ doped with Er ions

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Supported by the National Natural Science Foundation of China under Grant Nos 60208003 and 60178024.
To be published on Chin. Phys. Lett. **22**(3), (2005)

# Light Induced Interfacial Electron Transfer in Phenylcapped Aniline Tetramer /$TiO_2$/ ITO Film Electrode

CAO Ya-An

$TiO_2$ monolayer film and $TiO_2$ sensitized with phenylcapped aniline tetramer (Pat) complex film(Pat/$TiO_2$), were prepared by the rolling coat and soak method respectively. By means of surface photovoltage spectroscopy (SPS), cyclic voltammograms with irradiation(CAGI) and the photocurrent action spectra(PAS), the band gap and energy level of surface states of $TiO_2$ monolayer film, the energy level of ground state, energy level gap(HOMO~LUMO) and energy level of dual polarons of phenylcapped aniline tetramer and the properties of photo-to-electric conversion of Pat/$TiO_2$ complex film were investigated. By the results of SPS, CAGI and PAS and the energy band structure of the Pat/$TiO_2$ complex film, the reasonable mechanism of interfacial electron transport in $TiO_2$ sensitized with phenylcapped aniline tetramer film electrode was analysed.

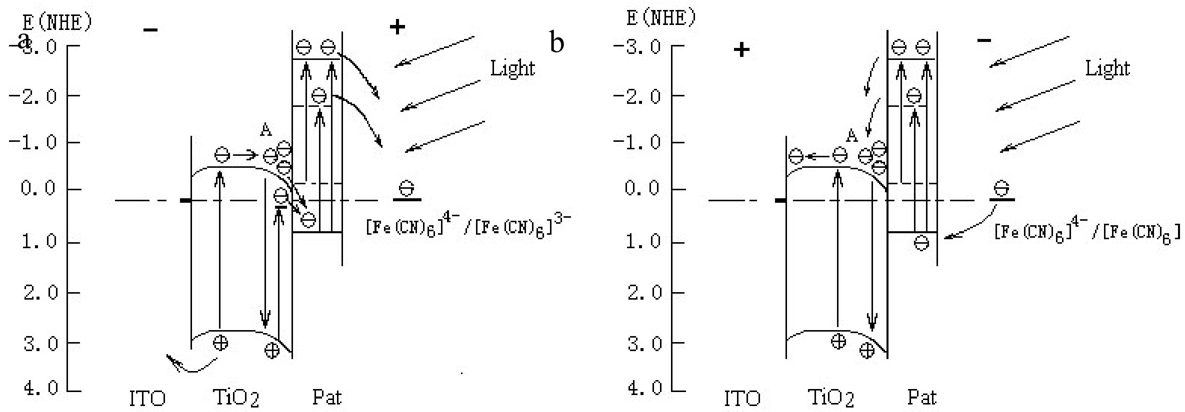


**Fig.1** Schematic representation for energy band levels of the phenylcapped aniline tetramer/TiO2/ITO film.

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# The study of umpty important question of photovoltaic photorefractive nonlinearity

Guo Ru, Liu Si-Min, Gao Yuan-Mei, Huang Chun-Fu, Yang Li-Sen

First, we have observed an effect of light-induced refractive index change in $LiNbO_3$:Fe crystal sheet, which belong to the second pyroelectricity effect. It has characters of faster response (<0.1s), isotropy and function of information storage. Second we have study the dynamic propagation of an optical beam from self-defocusing to self-focusing in photovoltaic photorefractive $LiNbO_3$:Fe crystal only when the normalized dark irradiation is very small, and we discuss the influence of pyroelectric effect on the transition process. Third, we experimentally study the light coupling behaviors between the transmitting light and reflected light in y-cut $LiNbO_3$:Fe crystal. When the e-polarized incident light is launched into the crystals along +y axis and -y axis, respectively, we find that the time behaviors of the reflectivity and transmissivity are almost identical for both cases, respectively. Whereas when the o-polarized incident light is launched into the crystals along +y axis and -y axis, respectively, the time behaviors of the reflectivity and transmissivity for both cases are obviously different. Finally, based on the z-scan method, we present a new method, the time-scan method, to measure the dynamic behavior of the photorefractive nonlinear parameter, we prove theoretically and experimentally that the new method is precise and feasible.

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Publications concerning,
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[2] Chunfu Huang, Ru Guo, Simin liu, Acta Physica Sinica 53, 1367(2004)
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[4] Yuanmei Gao, Simin Liu, Ru Guo, Acta Physica Sinica 53, 2958(2004)

# The study of the nonlinear optical effect of incoherent light

Simin Liu, Ru Guo, Yi Lu

We have observed experimentally one-dimensional photovoltaic dark spatial solitons in $LiNbO_3$:Fe crystal by using incoherent white light. We have also fabricated a directional coupler consisting of two waveguides induced by two mutually incoherent white-light photovoltaic dark spatial solitons propagating in parallel in close proximity. It was found that the light field of a probe laser beam launched into one of the two proximate waveguides can by efficiently coupled into the other waveguide because of the presence of evanescent waves. We also studied the dependence of coupling efficiency on thr distance between the two proximate soliton-induced waveguides.

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# Dispersive phase coupling induced superluminal and subluminal light propagation in $Bi_{12}SO_{20}$ crystals at room temperature

Guoquan Zhang, Fang Bo, Rong Dong, Bin Han and Jingjun Xu

The group velocity of light pulses can be controlled by various ways. Both superluminal and subluminal light pulse propagation has been realized by means of the electromagnetically induced transparency and the coherent population oscillation effect. Such techniques have important applications such as optical delay lines, novel acousto-optic devices as well as giant nonlinear optics.

We have predicted theoretically and demonstrated experimentally both superluminal and subluminal light propagation in $Bi_{12}SO_{20}$ (BSO) crystals by means of the dispersive phase coupling effect in the photorefractive two-wave mixing process at room temperature. We have observed a group velocity $V_g$ from as slow as ~ 0.5 m/s to as fast as -2.6 m/s for a single Gaussian pulse and $V_g$ of 0.05 m/s for a train of sinusoidal pulses. We are able to modify $V_g$ for both Gaussian pulses and sinusoidal pulse train to quite a large extent by adjusting the experimental conditions such as the total intensity of the coupling beams and the external direct-current electric field applied on the BSO crystal.

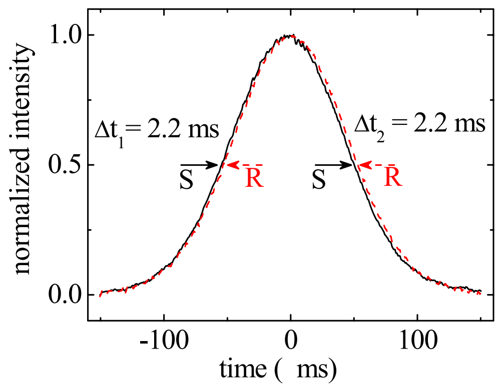


**Fig. 1** Typical temporal traces of the reference pulse (dashed red curve) and the transmitted signal pulse (solid black curve) for measuring $V_g$ of single Gaussian pulse. An advanced time of 2.2 ms corresponds to $V_g$ of -2.6 m/s.

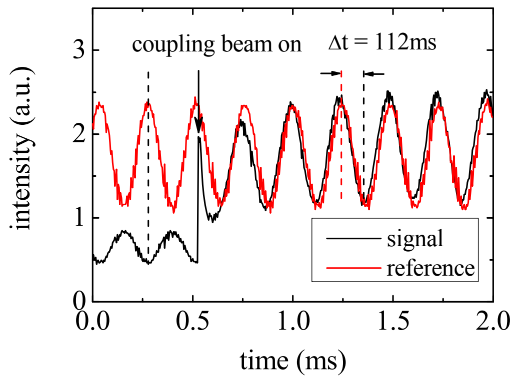


**Fig. 2** Temporal traces of the reference beam (red) and the transmitted sinusoidal signal wave (black) for measuring $V_g$ of the sinusoidal pulse train, a 112 ms time delay corresponds to a group velocity as slow as 0.06 m/s.

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Published on Appl. Opt. **43**, (2004) 1167-1173 and Phys. Rev. Lett. **93**, 133903 (2004).

# Nonvolatile two-step, two-color holography with continuous-wave lights for both congruent and near-stoichiometric $LiNbO_3$:Fe

Yan Shen, Guoquan Zhang, Bo Fu, Qingjun Xu and Jingjun Xu

Nonvolatile holographic recording has attracted much attention because of its potential application on reversible data storage with a high storage capacity, short access times, and high data-transfer rates. We have studied theoretically the steady-state nonvolatile two-step, two-color holographic recording performance for both the congruent and the near-stoichiometric $LiNbO_3$:Fe based on the two-center model. The results show that the direct electron exchange between the $Fe^{2+}/Fe^{3+}$ centers and the $Nb_{Li}^{4+}/Nb_{Li}^{5+}$ centers due to the tunneling effect dominates the charge transfer process during the nonvolatile two-step, two-color holography and determines the two-step, two-color holography performance in $LiNbO_3$:Fe. We have further studied the effects of the crystal stoichiometry on the performance of the two-step, two-color holography. Figure 1 shows the dependence of the amplitude of the total space-charger field $|E_1|$ on the recording intensity $I_R$ with the gating intensity set to be $1.0\times10^4$ W/m$^2$. Note that the solid and the dashed curves are for the near-stoichiometric and the congruent $LiNbO_3$:Fe, respectively. It is seen that, as far as the total space charge field is considered, the nonvolatile two-step, two-color holography performance in the near-stoichiometric $LiNbO_3$:Fe is much better than that in the congruent $LiNbO_3$:Fe within the intensity range reachable by the continuous-wave lights.

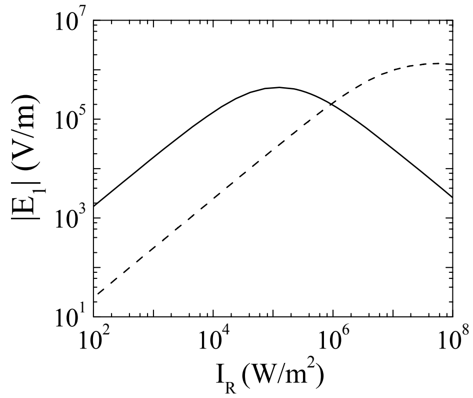


**Fig. 1:** Comparison of the two-step, two-color holography performance between the near-stoichiometric and the congruent $LiNbO_3$:Fe

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Published on Journal of Applied Physics **96**, 5405(2004).

# Studies on the threshold effect of the ultraviolet-light-induced absorption changes in congruent $LiNbO_3$:Mg

Bo Fu, Guoquan Zhang, Lubing Zhao, Haijun Qiao, Qingjun Xu, Yan Shen, Jingjun Xu, Yongfa Kong, Jun Sun, Shaolin Chen

We investigate the ultraviolet-light-induced absorption (UV-LIA) changes in congruent $LiNbO_3$ crystals doped with Mg of different concentrations. By measuring the UV-LIA coefficient changes and the UV-light-gated two-color recording sensitivity at 633 nm for congruent $LiNbO_3$:Mg, we find the UV-LIA coefficient changes in congruent $LiNbO_3$:Mg has a threshold effect with respect to the Mg doping concentration. It is only when the concentration of Mg is more than 3.0 mol.% that the UV-LIA coefficient changes extending from the near-UV to the near-infrared spectral region appears. Such a threshold behaviour is further confirmed by the measurement of the UV-light-gated two-color recording sensitivity at 633 nm. The dependence of the UV-LIA coefficient changes on the Mg doping concentration has the same tendency as the dependence of the Li vacancy on the Mg doping concentration based on the Li vacancy model of $LiNbO_3$:Mg. We attribute the UV-LIA coefficient changes to the formation of $O^-$ where a hole is trapped at an $O^{2-}$ site near a negatively charged center with respect to the lattice. The observed concentration threshold effect of the UV-LIA coefficient changes can be well explained in terms of the formation of $O^-$ centers near negatively charged centers based on the Li vacancy defect model of $LiNbO_3$:Mg.

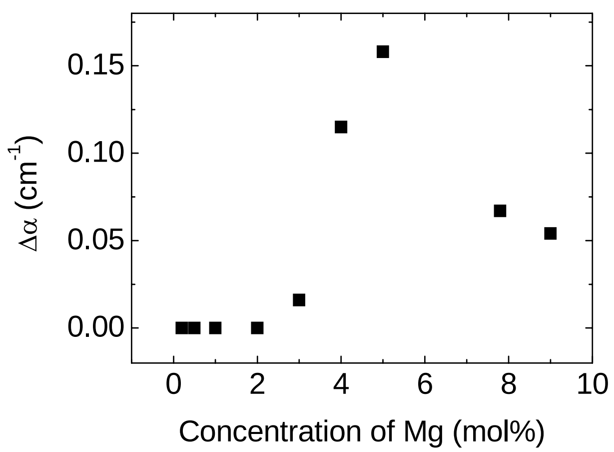


**Fig. 1** Dependence of the UV-LIA coefficient changes Δα on the Mg-doping concentrations. An incoherent UV pump beam of 740 $mW/cm^2$ and a probe beam of 1.27 $mW/cm^2$ at 633 nm were used in the experiments.

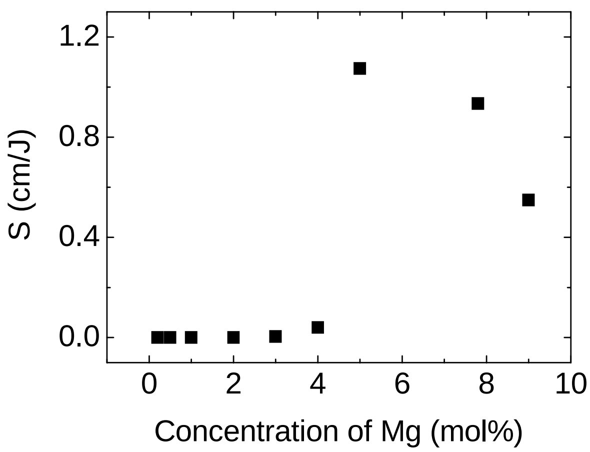


**Fig. 2** Dependence of S on the Mg-doping concentration. An UV gating beam of 120 $mW/cm^2$ and two extraordinarily polarized recording beams with equal intensities of 277 $mW/cm^2$ at 633 nm were used. The grating spacing was set to be 1.1μm.

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# Studies on thermal activation energy of ultraviolet light induced small polarons $O^-$ in damage-resistant lithium niobate crystals

Qingjun Xu, Guoquan Zhang, Haijun Qiao, Bo Fu, Yan Shen, Jingjun Xu
Yongfa Kong, Jun Sun and Shaolin Chen

We studied on the dark decay dynamics of the ultraviolet light induced absorption (UV-LIA) coefficient changes and the thermal activation energy of the generated small polarons $O^-$ in $LiNbO_3$ doped with Mg, Zn, and In, respectively. In our experiment, a coherent UV light source from $Ar^+$ ion laser at 351 nm was employed as a pump beam. Extraordinarily polarized probe beam from He-Ne laser at 632.8 nm was used. Our results are shown in Fig. 1 and Fig. 2. The thermal activation energy is measured to be ~ 0.5 eV for $LiNbO_3$:Mg with Mg doping concentrations below 9.0 mol.% and $LiNbO_3$:Zn of 9.0 mol.% Zn. For the cases when the Mg doping concentration is of 9.0 mol.% and when the doping element is $In^{3+}$ of 5.0 mol%, the thermal activation energies were found to be ~ 0.29 eV and ~ 0.18 eV, respectively. We show that the thermal activation energy of the small polarons $O^-$ is dependent on the surrounding negatively charged defect centers since a small polaron $O^-$ is formed when a hole is trapped at a $O^{2-}$ site near a negatively charged defect center.

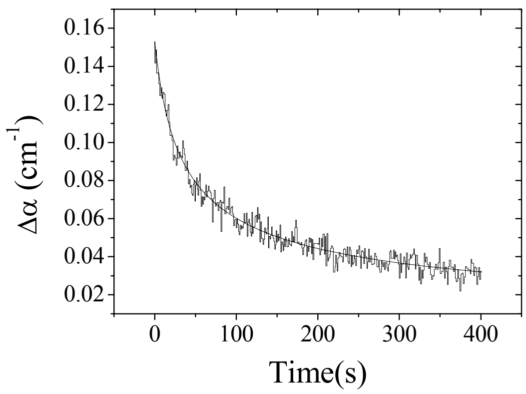


**Fig.1** Dark decay traces of $\Delta\alpha$ for the sample LNMg50. The absorption coefficient change $\Delta\alpha$ was induced by an UV light of 0.66 W/cm$^2$. The decay trace was fitted well using Eq.

$\Delta\alpha(t) = \Delta\alpha_0 / \sqrt{1 + 2\gamma\Delta\alpha^2 t}$

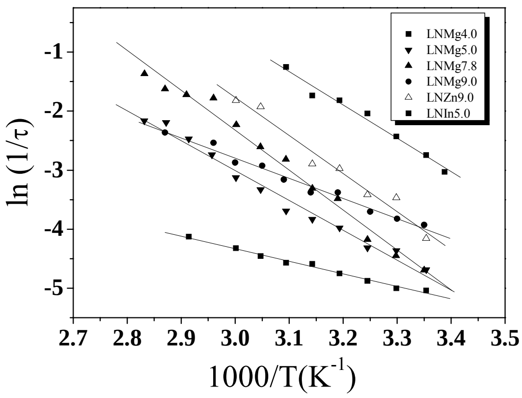


**Fig.2** Arrhenius plot of the dark decay time constants $\tau$ of the light-induced absorption coefficient changes for our samples (pump intensity I=0.66 W/cm$^2$). From the slope of the fit (solid lines), we can obtain the activation energy $E_{A.}$

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Supported by EYTP (No. 2002-350), the Scientific Research Foundation for the Returned Overseas Chinese Scholars (No. 2003-406) and the National Natural Science Foundation of China under Grant Nos. 60308005 and 10334010.

# Ultraviolet one-color and ultraviolet-red two-color photorefractive effects in near stoichiometric $LiNbO_3$:Mg crystals

Haijun Qiao, Jingjun Xu, Bo Fu, Dengsong Zhu, Guoquan Zhang, Xuanyi Yu, Wei Li, and Guangyin Zhang

We investigated the ultraviolet photorefraction (abbr. UV-PR) at 351 nm of several $LiNbO_3$ crystals with different Mg-doping concentrations and different [Li]/[Nb] ratios and found that they both bring great influences on the UV-PR properties of $LiNbO_3$. In general, with the increase of the Mg concentration and [Li]/[Nb] ratio, the amplitude of index change $\Delta n$ increases and the photorefractive response time reduces. Especially we obtained a short response time of 120 ms under a recording intensity of 1.27 W/cm$^2$ and the corresponding UV-PR recording sensitivity is up to 26.7 cm/J. This sensitivity is around an order of magnitude higher than that ever reported so far. Such a fast response may find potential applications in real-time optical information processing. In the meantime we studied the ultraviolet-gating-red two-color photorefraction (abbr. UV-Red-PR) in the same samples and found that UV-Red-PR can be observed only in the near stoichiometric crystals. It is also observed that the behavior of the UV-Red-PR grating depends on the Mg concentration greatly and the RV-Red-PR recording sensitivity increases with the increase of Mg concentrations. Based on the results, we demonstrated that, unlike the usual consideration, the influences on the defect structures of $LiNbO_3$ by doping Mg and varying [Li]/[Nb] ratio are not exactly the same, and some discussion was also made about the novel results. And the concentration threshold for the damage resistance is a milestone for the defect structure and consequently plays an important role in both UV-PR and UV-Red-PR properties.

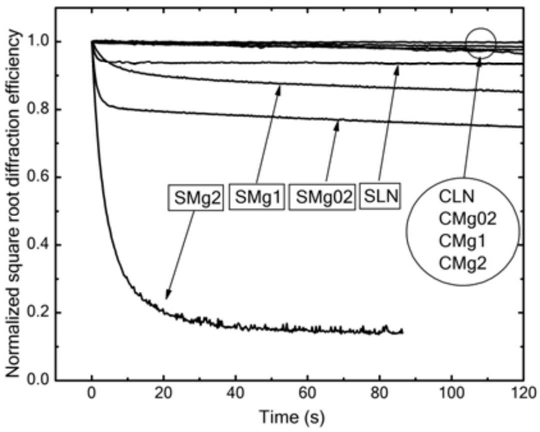


**Fig. 1**: Dark decaying behaviors of UV-PR grating

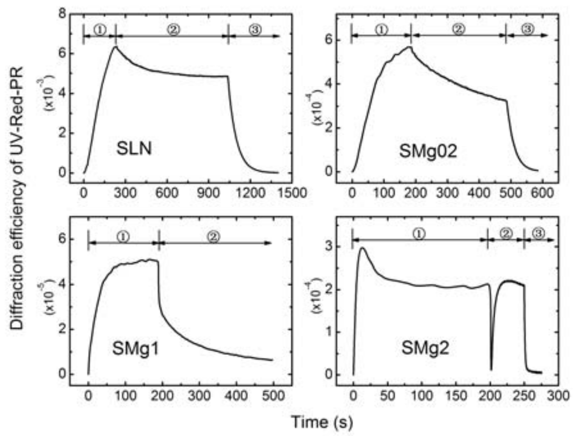


**Fig. 2**: the typical UV-Red-PR behaviors

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# The photo-assisted wet-etching effect in lithium niobate crystals by laser irradiation at different wavelengths

Xuanyi Yu, Jingjun Xu, Haijun Qiao, Baiquan Tang, Hua Yu

The photo-assisted wet-etching has been the subject of numerous research interests, especially in controlling the process of fabricating micro-structure accurately.Light-induced latency effect on etching in lithium niobate crystals was investigated. We chose the undoped congruent lithium niobate (CLN), undoped near stoichiometric lithium niobate (SLN) and congruent lithium niobate doped with Mg and Fe (LN:Mg,Fe) as samples. Prepared in z-cut sheets, these crystals (-c surface) were etched in a mixture of HF and $HNO_3$ acids under simultaneous illumination at different wavelengths of 532nm, 488nm and 351nm. Under the intensity of around 100W/cm$^2$, it was found that different composition and illuminate wavelength had different influence to latency effect of etching. In the sample of LN:Mg,Fe, etching process was inhibited under all the wavelengths of 532nm, 488nm and 351nm, as is similar to what was seen in LN:Fe crystal. And light-induced etching frustration is also observed under the illumination at 351nm in all the samples except SLN. In general, the explanation of the effect involves the charge redistribution. The results are of interest to fabrication of photonic surface-microstructure and research mechanism of photo-assisted wet-etching effect in lithium niobate.

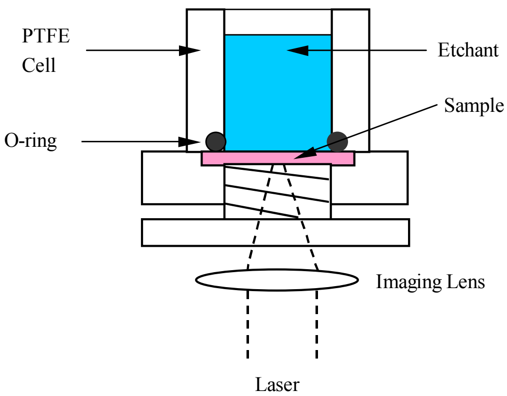


Fig.1: Experimental arrangement for $LiNbO_3$ etching

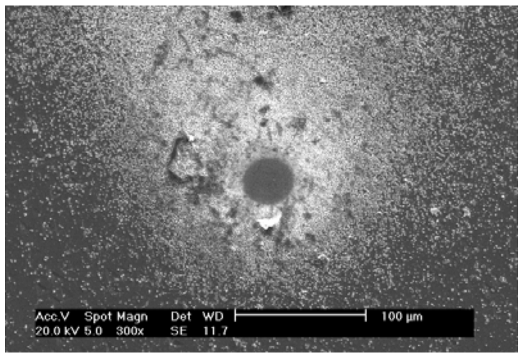


Fig.2: The illuminated region under the SEM in SLN crystal

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Supported by the Start-up foundation of Nankai University

# Observation of superluminal and slowdown light propagation in doped lithium niobate crystals

Feng Gao, Jingjun Xu, Haijun Qiao, Qiang Wu, Yin Xu, and Guoquan Zhang

We investigate the group velocity of light in a one-dimensional volume grating inside lithium niobate crystals doped with three different impurities. These crystals are referred as crystal #a doped with 0.025wt% Fe, #b codoped with 0.05wt% Fe and 0.8mol% Mg, and #c codoped with 0.15wt% Fe and 0.01wt% Mn, respectively. The superluminal and slowdown light propagations are both observed in the crystals. The relationships between the group refractive index and the grating amplitude and phase shift are presented and discussed separately.

We find that besides the diffraction efficiency and the phase mismatch due to the off-Bragg angle, the gratings with different mechanism origins are also of great influence on the results. In the crystal doped with Fe, it agrees the existing theory much more than the other two. In the crystal doped with Mg and Fe, the group velocity is oscillating while the diffraction efficiency of the grating agrees the theory[1][2][3]. We owed this to the bigger phase shift of the grating[4]. In the crystal doped with Mn and Fe, both the curve of the group velocity and the diffraction efficiency is oscillating. This may come from the relative movement of the phase gratings and the absorption gratings due to the existence of Mn.

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# Observation nonlinearity-induced symmetry breaking in a photorefractive waveguide lattice

Cibo Lou, Jingjun Xu, Zhigang Chen and P.G. Kevrekidis

Spontaneous symmetry breaking (SSB) is one of universal nonlinear phenomena in modern physics. In this paper, we provide a clear experimental demonstration of SSB in a simply system, namely, a 2D photonic lattice optically induced in a photorefractive crystal. We show that SSB of a probe beam propagating in a symmetric double-well potential as embedded in a photonic lattice happens as the strength of the nonlinearity experienced by the probe beam exceeds a threshold value, while no such SSB occurs should the probe beam itself experiences null or only weak nonlinearity.

Experiments were performed in a biased photorefractive crystal (SBN:60, 5x10x5 $mm^3$). The waveguide lattice was achieved with an ordinarily-polarized, partially-coherent beam ($\lambda$= 488 nm) periodically modulated with an amplitude mask [1]. A Gaussian beam was used as a coherent probe beam propagating between two lattice sites in the vertical direction. When the probe beam was extraordinarily polarized, we observed SSB as the intensity of the probe beam was increased gradually while keeping all other experimental conditions unchanged (Fig. 1, top panel). In contrast, when the probe beam was ordinarily polarized, or replaced with a much less photosensitive wavelength ($\lambda$= 633 nm), such SSB did not occur regardless the increase of probe intensity. Our experimental results are in good agreement with recent theoretical predictions [2].

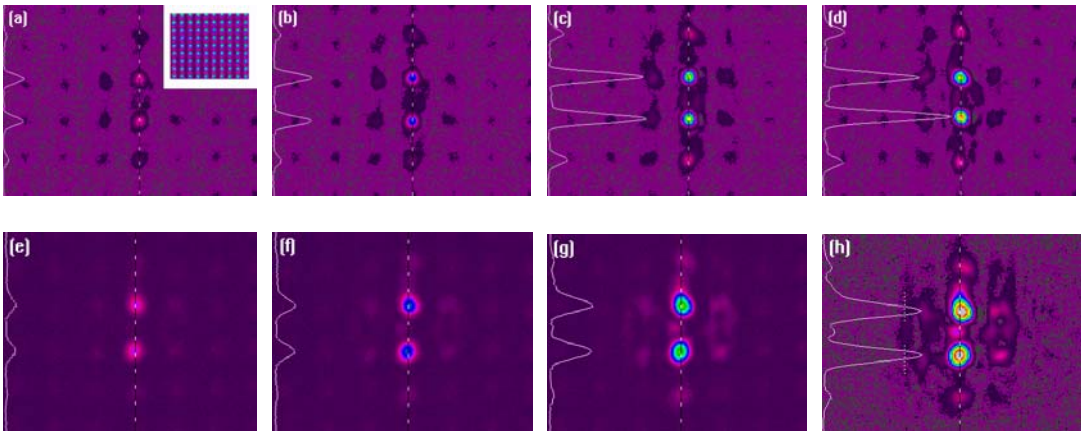


FIG. 1: Experimental demonstration of SSB in an optically induced photonic lattice. From (a) to (h), shown are the transverse intensity patterns of the probe beam (initially a fundamental Gaussian beam) at an intensity (normalized to the lattice intensity) of 0.1, 0.2, 0.4, 0.5; 0.2, 0.4, 1.0 and 2.0. Top panel: 4 figures from 488 e-beam, showing SSB. Bottom Panel: 4 figures from 633 e-beam, showing no SSB. The bias field was kept at 2 kV/cm, and all other parameters were fixed. The insert in (a) shows the output lattice pattern.

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# Adopting Cross-correlation analyse to increase the predicted results' accuracy of Grey multi-component system

Zhong-chen Wu, Xiao-xuan Xu, Qi-nan Li, Gang Yu, Cun-zhou Zhang

The ethanol's concentration in a Grey multi-component is quantitatively measured adopting cross-correlation analysis with Partial Least-Squares Regression by near infrared spectrum, and the relation that the signal's amplitude transformed by cross-correlation analysis is proportional to the concentration of the measured component is proved. The author point out that the cross-correlation can effectively enhance valuable information of the measured component and adopting Cross-correlation analysis combining Partial Least-Squares Regression can greatly increase the predicted results' accuracy of. The part cross-correlation spectra of the Grey multi-component system are shown in Fig.1.

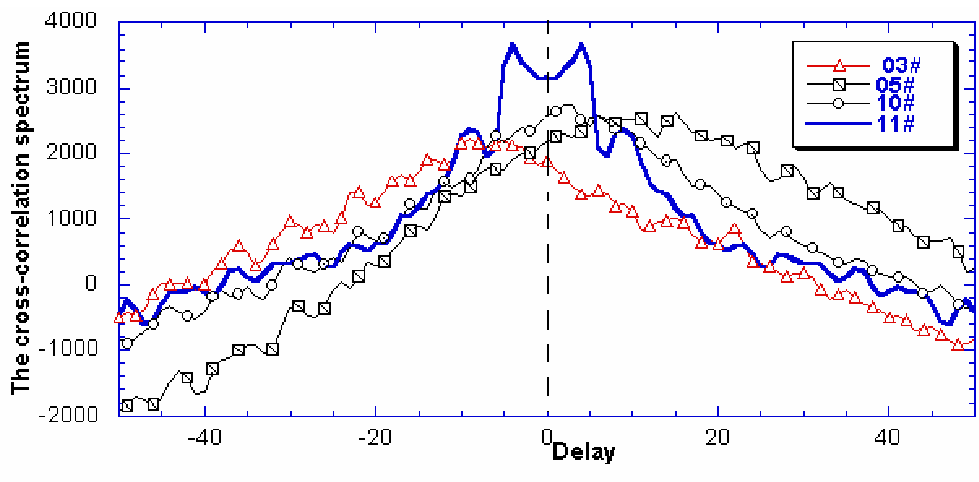


**Fig. 1**: The cross-correlation spectrum at span of delay near zero.03# the mixture :20% Ethanol and 80% Butanol;05# the mixture: 30% Ethanol and 70% De-ionized Water;10#: the mixture: 40% Ethanol and 60% ethyl acetate;11# the pure Ethanol.

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# The application of cross-correlation analysis in Model Transfer of Near infrared spectrum

Zhong-chen Wu, Xiao-xuan Xu, Qi-nan Li, Gang Yu, Cun-zhou Zhang

Model transfer is researched by cross-correlation in near infrared spectrum .The hypothesis that this is a inherent proportional constant between the two spectrums for model building measured by two different spectrometers after cross correlation analysis is put forward and approved . The compatibility of two model is enhanced after making up the proportional constant. So the good results are got. The figure 1 show that the difference between two different kinds of spectrometer was made up by adopting the cross-correlation analysis.

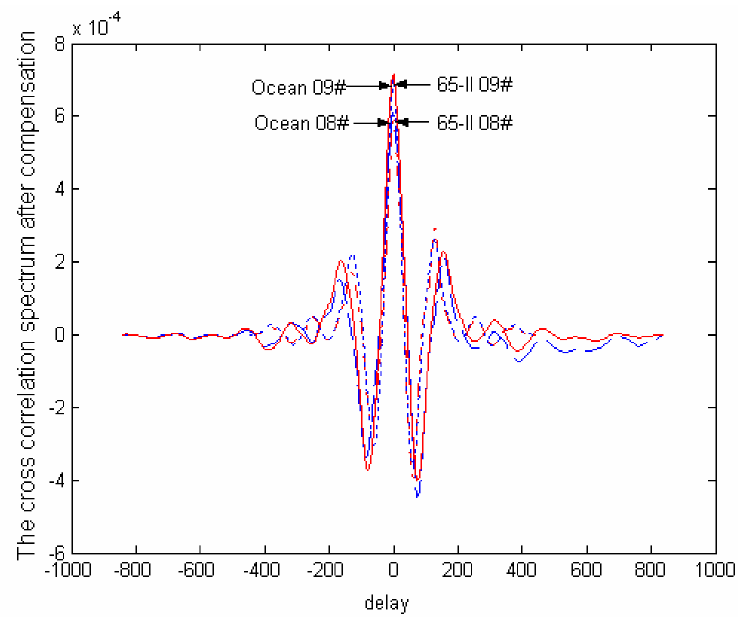


**Fig. 1**: The Cross-correlation spectrum of Partial samples after compensation

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Published on Spectroscopy and Spectral Analysis **24(11)**, 195(2004)

# Adopting the method of principal Components analysis combining with Correlation Coefficient to increase the predicted Concentration's accuracy of the Benzene and its Homologen's Mixture

Zhong-chen Wu[1] , Xiao-xuan Xu[1],Qi-nan Li[1], Gang Yu[2], Cun-zhou Zhang[1]

The Concentration of the Benzene and its homologue's mixture is measured by near infrared spectrum, the emphasis is put on the character of the principal component and its physical significance. The author point out the anterior principal components are very similar with the correlation coefficient of the multi-component solution and give the theoretical prove for the right condition. The high frequency noise of the system can be checked out by principal component combing with the correlation coefficient. Removing the noise can greatly increase the accuracy of the prediction model.The correlation coefficient and the first principal component are shown in figure1.

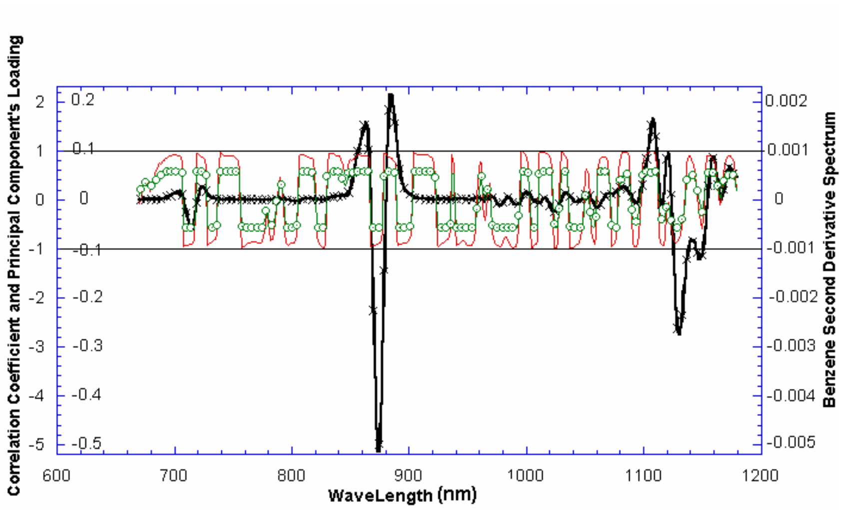


**Fig. 1**: the benzene second derivative spectrum and its correlation coefficient comparing with the first principal component.×the second derivative spectrum;-the correlation coefficient; ⊙the first principal component

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# Studies on Human Breast Cancer Tissues with Raman Microspectroscopy

YU Ge, XU Xiao-xuan, NIU Yun, WANG Bin, SONG Zeng-fu, ZHANG Chun-ping

The microscopic Raman Spectra from normal and malignant human breast tissues have been measured and investigated. The spectra difference and changes between normal and malignant breast tissue samples mainly involve:(1) The band from the symmetric stretching modes of $PO^{-}_{2}$ group in the DNA shifts from 1082 to 1097 $cm^{-1}$ and becomes stronger. The intensity of the symmetric stretching modes of O-P-O at 817$cm^{-1}$ in RNA increases greatly. (2) The bands of Amide Ⅰ and Ⅲ at 1657 and 1273$cm^{-1}$ change to 1662 and 1264$cm^{-1}$ respectively with their intensity and band width increasing. The peak of the C-O stretching modes in the amino acids shifts to higher wave number. The tryptophane band at 1368$cm^{-1}$ almost disappears. (3) Fewer characteristic Raman bands from lipids are observed. These spectral changes indicate that nucleic acids increase in contents relatively, while their conformation changes in cancer tissues. The proteins show various conformation and disorder structures with their molecular hydrogen bonds nearly broken. The contents of lipids decrease obviously. This investigation shows that Raman microspectroscopy is useful to biochemical study an vivo diagnosis of human breast cancers.

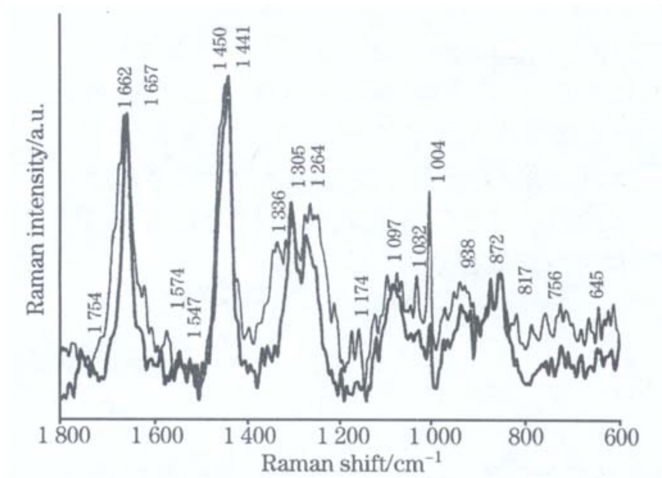


**Fig. 1**: Raman spectra of normal and malignant breast tissues.━,normal; ─,malignant

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# Studies on breast cancer tissues with ATR-FTIR spectroscopy

G. Yu, J. Xu, C. Zhang, C. Zhang

Attenuated total reflection (ATR) FTIR spectra of benign and malignant human breast tissues have been determined and investigated. The spectral differences and changes (shape, peak position and relative intensities) have been observed between these two types of samples. In comparison with the benign tissues, the mainly characteristic changes of malignant breast tissues involve: (1) The absorption band near 1162cm-1 due to the C-O(H) stretching modes of serine, threonine, tyrosine groups evidently shifted to a higher wavenumber, suggesting that the intermolecular hydrogen bonds were nearly broken; A1162/A1637 ratio rose significantly, indicating that the activity of oncogenes increased; and the collagen absorption peaks at 1033 cm-1, 1205 cm-1, 1282 cm-1 and 1342 cm-1 became lower, showing its relative contents decreased. (2) The bands from the symmetric and asymmetric stretching modes of the PO group in DNA shifted to 1083 cm-1and 1238 cm-1, respectively, and became stronger; and (A1083/A1637) malignant > (A1081/A1637)benign, (A1238/A1637) malignant > (A1240/A1637) benign. All these indicated that the relative content of DNA increased greatly. (3) The absorption bands at 2854 cm-1, 2958 cm-1and 2923 cm-1 were due to the symmetric and asymmetric stretching modes of CH2, CH3 in cellular nucleic acids, proteins and lipids, respectively. The ratio of A2958/A2854 also decreased. This suggested that there were changes in the conformational structure of the methylene chains of membrane lipids. These results showed that ATR-FTIR spectroscopy was able to become a powerful tool for the biochemical study and the vivo diagnosis of human breast cancers.

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# Laser-induced fluorescent characteristic of micromineral oil in water

L. Shang, X. Zhang, J. Xu

Laser-induced fluorescence emission contains information about both spectra and time, so the different shapes, intensities and fluorescent lifetimes of fluorescence emission spectra can be used to measure the categories and contents of fluorescent substances with high sensitivity and good selectivity.

To measure the oil micro-contamination in water, we utilized femtosecond ultraviolet laser pulse (fs Laser: MaiTai, Spectra Physics, US) as driving source and gated enhanced type ICCD (Time-resolved Fluorescence Spectroscopy, Lavision, German) as detector. We carried through laser-induced fluorescence measurement on DaGang crude oils and machine oils, accomplished data processing, and analyzed the differences of shapes of fluorescence spectra and lifetimes between crude oil and refined oil.

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# The study on three-dimensional fluorescencespectra of mineral oil and extraction method of characteristic parameters

L. Shang, X. Xu, J. Xu

To realize the on-line fluorescence monitoring of mineral oil pollution in water, we need to study the three-dimensional spectral characters of intermixture of mineral oil and water, and extract their features. Using threedimensional system of coordinate to denote excitation wavelength fluorescence wavelength and fluorescence intensity, through sampling and surface fitting, we can get three-dimensional fluorescence spectra. And after showed by contour chart, finger-print map of oil is achieved, which can provide proofs for oil discrimination. However, because of the similarity of components and structures in close oils, the features of threedimensional fluorescence spectra are different tinily, so this paper introduces quantitative analysis method—characteristic parameter method which starts with analyzing statistical features of three-dimensional fluorescence spectra. Adopting SPEX-F111AL fluorescent spectrometer, we measured the excitation spectra and three-dimensional fluorescence spectra of two kinds of domestic mineral crude oil, two kinds of imported mineral crude oil and two kinds of mineral product oil, and carried out parameterization study. The results showed that, as a quantitative classification and identification method of three-dimensional fluorescence spectra, the parameters of characteristic parameter method has determinacy on three-dimensional fluorescence spectra, which is applicable and effective to oil discrimination.

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# Microscopic Fluorescence Imaging Spectra of Oily Core

Xu Xiao-xuan , Xu Jia-lin, Yang Ren-jie

We have found a use for an small size microscopic fluorescence imaging spectroscopy to the identification of petroleum species. This instrumentation consists of microscope, variable interference filter, micro-motion stage, CCD camera, picture acquisition card and computer. The interference filter scans across every pixel of CCD array. The different column pixel in the picture which we get at every step is monocolour partial image under different wavelength, with the step by step, these column monocolour pixels change the wavelength. And finally we cut off and reassembled these images and get the whole monocolour images with different wavelength. The interval of sweep step length decided by the required spectral resolution and the required wavelength interval of different pictures. The spatial resolution of the instrument decided ultimately by the CCD, filter and imaging objective. This microscopic imaging fluorescence spectrometer has some excellent characters such as compact structure, higher spatial resolution and spectral resolution, higher scan rate and so on.

The microscopic morphologies of some oil core sections were observed. According to three dimension fluorescence spectra features data of some crude oil, we have selected proper excitation wavelengths and emission wavelengths to distinguish different fluorescence from inorganic mineral and organic hydrocarbons. The high spatial contrast distribution picture of crude oil was obtained.

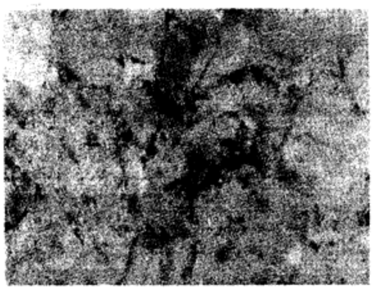

**Fig. 1**: High spatial contrast distribution image of crude oil.

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# Performance Improvement of Polymer Light-emitting Diodes with Metal Fluoride Cathode

Haibo Lin, hongbin Wu, Xiaoxuan Xu, Bin Wang, Cunzhou Zhang, Gang Yu

The performance of polymer light-emitting diodes of inserting metal fluoride insulating layer between the metal cathode and active polymer are studied. As for the polymer light-emitting diodes,optimization of charge injection lies in the dominant factors for substantive improvement performance. Since it is minority carriers dominate the combination thus the radiation, their injection takes priority over that of majority carriers. Generally in semiconducting polymers, holes are majority carriers while electrons minority, the carrier misbalance between electrons and holes further deteriorate in the fact that hole usually take possession of higher mobility and smaller injection barrier. To balance injection charge carriers and facilitate the electron injection, there are two commonly used stratagems in cathode fabrication. One is to employ low work function metals such as barium and calcium as cathode though they are susceptible to degradation upon water vapor and oxygen. The other choice is proposed to insert an insulating thin layer usually metal fluoride between polymer/ electrode interfaces to build a bilayer cathode. Proper inserting of insulating layer would lead to improvement in the overall working performance. But the thickness of the insulating layer is a fatal factor which influence the enhancement effect. As show in the experiment result, the LiF/Al double-layer-cathode devices are capariable with Ba(Ca)/Al electrode devices in luminescence performance. Band bending and injection potential decrease of minority carrier caused by the inlay of metal fluoride insulating layer, are proposed to be responsible for the enhanced electron injection and improved performance in polymer light emitting diodes.

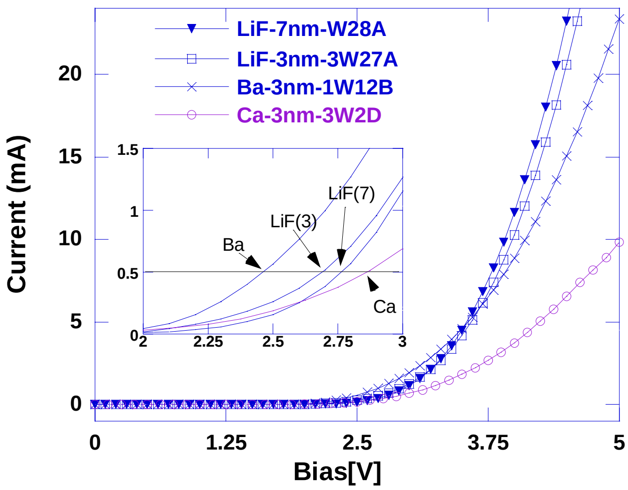


**Fig. 1** I-V curves of different-cathode PLEDs with MEH-PPV as active layer

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# Photo-degradation of polymer light-emitting diodes with water diffusion

H. Lin

Photo-degradation process of water-diffused polymer light emitting diodes have been investigated using the device structure indium tin oxide/ doped PEDOT: PSS/Poly (2-(4-Ethylexyl) phenyl-1,4-phenylene vinylene)/ Ba/Al. Except for a significant decrease in photoluminescence intensity, the devices used in this report show a 15 nm blue shifts for photo luminescence spectrum after photo-soaking. The shift results match those expected for PPV oligomers with reduced conjugation length. The vibration mode at 1624 cm-1, which represents the trans-vinylenes stretching mode, decreased after photo stressing. Furthermore, 2 cm-1 blue shifts at 1584 cm-1, which represent the C-C symmetric quadrant stretching of phenylene moiety, suggest that photo-oxidation has happened on the photo stressing process. All above results indicate that the effective conjugation length of electroluminescent polymer is partly of scission. But no typical carbonyl vibration modes are observed in the degradated luminescence device by the Raman spectrum. Different from photo degradation process without water diffusion, the PEDOT: PSS is dedoped to nonconducting state with concurrent local-oxidation of metal cathode because of the diffused water. Dedoped PEDOT: PSS cause resonance Raman effect that results in a strong resonance enhancement.

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# Study on the Degradation of Polymer Light-Emitting Diodes by In-Situ Micro2Raman Spectroscopy

LIN Hai-bo, XU Xiao-xuan, WU Hong-bin, WU Zhong-chen , YU Gang, XU Jing-jun, and ZHANG Cun-zhou

The authors report Raman degradation study of polymer light2emitting devices under ambient conditions. In order to investigate the chemical degradation reaction in polymer light2emitting diode (PL EDs) devices , the chemical structure of the poly (22 (42Ethylhexyl) phenyl21 , 42phenylene vinylene) (P2PPV) polymer was analyzed by micro2Ramam spectroscopy during the lifetime of the devices. The evidence for the reduction of conjugation length is provided by Raman spectroscopy. This reduction of the conjugation length , which dramatically increases the resistance and cuts off the current density , was the main reason for the failure of lighting. These findings provide an important insight into the intrinsic degradation mechanisms of the polymer L EDs and help in the development of even more stable devices.

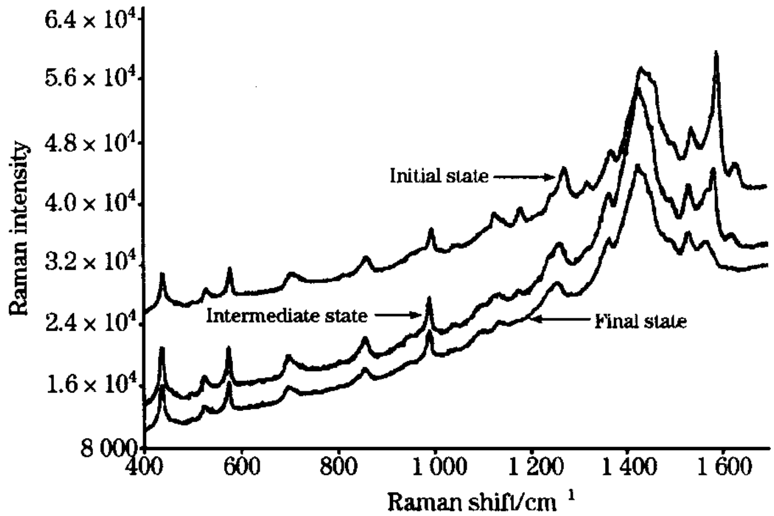


**Fig. 1** Raman comparison of PLEDs in the process of stressing from 400 to 1 700 $cm^{-1}$

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# Study on resonator of high power and high brightness solid state laser

Zhang Guangyin, Yan Caifan, Zhang Xiaohua, Gu Xuewen, Wu Dinger

LD-pumped solid-state laser is the most active field in the laser techniques. It has a lot of advantages, such as high efficiency, longer lifetime, compactness, stability and reliability. So it has been well developed in the solid-state laser field. High-power and high-brightness solid-state laser is a very important branch in this field. This paper describes some work on the high-brightness laser and its resonator.

Using the Propagation-Circle and Transform-Circle Graphic Analytic Method [1], the dynamic stable regions of several kinds of resonators, which can be used by high-power laser, have been analyzed. The best design for high power and high brightness has been put forward, which is composed of a short radius concave mirror and a convex mirror[2-3]. The dynamic stable regions of several kinds of resonators, which can be used by high-power laser, have been given.

As shown in Fig. 1, there are three kinds of choices for mirror $M_1$: short radius concave mirror $M_{11}$, plane mirror $M_{12}$ and long radius concave mirror. The analysis shows that cavity $M_{11}-M_{22}$ is the best choice, because it can help boost the input and output power of the solid-state lasers comparing with other kinds of cavities, and shorten the cavity length as well.

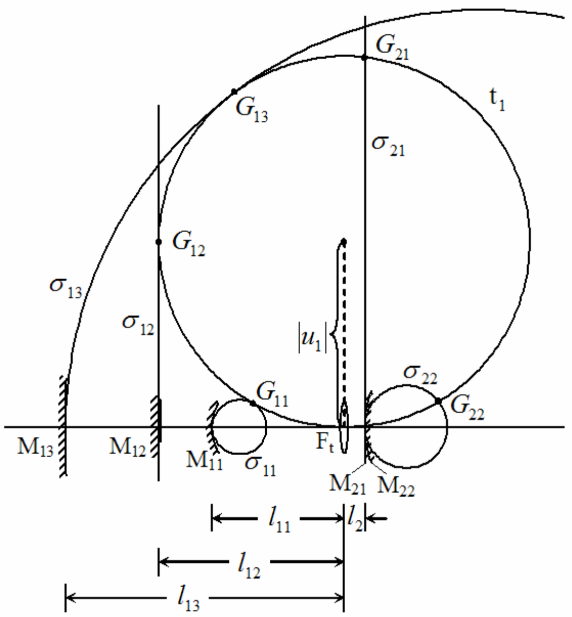


**Fig. 1** The dynamic stable regions of several kind of resonator

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# Review of MBE Laboratory in 2004

Yongchun Shu, Jianghong Yao, Xiaodong Xing, Biao Pi, Zhangcheng Xu

First, two dimensional electronic gas materials, as GaAs, InP, were studied in 2004 when MBE system was set up and checked. By designing and optimizing of the key technologies, the materials of the highest performances in China and in Compact 21/T MBE system were fabricated. The main materials and performance were listed as table 1.

Table.1 2DEG materials and performances

| Materials | Structure | 77K mobility($cm^2/V\cdot s$) | 2K mobility($cm^2/V\cdot s$) |
|---|---|---|---|
| AlGaAs/GaAs | 2DEG | $1.86\times10^5$ | $1.78\times10^6$ |
| AlGaAs/GaAs | $\delta$-2DEG | $2.09\times10^5$ | $1.28\times10^6$ |
| InP/InP | homostructure | $4.6\times10^4$ | |

Second, the materials of quantum dot, 808nm quantum well lasers and DBR of VECSEL were fabricated success. Figure 1 is the AFM image of quantum dot specimen and shows the uniformity of quantum dot size and density is lower than 10%. The transverse cross sectional SEM image of DBR materials is figure 2.

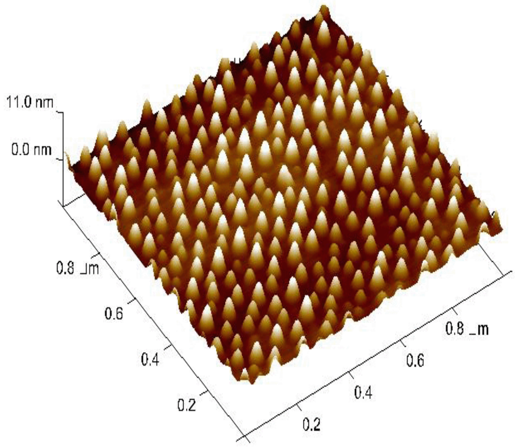


**Fig. 1** the AFM image of quantum dot

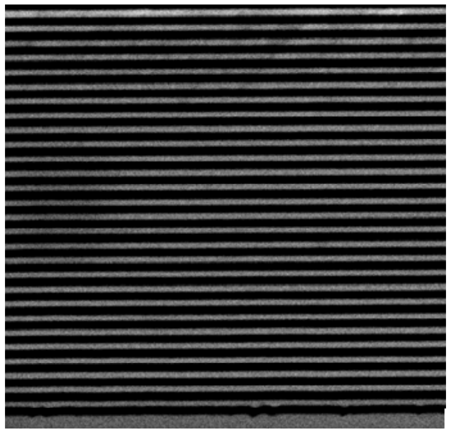

**Fig. 2** the SEM image of DBR

Third, we recovered the MBE system firstly in China from the bad vacuum state when phosphor source was used. It is a difficulty work how to use phosphor source and fabricate phosphor compound materials in all of the world.

Fourth, the Hall measuring system and optics microscope were built and set well. The maintenances of MBE system, LN2, high purity N2 and high purity water system were done excellently daily.

Lastly, one national fund item was declared in 2004. We invited 5 people come here to give a lecture and also two people studied abroad work in TEDA for about one month.

# Sub-monolayer Deposited InGaAs/GaAs Quantum Dot Heterostructures and Lasers

Zhangcheng Xu

As an alternative growth mode to the conventional Stranski-Krastanow (SK) mode of growing self-assembled semiconductor quantum dots (QDs), sub-monolayer (SML) deposition has recently received some attention, due to its potential of fabricating QDs with high density and high uniformity. An SML InGaAs/GaAs QD heterostructure is verified to be a quantum-dot-quantum-well (QDQW) structure, i.e., the indium-rich QDs are embedded in a lateral quantum well (QW) with lower indium content.[1,2] High-power lasers with SML InGaAs/GaAs QDs as the active region have been demonstrated.[3] In this paper, we report the measurement of the gain spectra and the determination of the linewidth enhancement factor of an SML InGaAs/GaAs QD laser. The lasing wavelength, the threshold current density, and the characteristic temperature of an SML InGaAs/GaAs QD broad area laser with a 628 μm-long cavity and a 100 μm-wide stripe, are 965 nm, 373 A/cm$^2$ and 81 K, respectively, at 30 $^o$C. The gain spectra at 30 $^o$C were measured, by using the Hakki-Paoli method, as shown in Fig.1. It is found that ***the maximum modal gain of QD ground states is 43.9 cm$^{-1}$(= 33 + 10.9 cm$^{-1}$ ) which is the highest value obtained for a single sheet of self-assembled In(Ga)As/GaAs QDs, to the best of our knowledge.*** Furthermore, no gain saturation takes place below the threshold, and the gain spectrum becomes symmetric with respect to the lasing wavelength when the injection current is about 0.98. The zero linewidth-enhancement-factor (α factor) at the lasing wavelength has been observed, when the injection current is about 0.98, as shown in Fig. 2. ***This is the first time for the zero linewidth-enhancement- factor to be observed for a QD laser.*** These properties are attributed to the high density and the high uniformity of SML QDs in our laser diodes, which are very useful for the application of SML QDs in high power lasers or vertical cavity surface emitting lasers.

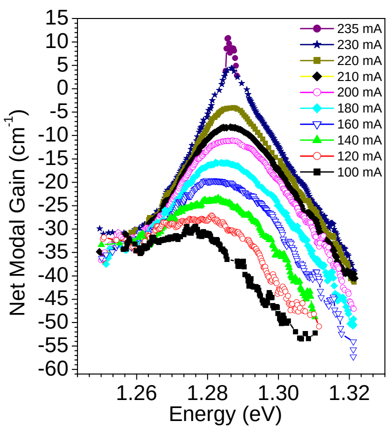


**Fig.1** Gain spectra of an SML InGaAs QD Laser

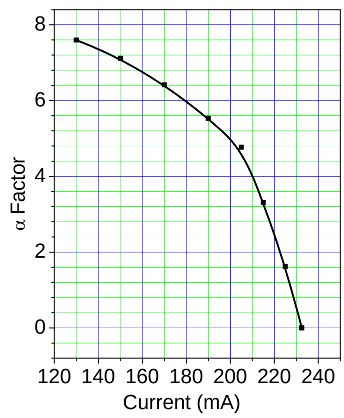


**Fig.2** α-factor at lasing wavelength

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Published in Appl. Phys. Lett., **85**, 3259 (2004)

# Raman spectra of annealed self-assembled quantum dots

B. Wang, X. Xu, Y. Shu, J. Yao

We have measured Raman spectra of annealed self-assembled In0.65Al0.35As quantum dots. The samples are annealed at either 600K or 700K; the annealed time is either 30 minutes or 60 minutes. We have systematically analyzed the changes of Raman spectra between the samples annealed and not annealed, and further studied the new characteristics of semiconductor quantum dots. It found that:

1) With the decrease of the size of the quantum dot, there is an obvious sharp-line phenomenon in its LO optical phonon mode structure, and the peak of like AlAs LO mode of the In0.65Al0.35As quantum dot near 382cm-1 has a tiny red shift.

2) After the structure of the annealed quantum dots is reorganized, the peak of like AlAs LO mode near 382cm-1 disappears, and peak of the like InAs LO mode appears. It shows the new quantum dot is created after annealing.

3) The enhanced Raman phenomena exist universally in quantum dots. It shows that Raman pectrum is one of the powerful methods to examine the growth and components of quantum dots.

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| 4 | S. Linsey | USA | University of Arizona | Professor | 2004.05 | Seminar Lecture |
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