

ISSN: 0256-307X

# 中国物理快报

# Chinese Physics Letters

Volume 29 Number 1 January 2012

A Series Journal of the Chinese Physical Society  
Distributed by IOP Publishing

Online: <http://iopscience.iop.org/cpl>  
<http://cpl.iphy.ac.cn>

CHINESE PHYSICAL SOCIETY  
**IOP** Publishing

JUST FOR AUTHORS  
— CHINESE PHYSICS LETTERS

# Comparison of the Noise Properties of Squeezed Probe Light in Optically Thick and Thin Quantum Coherence Media for Weak and Strong Coupling Lights \*

LI Zhong-Hua(李中华), LI Yuan(李媛), DOU Ya-Fang(豆亚芳), GAO Jiang-Rui(郜江瑞),  
ZHANG Jun-Xiang(张俊香)\*\*

State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Opto-Electronics,  
Shanxi University, Taiyuan 030006

(Received 19 October 2011)

The output amplitude noises of one squeezed probe light which is at resonance throughout different optical depths media in strong- and weak-coupling-field regimes are investigated theoretically. By comparing the output quantum noises for different Rabi frequencies of coupling field and also for different optical depths, it is found that the optimal squeezing preservation of the probe light occurs in an optically thin medium with strong-coupling-field, where we can obtain the output squeezing close to the input one at nonzero detection frequency.

PACS: 42.50.Gy, 42.50.Hz, 42.50.Lc

DOI:10.1088/0256-307X/29/1/014202

Quantum coherence of electromagnetically induced transparency (EIT) provides an elegant approach for slowing and storage of light without absorption and even localizing atoms.<sup>[1,2]</sup> In an EIT medium, the coupling field can reversibly map and retrieve the information between the weak probe field and the atoms which have long lived ground states.<sup>[3]</sup> Experiments involving squeezing storage through the EIT medium in hot atoms or magneto-optical trap (MOT) have been demonstrated.<sup>[4–7]</sup> Measuring the quantum noise of the retrieved states can verify whether the atomic memory is faithful. In Ref. [8], the authors concluded that both entanglement and squeezing of the probe field could be almost perfectly preserved in an EIT medium under the condition of sufficiently small ground state decoherence rate. The theoretical calculation also demonstrated the validity of the preservation and transfer of quantum state in an EIT medium by choosing suitable parameters.<sup>[9]</sup> Moreover, the survival and transfer of the squeezed vacuum in double EIT have also been investigated.<sup>[10]</sup> However, the Rabi frequencies of the strong coupling field in all those calculations<sup>[8–10]</sup> were considered to be larger than the decay rate of the optical transition of probe light, which was discussed from the view of quantum interference<sup>[11]</sup> in which the medium exhibits Autler–Townes (AT) splitting in the absorption line under the condition of strong coupling field. Also, EIT is a similar but distinct phenomenon which should be the consequence of destructive interference between two competing excitation pathways under the condition of weak coupling field.<sup>[12]</sup> If the Rabi frequency of the coupling field is greater than the polarization decay rate of the probe transition, which is named as

the strong-coupling-field regime, the absorption spectrum of the probe light exhibits AT splitting with a transparency gap between two absorption peaks.<sup>[13]</sup> In the weak-coupling-regime where the Rabi frequency of the coupling field is less than the polarization decay rate, the destructive interference leads to the reduction of the probe absorption, which is shown as EIT. It was also pointed out that efficient coupling between atoms and light needs the atoms to have large optical depth, especially in quantum memory.<sup>[14,15]</sup> However in this Letter, the theoretical study of the quantum noise spectra of the outgoing probe light in optically thick and thin media shows that the optimum quantum preservation of squeezed light depends on not only the optical depth but also the coupling regime of EIT or AT splitting effect.

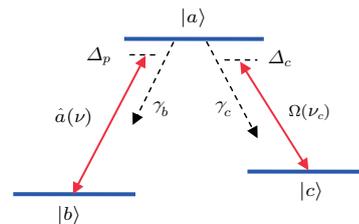


Fig. 1. Schematic of the  $A$ -type system.

Consider a closed three-level  $A$ -type system as shown in Fig. 1. A classical coupling field of frequency  $\nu_c$  with Rabi frequency  $\Omega$  and a weak quantum probe field of frequency  $\nu$  interact with the transitions  $|c\rangle \leftrightarrow |a\rangle$  and  $|b\rangle \leftrightarrow |a\rangle$ , respectively. The decays of the corresponding atomic dipole operators are  $\gamma_{ba}$  and  $\gamma_{ca}$ , respectively;  $\gamma_b$  and  $\gamma_c$  are the spontaneous decays for each transition. The corresponding one-

\*Supported by the National Natural Science Foundation of China under Grant No 10974126, and the National Basic Research Program of China under Grant No 2010CB923102.

\*\*Correspondence author. Email: junxiang@sxu.edu.cn

© 2012 Chinese Physical Society and IOP Publishing Ltd

photon detunings and two-photon detuning are given by  $\Delta_p = \omega_{ab} - \nu$ ,  $\Delta_c = \omega_{ac} - \nu_c$ , and  $\delta = \Delta_p - \Delta_c$ .

The zeroth-order steady state solutions of the slowly varying atomic operators described in Ref. [8] are obtained as

$$\begin{aligned}\hat{\sigma}_{aa}^{(0)} &= \frac{-2\gamma_{ca}\gamma_{bc}|\Omega|^2}{-2\gamma_{bc}\gamma_a|\gamma_{ca} + i\Delta_c|^2 - 2\gamma_{ca}|\Omega|^2(\gamma_b + 3\gamma_{bc})}, \\ \hat{\sigma}_{bb}^{(0)} &= \frac{-\gamma_{bc}\gamma_a|\gamma_{ca} + i\Delta_c|^2 - 2\gamma_{ca}|\Omega|^2(\gamma_b + \gamma_{bc})}{-2\gamma_{bc}\gamma_a|\gamma_{ca} + i\Delta_c|^2 - 2\gamma_{ca}|\Omega|^2(\gamma_b + 3\gamma_{bc})}, \\ \hat{\sigma}_{ca}^{(0)} &= \frac{i\Omega - 2i\Omega\hat{\sigma}_{aa}^{(0)} - i\Omega\hat{\sigma}_{bb}^{(0)}}{\gamma_{ca} + i\Delta_c},\end{aligned}\quad (1)$$

with the dephasing rate for the two ground states  $\gamma_{bc}$ , and the total spontaneous decay of the excited state satisfying  $\gamma_a = \gamma_b + \gamma_c$ . It can be seen from Eq. (1) that for the case of weak coupling limit ( $\Omega \leq \gamma_{ba}$ ), the assumption that all the atoms are in the ground state  $|b\rangle$  is not valid. We will consider a general case without taking the assumption in the following.

The evolution equation for the slowly varying annihilation operator of the quantum probe  $\hat{a}$  and the first-order equations which determine the coherence  $\hat{\sigma}_{ba}^{(1)}$  as a function of  $\hat{a}$  are given by

$$\begin{aligned}\left(\frac{\partial}{\partial t} + c\frac{\partial}{\partial z}\right)\hat{a}(z, t) &= ig^*N\hat{\sigma}_{ba}(z, t), \\ \frac{\partial}{\partial t}\hat{\sigma}_{ba}^{(1)} &= -(i\Delta_p + \gamma_{ba})\hat{\sigma}_{ba}^{(1)} + ig\hat{a}(\hat{\sigma}_{bb}^{(0)} - \hat{\sigma}_{aa}^{(0)}) \\ &\quad + i\Omega\hat{\sigma}_{bc}^{(1)} + \hat{F}_{ba}, \\ \frac{\partial}{\partial t}\hat{\sigma}_{bc}^{(1)} &= -(i\delta + \gamma_{bc})\hat{\sigma}_{bc}^{(1)} - ig\hat{a}\hat{\sigma}_{ac}^{(0)} + i\Omega^*\hat{\sigma}_{ba}^{(1)} + \hat{F}_{bc},\end{aligned}\quad (2)$$

with  $g = \wp_{ab}\sqrt{\nu/2\epsilon_0 V\hbar}$  representing the atom-field coupling constant and  $\wp_{ab}$  being the atomic dipole moment for the  $|b\rangle \leftrightarrow |a\rangle$  transition.  $V$  is the interaction volume and  $N$  is the number of atoms. Taking Fourier transform of Eqs. (2) and solving them for  $\hat{a}(z, \omega)$ , then we obtain the output field at the exit of the cell which has the length  $L$ :

$$\begin{aligned}\hat{a}(L, \omega) &= e^{-\Lambda(\omega)L}\hat{a}(0, \omega) + \frac{g^*N}{c}\int_0^L e^{-\Lambda(\omega)(L-s)} \\ &\quad \times \frac{i\gamma_2\hat{F}_{ba}(s, \omega) - \Omega\hat{F}_{bc}(s, \omega)}{\gamma_1\gamma_2 + |\Omega|^2} ds,\end{aligned}\quad (3)$$

$$\Lambda(\omega) = \frac{|g|^2N}{c} \times \left[ \frac{\gamma_2(\hat{\sigma}_{bb}^{(0)} - \hat{\sigma}_{aa}^{(0)})}{\gamma_1\gamma_2 + |\Omega|^2} - i\frac{\Omega\hat{\sigma}_{ac}^{(0)}}{\gamma_1\gamma_2 + |\Omega|^2} \right] - \frac{i\omega}{c},\quad (4)$$

where  $\omega$  is the detection frequency and  $\gamma_1 = \gamma_{ba} + i(\Delta_p - \omega)$ ,  $\gamma_2 = \gamma_{bc} + i(\delta - \omega)$ .

In terms of the definition of quadrature flux spectrum and the correlation functions of Langevin noise operators described in Refs. [8,16], one obtains the

normalized quadrature amplitude spectrum of the output probe related to the input via the relation

$$S_X(L, \omega) = S_1(\omega) + S_2(\omega) + S_3(\omega),\quad (5)$$

$$\begin{aligned}S_1(\omega) &= \frac{S_X^{in}(\omega)}{4} (\exp\{-[\Lambda(\omega) + \Lambda(-\omega)]L\} \\ &\quad + \exp\{-[\Lambda(\omega) + \Lambda^*(\omega)]L\} \\ &\quad + \exp\{-[\Lambda^*(-\omega) + \Lambda(-\omega)]L\} \\ &\quad + \exp\{-[\Lambda^*(-\omega) + \Lambda^*(\omega)]L\}),\end{aligned}\quad (6)$$

$$\begin{aligned}S_2(\omega) &= -\frac{S_Y^{in}(\omega)}{4} (\exp\{-[\Lambda(\omega) + \Lambda(-\omega)]L\} \\ &\quad - \exp\{-[\Lambda(\omega) + \Lambda^*(\omega)]L\} \\ &\quad - \exp\{-[\Lambda^*(-\omega) + \Lambda(-\omega)]L\} \\ &\quad + \exp\{-[\Lambda^*(-\omega) + \Lambda^*(\omega)]L\}),\end{aligned}\quad (7)$$

$$\begin{aligned}S_3(\omega) &= \frac{|g|^2N}{c} \times \frac{1 - \exp[-(\Lambda(\omega) + \Lambda^*(\omega))L]}{\Lambda(\omega) + \Lambda^*(\omega)} \\ &\quad \times \left\{ \frac{|\gamma_2|^2[(\gamma_b + \gamma_a)\sigma_{aa}^{(0)} + \gamma_{bc}(1 - \sigma_{aa}^{(0)} - 2\sigma_{bb}^{(0)})]}{|\gamma_1\gamma_2 + |\Omega|^2|^2} \right. \\ &\quad + \frac{|\Omega|^2[\gamma_b\hat{\sigma}_{aa}^{(0)} + \gamma_{bc}(1 - \sigma_{aa}^{(0)})]}{|\gamma_1\gamma_2 + |\Omega|^2|^2} \left. \right\} + \frac{|g|^2N}{c} \\ &\quad \times \frac{1 - \exp[-(\Lambda(-\omega) + \Lambda^*(-\omega))L]}{\Lambda(-\omega) + \Lambda^*(-\omega)} \\ &\quad \times \left\{ \left[ i\tilde{\gamma}_2^*\Omega\gamma_{bc}\hat{\sigma}_{ac}^{(0)} - i\tilde{\gamma}_2\Omega^*\gamma_{bc}\hat{\sigma}_{ca}^{(0)} \right. \right. \\ &\quad + \left. \left. |\Omega|^2[\gamma_c\hat{\sigma}_{aa}^{(0)} + \gamma_{bc}(1 - \sigma_{aa}^{(0)})] \right] \right. \\ &\quad \cdot \left. \left[ |\tilde{\gamma}_1\tilde{\gamma}_2 + |\Omega|^2|^2 \right]^{-1} \right\},\end{aligned}\quad (8)$$

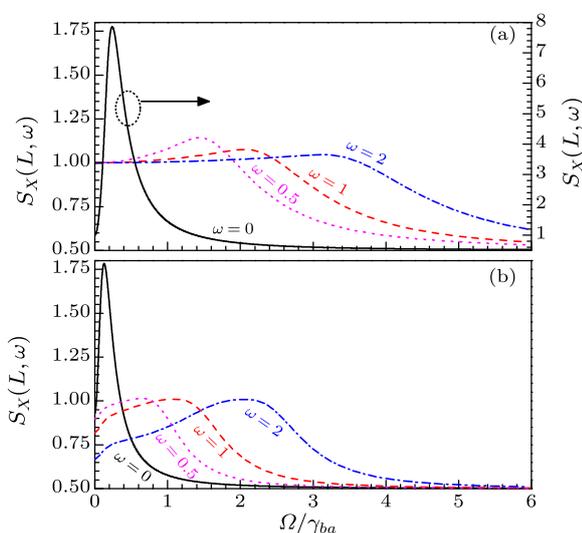
$$\tilde{\gamma}_1 = \gamma_{ba} + i(\Delta_p + \omega),$$

$$\tilde{\gamma}_2 = \gamma_{bc} + i(\delta + \omega).$$

In our calculation and discussion, all the parameters are normalized to the decay rate  $\gamma_{ba}$  of the probe transition. In addition, we have set  $\gamma_{ba} = \gamma_{ca}$  and  $\Delta_c = 0$  for simplicity. As described in Refs. [14,17], the parameter  $|g|^2NL/c$  represents the coupling strength between the light and atoms, and it is related to the optical depth (OD) of the system, which satisfies  $|g|^2NL/c = \gamma_a \times OD/4$ . For optically thin and thick media,  $|g|^2NL/c$  takes different values.

Consider an input 3dB squeezed vacuum state with  $S_X^{in}(\omega) = 0.5$ ,  $S_Y^{in}(\omega) = 2$ , which is resonant to its corresponding transition satisfying  $\Delta_p = 0$ . Note that  $S_X(L, \omega) = 1$  represents the shot noise level (SNL). Figure 2 shows the amplitude noise of the outgoing probe versus the Rabi frequency of the coupling field for different detection frequencies in optically thick medium with  $|g|^2NL/c = 25$  (Fig. 2(a)) and optically thin medium with  $|g|^2NL/c = 2$  (Fig. 2(b)). It is obviously seen that the amplitude noise decreases with the increase of the Rabi frequency of coupling field for any detection frequency after reaching maximum. Once the Rabi frequency of the coupling field

becomes large enough, the amplitude noise  $S_X(L, \omega)$  of the outgoing probe beam can always get close to the initial squeezing value no matter whether the medium is optically thick or thin, which indicates that the ideal situation of squeezing preservation occurs in the regime of strong-coupling-field. We can also see that the larger the detection frequency is, the higher the Rabi frequency of the coupling field is needed to obtain the ideal squeezing preservation. For the case of an optically thick medium with  $|g|^2NL/c = 25$ , the output noise decreases more slowly than that for the case of an optically thin medium with  $|g|^2NL/c = 2$  when the Rabi frequency of coupling light increases. Thus, it can be concluded that the ideal squeezing preservation may need to be performed in an optically thin system in strong-coupling-field regime with a large enough Rabi frequency of the coupling field.

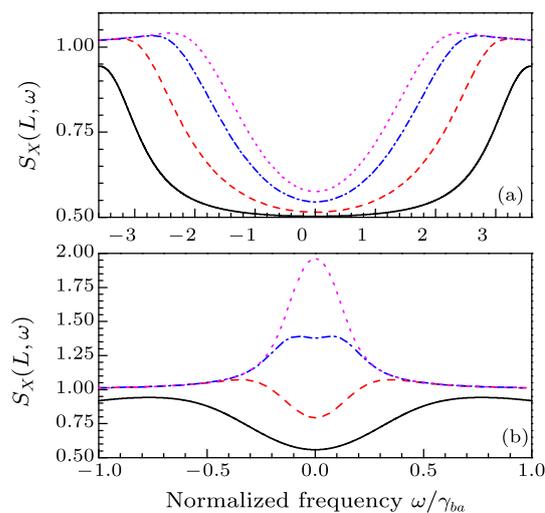


**Fig. 2.** The amplitude noise vs the Rabi frequency of the coupling field  $\Omega$  for different detection frequencies. Solid lines:  $\omega = 0$ , dotted lines:  $\omega = 0.5$ , dashed lines:  $\omega = 1$ , dash-dotted lines:  $\omega = 2$  with (a)  $|g|^2NL/c = 25$ , (b)  $|g|^2NL/c = 2$ . Other parameters are  $\gamma_b = 1$ ,  $\gamma_c = 1$ ,  $\gamma_{bc} = 0.01$ ,  $\Delta_p = \Delta_c = 0$ ,  $S_X^{in}(\omega) = 0.5$ ,  $S_Y^{in}(\omega) = 2$ .

Figure 3(a) illustrates the noise spectra versus the detection frequency for different optical depths in strong-coupling-field regime with  $\Omega = 3.6$ . It can be seen that there appears a dip like an EIT window around  $\omega = 0$  for each outgoing squeezing spectrum, the output noise turns out to be larger when the optical depth increases. As was discussed in Ref. [10], the transparency interval  $2\Omega$  between the two absorption peaks of the AT splitting in the strong-coupling-field regime can be viewed as the transparency width in which the squeezing of light can be preserved in the frequency domain. Outside this transparency window, the outgoing field fluctuations are absorbed by atoms,<sup>[9]</sup> and the noise from the atoms will contaminate the output light. Here we can see that, however,

for an optically thick medium (e.g. dotted line), the squeezing of the output probe can not be well preserved even in the transparency window.

Although the optimal squeezing preservation occurs at the zero detection frequency, the relaxation oscillation of the laser at low frequency prevents us from obtaining the best squeezing at zero detection frequency in realistic measurement. However, we can obtain much smaller noise close to the input one in an optically thin medium, i.e. small enough OD at nonzero detection frequency as illustrated in Fig. 3. This result can also be demonstrated in terms of Eq. (19) in Ref. [8], Eq. (6) in Ref. [9] and Eq. (18) in Ref. [10]. In addition, we can find that the width which describes the squeezing preservation range decreases when the optical depth becomes larger. The result is consistent with the prediction of Ref. [9]. If we keep the Rabi frequency of the coupling field unchanged, the width of the squeezing window will decrease gradually with the increase of OD. From the above analyses, it can be concluded that it is more effective to manipulate the quantum state preservation at nonzero detection frequency in an optically thin medium than in optically thick one.



**Fig. 3.** The amplitude noise spectra vs the detection frequency  $\omega$  for different optical depths in the strong-coupling-field regime with  $\Omega = 3.6$  (a) and in the weak-coupling-field regime with  $\Omega = 0.8$  (b). The solid, dashed, dash-dotted and dotted lines are the noises of  $|g|^2NL/c = 1$ ,  $|g|^2NL/c = 5$ ,  $|g|^2NL/c = 15$ ,  $|g|^2NL/c = 25$ , respectively. The other parameters are the same as those in Fig. 2.

Figure 3(b) shows the similar results that the dependence of noise spectra on the detection frequency for different optical depths in weak-coupling-field regime. When  $|g|^2NL/c$  increase from 1 to 5 (see the solid and dashed curves), the squeezing window becomes narrow. However, if we further increase  $|g|^2NL/c$  (see the dash-dotted and dotted curves), the output noise will be higher than SNL.

From the above analyses, it is evident that the squeezing preservation in a quantum coherence medium can be well performed in a strong-coupling-field regime, and it is suggested that the experiments on storage and retrieval of quantum state should be investigated in an optically thin medium with large enough coupling field. However, as analyzed in Refs. [14,15], the optimal memory performance needs optical depth to be significantly greater than one. Thus, we can conclude that proper optical depth is necessary to satisfy the conditions of optimal storage efficiency and optimal quantum state preservation at the same time. In addition, Refs. [15,18] gave a possible reason for the background noise in the retrieved signal that the thermal photons emitted by the excited state contaminates the signal mode due to the repopulation of the ground states. While in our calculation, the excess noise originates not only from the Langevin atomic noise  $S_3(\omega)$  resulted from the random decay process, but also from the phase-to-amplitude converted noise  $S_2(\omega)$  due to the interaction between atoms and lights.

In conclusion, the theoretical calculation and discussion show that the squeezing of the probe light can be well kept in the strong-coupling-field regime for either optically thick or optically thin media. While in the weak-coupling-field regime, only an optically thin medium can be used to preserve the input squeezing. It is more efficient to store the quantum state in an optically thin medium for a strong coupling field instead of an optically thick medium.

## References

- [1] Xiao F, Guo R M, Chen S, Zhang Y, Li L M and Chen X Z 2003 *Chin. Phys. Lett.* **20** 1257
- [2] Gong C, Hu X M and Peng Y D 2008 *Chin. Phys. Lett.* **25** 505
- [3] Hétet G, Buchler B C, Glöckl O, Hsu M T L, Akulshin A M, Bachor H -A and Lam P K 2008 *Opt. Express* **16** 7369
- [4] Arikawa M, Honda K, Akamatsu D, Yokoi Y, Akiba K, Nagatsuka S, Furusawa A and Kozuma M 2007 *Opt. Express* **15** 11849
- [5] Akamatsu D, Yokoi Y, Arikawa M, Nagatsuka S, Tanimura T, Furusawa A and Kozuma M 2007 *Phys. Rev. Lett.* **99** 153602
- [6] Appel J, Figueroa E, Korystov D, Lobino M and Lvovsky A I 2008 *Phys. Rev. Lett.* **100** 093602
- [7] Honda K, Akamatsu D, Arikawa M, Yokoi Y, Akiba K, Nagatsuka S, Tanimura T, Furusawa A and Kozuma M 2008 *Phys. Rev. Lett.* **100** 093601
- [8] Peng A, Johnsson M, Bowen W P, Lam P K, Bachor H-A and Hope J J 2005 *Phys. Rev. A* **71** 033809
- [9] Dantan A, Bramati A and Pinard M 2005 *Phys. Rev. A* **71** 043801
- [10] Ding J L, Hou B P and Wang S J 2010 *J. Phys. B: At. Mol. Opt. Phys.* **43** 225502
- [11] Abi Salloum T Y 2010 *Phys. Rev. A* **81** 053836
- [12] Harris S E 1997 *Phys. Today* **50** 36
- [13] Du Z J, Zhang S G, Wu C J, Guan Y, Zhao W Y and Chang H 2010 *Chin. Phys. Lett.* **27** 104202
- [14] Gorshkov A V, André A, Fleishhauer M, Sørensen A S and Lukin M D 2007 *Phys. Rev. Lett.* **98** 123601
- [15] Lvovsky A I, Sanders B C and Tittel W 2009 *Nature Photon.* **3** 706
- [16] Zhang J X, Cai J, Bai Y F, Gao J R and Zhu S Y 2007 *Phys. Rev. A* **76** 033814
- [17] Glorieux Q 2011 arXiv:1101.5166v1[quant-ph]
- [18] Figueroa E, Vewinger F, Appel J and Lvovsky A I 2006 *Opt. Lett.* **31** 2625

# Chinese Physics Letters

Volume 29

Number 1

January 2012

## GENERAL

- 010201 **Symmetry and Period-Adding Windows in a Modified Optical Injection Semiconductor Laser Model**  
LI Xian-Feng, Andrew Y. -T. Leung, CHU Yan-Dong
- 010202 **Note on the Lax Pair of a Coupled Hybrid System**  
LIU Ping, FU Pei-Kai
- 010203 **Inhomogeneous Quantum Invariance Group of Multi-Dimensional Multi-parameter Deformed Boson Algebra**  
Azmi Ali Altintas, Metin Arik, Ali Serdar Arikan, Emre Dil
- 010301 **New View of Ping-Pong Protocol Security**  
Piotr Zawadzki
- 010302 **Exact Propagator for the Anisotropic Two-Dimensional Charged Harmonic Oscillator in a Constant Magnetic Field and an Arbitrary Electric Field**  
ZHAI Zhi-Yuan, YANG Tao, PAN Xiao-Yin
- 010303 **Repeater-Assisted Zeno Effect in Classical Stochastic Processes**  
GU Shi-Jian, WANG Li-Gang, WANG Zhi-Guo, LIN Hai-Qing
- 010304 **Chiral Fermion Conductivity in Graphene-Like Samples Subjected to Orthogonal Fields**  
Ciprian Dariescu, Marina-Aura Dariescu
- 010305 **Randomly Generating Four Mixed Bell-Diagonal States with a Concurrences Sum to Unity**  
S. P. Toh, Hishamuddin Zainuddin, Kim Eng Foo
- 010401 **Phantom Energy Accretion by a Stringy Charged Black Hole**  
M. Sharif, G. Abbas
- 010402 **Propagation and Evolution of a Scalar Field in Einstein–Power–Maxwell Spacetime**  
LIU Yan, JING Ji-Liang
- 010403 **LRS Bianchi Type-II Cosmological Model with a Decaying Lambda Term**  
R. K. Tiwari, D. Tiwari, Pratibha Shukla
- 010501 **Evaluation of an Asymmetric Bistable System for Signal Detection under Lévy Stable Noise**  
HUANG Jia-Min, TAO Wei-Ming, XU Bo-Hou
- 010502 **Relationship between the Permeation-Diffusion Parameters of a Single-File Channel**  
LIU Jian, FAN Jian-Fen
- 010503 **Size Segregation in Rapid Flows of Inelastic Particles with Continuous Size Distributions**  
LI Rui, ZHANG Duan-Ming, LI Zhi-Hao
- 010504 **Directed Dynamic Small-World Network Model for Worm Epidemics in Mobile ad hoc Networks**  
ZHU Chen-Ping, WANG Li, LIU Xiao-Ting, YAN Zhi-Jun
- 010701 **Torsional Vibrations of a Cantilever with Lateral Friction in a Resonance Friction Microscope**  
CHEN Jian-Song, GE Yun, ZHANG Hui

## NUCLEAR PHYSICS

- 012101 **Second-Order Contribution of the Incompressibility in Asymmetric Nuclear Matter**  
LI Zeng-Hua, ZHANG Da-Peng, SCHULZE Hans-Josef, ZUO Wei
- 012102 **Single-Particle Properties of Isospin Asymmetric Nuclear Matter**  
LI Zeng-Hua, ZUO Wei, GUO Wen-Jun
- 012501 **Thermal Annealing Behavior of Helium in Ti Films Deposited by Magnetron Sputtering**  
ZHANG Lei, HE Zhi-Jiang, LIU Chao-Zhuo, WANG Xu-Fei, SHI Li-Qun
- 012502 **Observation of the Superheavy Nuclide  $^{271}\text{Ds}$**   
ZHANG Zhi-Yuan, GAN Zai-Guo, MA Long, HUANG Ming-Hui, HUANG Tian-Heng, WU Xiao-Lei, JIA Guo-Bin, LI Guang-Shun, YU Lin, REN Zhong-Zhou, ZHOU Shan-Gui, ZHANG Yu-Hu, ZHOU Xiao-Hong, XU Hu-Shan, ZHANG Huan-Qiao, XIAO Guo-Qing, ZHAN Wen-Long

**012503 Anomalous High Isotope Ratio  $^3\text{He}/^4\text{He}$  and Tritium in Deuterium-Loaded Metal: Evidence for Nuclear Reaction in Metal Hydrides at Low Temperature**  
JIANG Song-Sheng, HE Ming, WU Shao-Yong, QI Bu-Jia

**012901 A Cosmic-Ray Muon Hodoscope Based on Up-down THGEM Detectors**  
PANG Hong-Chao, LIU Hong-Bang, CHEN Shi, MIN Jian, ZHENG Yang-Heng, XIE Yi-Gang, TANG Ai-Song, YANG Ya-Dan, DONG Yang, LI Min

#### **ATOMIC AND MOLECULAR PHYSICS**

**013101 Narrow Near-Threshold Resonance in  $e^+-\text{He}^+$  Scattering**  
LIU Min-Min, HAN Hui-Li, GU Si-Hong, SHI Ting-Yun

**013102 First-Principles Study of Hydrogen Impact on the Formation and Migration of Helium Interstitial Defects in *hcp* Titanium**  
LU Yong-Fang, SHI Li-Qun, DING Wei, LONG Xing-Gui

**013201 Measurement of the Absolute Photoionization Cross Section for the  $5P_{3/2}$  State of  $^{87}\text{Rb}$  in a Vapor Cell Magneto-optic Trap**  
HUANG Wei, RUAN Ya-Ping, JIA Feng-Dong, ZHONG Yin-Peng, LIU Long-Wei, DAI Xing-Can, XUE Ping, XU Xiang-Yuan, ZHONG Zhi-Ping

**013202 Photodetachment of  $\text{H}^-$  near a Hard Spherical Surface**  
M. Haneef, Iftikhar Ahmad, A. Afaq, A. Rahman

**013203 Local Field Distributions in Systems with Dipolar Interaction**  
YAN Yue, WU Biao

**013204 Measurements of the Spectrum of Singly Ionized Argon between 320 and 520 nm**  
YANG Zhao-Rui, YUAN Ping, SONG Zhang-Yong, XU Qiu-Mei, YANG Zhi-Hu

**013401 Second-Order Born Effect in Single Ionization of Argon by Electron Impact**  
WANG Yang, ZHOU Ya-Jun, JIAO Li-Guang

#### **FUNDAMENTAL AREAS OF PHENOMENOLOGY(INCLUDING APPLICATIONS)**

**014101 Compact Dual-Band Zeroth-Order Resonance Antenna**  
XU He-Xiu, WANG Guang-Ming, GONG Jian-Qiang

**014102 Concealing a Passive Sensing System with Single-Negative Layers**  
ZHU Xue-Feng, ZOU Xin-Ye, ZHOU Xiao-Wei, LIANG Bin, CHENG Jian-Chun

**014201 Ultraviolet Continuum Generation in the Fundamental Mode of Photonic Crystal Fibers**  
HAN Ying, HOU Lan-Tian, YUAN Jin-Hui, XIA Chang-Ming, ZHOU Gui-Yao

**014202 Comparison of the Noise Properties of Squeezed Probe Light in Optically Thick and Thin Quantum Coherence Media for Weak and Strong Coupling Lights**  
LI Zhong-Hua, LI Yuan, DOU Ya-Fang, GAO Jiang-Rui, ZHANG Jun-Xiang

**014203 All-Optical Temporal Differentiator Using a High Resolution Optical Arbitrary Waveform Shaper**  
DONG Jian-Ji, LUO Bo-Wen, ZHANG Yin, LEI Lei, HUANG De-Xiu, ZHANG Xin-Liang

**014204 Influence of Multi-Cascaded Semiconductor Optical Amplifiers on the Signal in an Energy-Efficient System**  
CHEN Xiao-Yong, SHENG Xin-Zhi, WU Chong-Qing

**014205 Two-Detector Arbitrary  $N$ th-Order HBT-Type Ghost Diffraction**  
CAO Bin, ZHANG Chun-Xi, OU Pan, LIN Zhi-Li, SUN Ming-Jie

**014206 Optically Controlled Coherent Backscattering from a Water Suspension of Positive Uniaxial Microcrystals**  
SHI Fan, LI Wei, WANG Pi-Dong, LI Jun, WU Qiang, WANG Zhen-Hua, ZHANG Xin-Zheng

**014207 THz-Wave Difference Frequency Generation by Phase-Matching in  $\text{GaAs}/\text{Al}_x\text{Ga}_{1-x}\text{As}$  Asymmetric Quantum Well**  
CAO Xiao-Long, WANG Yu-Ye, XU De-Gang, ZHONG Kai, LI Jing-Hui, LI Zhong-Yang, ZHU Neng-Nian, YAO Jian-Quan

- 014208 **The Spectrum in Qubit-Oscillator Systems in the Ultrastrong Coupling Regime**  
CHEN Qing-Hu, LI Lei, LIU Tao, WANG Ke-Lin
- 014209 **A 100-TW Ti:Sapphire Laser System at a Repetition Rate of 0.1 Hz**  
TENG Hao, MA Jing-Long, WANG Zhao-Hua, ZHENG Yi, GE Xu-Lei, ZHANG Wei, WEI Zhi-Yi, LI Yu-Tong, ZHANG Jie
- 014210 **Polarization Beam Splitter Based on a Self-Collimation Michelson Interferometer in a Silicon Photonic Crystal**  
CHEN Xi-Yao, LIN Gui-Min, LI Jun-Jun, XU Xiao-Fu, JIANG Jun-Zhen, QIANG Ze-Xuan, QIU Yi-Shen, LI Hui
- 014211 **Frequency Modulation Induced by using the Linear Phase Modulation Method used in a Resonator Micro-optic Gyro**  
HONG Ling-Fei, ZHANG Chun-Xi, FENG Li-Shuang, YU Huai-Yong, LEI Ming
- 014212 **Polymer Electro-optic Modulator Linear Bias Using the Thermo-optic Effect**  
SUN Xiao-Qiang, CHEN Chang-Ming, LI Xiao-Dong, WANG Xi-Bin, YANG Tian-Fu, ZHANG Da-Ming, WANG Fei, XIE Zhi-Yuan
- 014213 **Rayleigh Doppler Lidar for Higher Tropospheric and Stratospheric Wind Observation**  
TANG Lei, WANG Cong-Rong, WU Hai-Bin, DONG Ji-Hui
- 014214 **The Measurement of Displacement and Optical Force in Multi-Optical Tweezers**  
LING Lin, GUO Hong-Lian, HUANG Lu, QU E, LI Zhao-Lin, LI Zhi-Yuan
- 014301 **Propagation of Shear Waves Generated by Acoustic Radiation Force in Nondissipative Inhomogeneous Media**  
LU Ming-Zhu, LIU Xue-Jin, SHI Yu, KANG Yan-Ni, GUAN Yu-Bo, WAN Ming-Xi
- 014302 **Generalized Coupled-Mode Formulation for Sound Propagation in Range-Dependent Waveguides**  
LUO Wen-Yu, YANG Chun-Mei, ZHANG Ren-He
- 014501 **Two Kinds of Localized Oscillating Modes in Strongly Nonlinear Hertzian Chains with Defect**  
CHEN Qiong, YANG Xian-Qing, WANG Zhen-Hui, ZHAO Xin-Yin
- 014601 **Shedding Phenomenon of Ventilated Partial Cavitation around an Underwater Projectile**  
WANG Yi-Wei, HUANG Chen-Guang, DU Te-Zhuan, WU Xian-Qian, FANG Xin, LIANG Nai-Gang, WEI Yan-Peng
- 014701 **Exact Solutions of Chemically Reactive Solute Distribution in MHD Boundary Layer Flow over a Shrinking Surface**  
Chandaneswar Midya
- 014702 **Numerical Simulation of Cavitation in a Centrifugal Pump at Low Flow Rate**  
TAN Lei, CAO Shu-Liang, WANG Yu-Ming, ZHU Bao-Shan

## PHYSICS OF GASES, PLASMAS, AND ELECTRIC DISCHARGES

- 015201 **Stimulated Raman Backscattering Amplification Using Multiple Pump Pulses**  
GE Zhe-Yi, YIN Yan, CHEN De-Peng, ZHUO Hong-Bin, MA Yan-Yun, SHAO Fu-Qiu
- 015202 **Single-Shot Measurement of Broad Bandwidth Terahertz Pulses**  
ZHOU Mu-Lin, LIU Feng, LI Chun, DU Fei, LI Yu-Tong, WANG Wei-Min, SHENG Zheng-Ming, CHEN Li-Ming, MA Jing-Long, LU Xin, DONG Quan-Li, ZHANG Jie

## CONDENSED MATTER: STRUCTURE, MECHANICAL AND THERMAL PROPERTIES

- 016101 **Hysteresis Loops and Phase Diagrams of the Spin-1 Ising Model in a Transverse Crystal Field**  
S. Bouhou, I. Essaoudi, A. Ainane, M. Saber, J. J. de Miguel, M. Kerouad
- 016401 **Cavitating Flow over a Mini Hydrofoil**  
LUO Xian-Wu, JI Bin, ZHANG Yao, XU Hong-Yuan
- 016402 **Si-Nanocrystals with Bimodal Size Distribution in Evenly Annealed SiO Revealed with Raman Scattering**  
KE Wei-Wei, FENG Xue, HUANG Yi-Dong

016801 **Amphiphilic Bio-molecules/ZnO Interface: Enhancement of Bio-affinity and Dispersibility**  
MENG Xiu-Qing, FANG Yun-Zhang, WU Feng-Min

**CONDENSED MATTER: ELECTRONIC STRUCTURE, ELECTRICAL,  
MAGNETIC, AND OPTICAL PROPERTIES**

- 017101 **Reddish Orange Long-Lasting Phosphorescence in  $\text{KY}_3\text{F}_{10}:\text{Sm}^{3+}$  for X-Ray or Cathode Ray Tubes**  
ZHANG Jin-Su, ZHONG Hai-Yang, SUN Jia-Shi, CHENG Li-Hong, LI Xiang-Ping, CHEN Bao-Jiu
- 017102 **Metal-Insulator Transition of Plutonium Hydrides: DFT +  $U$  Calculations in the FPLAPW Basis**  
AO Bing-Yun, AI Juan-Juan, GAO Tao, WANG Xiao-Lin, SHI Peng, CHEN Pi-Heng, YE Xiao-Qiu
- 017201 **Charge Transport and Electrical Properties in Poly(3-hexylthiophene) Polymer Layers**  
WANG Li-Guo, ZHANG Huai-Wu, TANG Xiao-Li, LI Yuan-Xun, ZHONG Zhi-Yong
- 017301 **Formation of Low-Resistant and Thermally Stable Nonalloyed Ohmic Contact to N-Face n-GaN**  
ZENG Chang, ZHANG Shu-Ming, WANG Hui, LIU Jian-Ping, WANG Huai-Bing, LI Zeng-Cheng, FENG Mei-Xin, ZHAO De-Gang, LIU Zong-Shun, JIANG De-Sheng, YANG Hui
- 017302 **Effect of Substrate Temperature on the Structural and Raman Properties of Ag-Doped ZnO Films**  
WANG Li-Na, HU Li-Zhong, ZHANG He-Qiu, QIU Yu, LANG Ye, LIU Guo-Qiang, QU Guang-Wei, JI Jiu-Yu, MA Jin-Xue
- 017303 **Structural, Electronic and Optical Properties of  $\text{KTa}_{0.5}\text{Nb}_{0.5}\text{O}_3$  Surface: A First-Principles Study**  
SUN Hong-Guo, ZHOU Zhong-Xiang, YUAN Cheng-Xun, YANG Wen-Long, WANG He
- 017304 **Terahertz Current Oscillation in Wurtzite InN**  
FENG Wei
- 017305 **The Theoretical Investigation and Analysis of High-Performance ZnO Double-Gate Double-Layer Insulator Thin-Film Transistors**  
GAO Hai-Xia, HU Rong, YANG Yin-Tang
- 017401  **$^{75}\text{As}$  Nuclear Magnetic Resonance Studies on  $\text{Ba}(\text{Fe}_{1-x}\text{Ni}_x)_2\text{As}_2$  Single Crystals under High Pressure**  
ZHANG Xiao-Dong, FAN Guo-Zhi, ZHANG Cheng-Lin, JING Xiu-Nian, LUO Jian-Lin
- 017701 **The Comprehensive Retrieval Method of Electromagnetic Parameters Using the Scattering Parameters of Metamaterials for Two Choices of Time-Dependent Factors**  
HOU Zhi-Ling, KONG Ling-Bao, JIN Hai-Bo, CAO Mao-Sheng, LI Xiao, QI Xin
- 017801 **Nanostructured Metal-Enhanced Photoluminescence of Micro- $\text{Sr}_2\text{Si}_5\text{N}_8:\text{Eu}^{2+}$  Phosphors**  
LIU Ling, XU Xiao-Liang, LEI Jie-Mei, YIN Nai-Qiang
- 017802 **The Preparation and Photoluminescence Properties of Fluorosilicate Glass Ceramics Containing  $\text{CeF}_3:\text{Dy}^{3+}$  Nanocrystals**  
WU Li-Ang, FU Heng-Yi, QIAN Jiang-Yun, ZHAO Da-Liang, LUO Qun, QIAO Xu-Sheng, FAN Xian-Ping, ZHANG Xiang-Hua
- 017803 **Comparative Study of the Characteristics of the Basal Plane Stacking Faults of Nonpolar  $\alpha$ -Plane and Semipolar (11 $\bar{2}$ 2) GaN**  
XU Sheng-Rui, LIN Zhi-Yu, XUE Xiao-Yong, LIU Zi-Yang, MA Jun-Cai, JIANG Teng, MAO Wei, WANG Dang-Hui, ZHANG Jin-Cheng, HAO Yue
- 017804 **The Annealing-Induced Shape Deformation of Hydrothermal-Grown ZnO Nanorods**  
ZHENG Zhong-Kui, DUANMU Qing-Duo, ZHAO Dong-Xu, WANG Li-Dan, SHEN De-Zhen
- 017805 **The Morphological Change of Silver Nanoparticles in Water**  
WANG Peng, WANG Rong-Yao, JIN Jing-Yang, XU Le, SHI Qing-Fan

## CROSS-DISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

- 018101 **The Growth of Semi-Polar ZnO (10 $\bar{1}$ 1) on Si (111) Substrates Using a Methanol Oxidant by Metalorganic Chemical Vapor Deposition**  
SANG Ling, WANG Jun, SHI Kai, WEI Hong-Yuan, JIAO Chun-Mei, LIU Xiang-Lin, YANG Shao-Yan, ZHU Qin-Sheng, WANG Zhan-Guo
- 018102 **A Study of GaN Grown on SiH<sub>4</sub> Pre-Treated 6H-SiC Substrates**  
SONG Shi-Wei, LIANG Hong-Wei, LIU Yang, XIA Xiao-Chuan, SHEN Ren-Sheng, LUO Ying-Min, DU Guo-Tong
- 018103 **The Field Emission Characteristics of Titanium-Doped Nano-Diamonds**  
YANG Yan-Ning, ZHANG Zhi-Yong, ZHANG Fu-Chun, DONG Jun-Tang, ZHAO Wu, ZHAI Chun-Xue, ZHANG Wei-Hu
- 018104 **The Photovoltaic Properties of BiFeO<sub>3</sub>La<sub>0.7</sub>Sr<sub>0.3</sub>MnO<sub>3</sub> Heterostructures**  
LUO Bing-Cheng, CHEN Chang-Le, FAN Fei, JIN Ke-Xin
- 018401 **The Electric Mechanism of Surface Pretreatments for Dye-Sensitized Solar Cells Based on Internal Equivalent Resistance Analysis**  
XU Wei-Wei, HU Lin-Hua, LUO Xiang-Dong, LIU Pei-Sheng, DAI Song-Yuan
- 018501 **Reactive Radiofrequency Sputtering-Deposited Nanocrystalline ZnO Thin-Film Transistors**  
LI Shao-Juan, HE Xin, HAN De-Dong, SUN Lei, WANG Yi, HAN Ru-Qi, CHAN Man-Sun, ZHANG Sheng-Dong
- 018701 **Temporal Correlation-Based Spatial Filtering of Rician Noise for Functional MRIs**  
Amir. A. Khaliq, I. M. Qureshi, Jawad. A. Shah
- 018901 **Intelligent Exit-Selection Behaviors during a Room Evacuation**  
Zarita Zainuddin, Lim Eng Aik

## GEOPHYSICS, ASTRONOMY, AND ASTROPHYSICS

- 019601 **An Internal Heating Model to Elucidate the Shape of a Small Planetary Body**  
LI Gen, CHEN Chu-Xin
- 019701 **Reanalysis of the Isotopic Mixture of Neutron-Capture Elements in the Metal-Poor Star HD 175305**  
ZHANG Jiang, WANG Bo, ZHANG Bo, HAN Zhan-Wen

## ERRATA AND OTHER CORRECTIONS

- 019901 **Erratum: Multilayer Antireflection Coating for Triple Junction Solar Cells [Chin. Phys. Lett. 28 (2011) 047802]**  
ZHAN Feng, WANG Hai-Li, HE Ji-Fang, WANG Juan, HUANG She-Song, NI Hai-Qiao, NIU Zhi-Chuan
- 019902 **Erratum: Dyadic Green Function for an Electromagnetic Medium Inspired by General Relativity [Chin. Phys. Lett. 23 (2006) 832]**  
Akhlesh Lakhtakia, Tom G. Mackay

JUST FOR AUTHORS  
— CHINESE PHYSICS LETTERS