## Session 9: Lasers and Nonlinear Optics

**Chairs:** Liejia Qian, Shanghai Jiao Tong University, China  
Dingyuan Tang, Nanyang Technological University, Singapore

**Location:** B507, 5F, Main Building, Harbin Institute of Technology No.2 Campus

### 18th July

**Chair:** Dingyuan Tang, Nanyang Technological University, Singapore

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**Chair:** Pu Zhou, National University of Defense Technology, China

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**Chair:** Xueming Liu, Zhejiang University, China

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**Chair:** Yangjian Cai, Soochow University, China

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11:30-11:45 Laser Beam Conditioning Using Spatial Shaping, Temporal and Polarization Smoothing (Oral)
Rui Zhang
Laser Fusion Research Center, China Academy of Engineering Physics, China

11:45-12:00 Multi-Target Ranging by Using Chaotic Laser Radar Based on the Complete Chaotic Synchronizations of the Polarization Components in the Drive-Response VCSELs (Oral)
Wei Luo, Zhongdong Zhou
Wuyi university, China

12:00-12:15 An Identification Technology for Crude Oil and Lubricant on Simulated Sea Surface (Oral)
Xiaobing Zhang, Changqing Cao
Xidian University, China

12:15-14:00 Lunch Time

Chair: Hong Jin Kong, Korea Advanced Institute of Science and Technology, Korea

14:00-14:45 The Nonlinear and Laser Optics of Diamond (Keynote)
Rich Mildren
Macquarie University, Australia

14:45-15:15 Langasite Crystals: From Crystal Growth to Nonlinear Optical Applications (Invited)
Haohai Yu
Shandong University, China

15:15-15:30 Output Characteristics of Actively Q-Switched Ho:CYA Laser (Oral)
Huiting Xia*, Fan Wu, Yongguang Zhao, Deyuan Shen
1 Jiangsu Normal University, China; 2 Fudan University, China

15:30-16:00 Coffee Break

Chair: Xiaoyan Liang, Shanghai Institute of Optics and Fine Mechanics, CAS, China

15:30-16:00 Recent Progress on High Power, Mid-IR, Ultra-fast Fiber Lasers (Invited)
Pu Wang
Beijing University of Technology, China

16:00-16:15 Graphene Binary/Ternary-Nanocomposites: Synthesis, Characterization and Their Application to Ultrafast Soliton Lasers (Oral)
Bo Guo
Harbin Engineering University, China

16:15-16:30 Novel Tm: CaYAlO4 Mode-Locked Laser at 2 μm Water Absorption Band (Oral)
Wei Zhou, Xiaodong Xu, Rui Xu, Xuliang Fan, Yongguang Zhao, Deyuan Shen, Dingyuan Tang
Jiangsu Normal University, China

16:30-16:45 Characterization of Chaotic Brillouin Dynamic Grating (Oral)
Zhuping Li, Jianzhong Zhang, Mingjiang Zhang, Yi Liu
Taiyuan University of Technology, China

16:45-17:00 Dynamic Characteristics of Packaged Chaotic Semiconductor Laser (Oral)
Yanan Niu, Mingjiang Zhang, Tong Zhao, Jianzhong Zhang, Yi Liu, Anbang Wang, Yuncai Wang
Taiyuan University of Technology, China

17:00-17:15 A Short-Cavity integrated Chaotic Semiconductor Laser Packaged by a Butterfly Package (Oral)
Yuhang Xu, Mingjiang Zhang, Tong Zhao, Jianzhong Zhang, Y Li, Yuncai Wang, Anbang Wang
Taiyuan University of Technology, China

17:15-17:30 Continuous-Wave Brightness Enhancement in an External Cavity Diamond Raman Laser (Oral)
Zhuxu Bai, Robert J. Williams, Hadiya Jasbeer, Soumya Sarang, Ondrej Kitzler, Aaron McKay, Richard P. Mildren
Macquarie University, Australia

18:00-20:00 Banquet

20th July

Chair: Guoqiang Xie, Shanghai Jiao Tong University, China

09:00-09:30 Temporal Dual-Pulse Pumped Ti: Sapphire Amplifier for 10 PW SULF Laser (Invited)
Xiaoyan Liang
Shanghai Institute of Optics and Fine Mechanics, CAS, China

09:30-10:00 Temporal Contrast Enhancement for LFEX Petawatt Laser (Invited)
Zhaoyang Li
Osaka University, Japan

10:00-10:15 Modelling End-Pumped Electro-Optic Q-Switching Lasers with the Influences of Thermal Effects and Spatial Mode Matching (Oral)
Hongli Wang, Yulei Wang, Zhiwei Lu
Harbin Institute of Technology, China
### Session 9: Lasers and Nonlinear Optics

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Coherent Beam Combination Using SBS-PCM for High Power Laser System

ABSTRACT

Coherent beam combination is one of the most promising technology for the next generation high power laser system. SBS-PCM is one of the most simple and scalable component to achieve this goal. The general aspects and experimental results using SBS-PCM for the coherent beam combination will be given in this talk.

He got Master of Physics from KAIST in 1978 and Ph.D. from KAIST in 1981. He joined Physics department of Inha University in 1981 as an assistant professor, and moved to the department of physics of KAIST in 1984 as an assistant professor.

BIOGRAPHY

He became a full professor in 1989, and the director of Laser Science Research Laboratory in 1990.

He was a visiting professor of LLE of Rochester University from 1988 to 1989. He was a 6-months invited professor of ILE, Osaka University in 1997. He was a invited professor of Guangzhou Normal University from 2001.


He became a Fellow of SPIE from 2010. He became a Senior Scientist of OSA from 2012.

He is a laser scientist. He has a lot of experiences on designing hyper spectral cameras, 2 photon absorption polymerization, 3Dimensional imaging LIDAR system, high power solid state laser, dye laser, and coherent beam combination using stimulated Brillouin scattering phase conjugate mirrors.

Coherent Polarization Beam Combining of High Power Fiber Lasers

ABSTRACT

We will report the recent advances in coherent beam combining of fiber lasers in our group. Power scaling of all-fiber linear-polarized fiber amplifier is studied with efficient suppression of SBS and modal instability, and a record power of 2.5 kW is achieved for this kind of fiber laser. Based on active phase control method, four channels of kilo-watt level narrow-linewidth linear-polarized fiber amplifiers are coherently polarization combined with an efficiency of 92%. The combined beam has an output power of 3.2 kW, and the beam quality $M^2$ factor of the combined beam is $\sim 1.3$ at 3 kW.

BIOGRAPHY

Pu Zhou (1984- ) received his Ph.D degree in Optical Engineering from National University of Defense Technology (NUDT) in 2009. He is the author of National Excellent Doctoral Dissertations of China, and now he is a Professor and supervisor for Ph.D student in NUDT. His recent research interests include fundamental investigation on high power fiber laser and beam combining, where novel research results on nonlinear optical effect manipulation, lasing at extreme wavelength and its application in tandem pumping, precise phase control of multi-channel laser beams, propagation of beam array and its performance evaluation have been achieved. As the first author or corresponding author, he has published more than 90 papers in Applied Physics Letters, IEEE Journal of Selected Topics on Quantum Electronics, Optics Letters, Optics Express, Scientific Reports and so on.
Ultrafast Fiber Soliton Lasers

ABSTRACT
We report a compact all-fiber laser system mode-locked by Nanomaterials such as nanotube and graphene. The proposed laser can deliver the multiple wavelengths and the central wavelengths are tunable. Nanomaterial-based mode-locked fiber laser emits the dissipative solitons with higher pulse energy. These results may provide helpful theoretical and experimental fundamentals for the in-depth study of new high-energy pulses, and bring the new understandings about nonlinear phenomenon of ultra-short high-energy pulses under extreme conditions.

BIOGRAPHY
Prof. Liu received the PhD degree in 2000. Successfully, He had engaged in the post-doctoral research in Tsinghua University and Seoul National University from 2000 to 2004. From May 2004 to Oct. 2005, He was a Scientist in Agency for Science, Technology and Research, Singapore. From Apr. 2007 to Jun. 2007 and from Nov. 2007 to Oct. 2008, He was a visiting scholar and research professor in the Chinese University of Hong Kong and Gwangju Institute of Science and Technology (GIST), respectively. From Mar. 2012 to Sep. 2012, He was a senior visiting scholar in the University of Cambridge. He has authored or coauthored papers more than 150. He was honored to the National Science Fund for Distinguished Young Scholars.
Frequency Noise Characteristics in Single-Frequency Fiber Laser

ABSTRACT

The frequency noise characteristics of single-frequency highly Er\textsuperscript{3+}/Yb\textsuperscript{3+} co-doped phosphate fiber laser is investigated experimentally. The frequency noise and the relative intensity noise (RIN) of the single-frequency fiber laser with various lengths of the phosphate fiber and different pumping powers. These results show that optimizing the length of phosphate fiber can reduce the frequency noise of this fiber laser. And the adjustment of the pumping power can also promote the frequency noise performance. These investigations are conducive to optimizing laser property and promote the wide application of this single-frequency fiber laser.

BIOGRAPHY

Shanhui Xu received the M.Sc. degree from the South China University of Technology (SCUT), Guangzhou, China, in 2001, and the Ph.D. degree from South China Normal University, Guangzhou, China, in 2009. From 2001 to 2003, he was a Research Engineer in Huawei Technologies Co., Ltd. He is currently a Professor in the State Key Laboratory of Luminescent Materials and Devices and Institute of Optical Communication Materials, South China University of Technology.
Generation and Propagation of Partially Coherent Beams

ABSTRACT
Coherence is an important property of laser beam. Laser beam with low spatial coherence named partially coherent beam exhibits many interesting propagation properties and is preferred in many applications. In this talk, we will introduce recent development on generation and propagation of partially coherent beams.

BIOGRAPHY
Prof. Yangjian Cai was born in Zhejiang, China, in 1977. He received Ph.D. degree in Physics from Zhejiang University, China, in 2005, and Ph.D. degree in electromagnetic theory from Royal Institute of Technology, Sweden, in 2006. From Dec. 2016 to Jan. 2009, he worked as a Postdoctoral Researcher and as a Humboldt Research Fellow in Max Planck Research Group, Institute of Optics, Information, and Photonics, University of Erlangen, Germany. In 2007, he won National 100 Excellent Ph. D. Theses Award of Ministry of Education of China. Since 2009, he works as a full professor in School of Physical Science and Technology, Soochow University, China. His research fields include optical coherence and polarization, laser physics, optical imaging and atmospheric optics. He has published more than 250 SCI-indexed papers in refereed international journals (over 100 papers in OSA journals), and the number of SCI citations (without self-citations) is over 3300. In 2015, he obtained the National Science Fund for Distinguished Young Scholars. In 2016, he was selected as a distinguished professor of Jiangsu Province.
**Dissipative Soliton Lasers and Beyond**

**ABSTRACT**

Ultrashort pulse generation in mode locked lasers is one of the hot topics of laser physics and engineering and has been extensively studied. Based on the textbook laser mode locking theory, when the phases of all oscillating longitudinal modes are synchronized, either by the active or passive mode locking techniques, a laser will emit a train of optical pulses whose minimum pulse width is ultimately limited by the laser gain bandwidth. However, the conventional laser mode locking theory didn’t consider the effects of nonlinear light propagation in the laser cavity. For many mode locked lasers this is also justified. Recent advance of the laser technology has demonstrated more and more mode locked laser operations where the nonlinear light propagation in the cavity is no longer ignorable. In this talk we show both theoretically and experimentally that many novel new features, such as the dissipative soliton formation, soliton period-doubling and route to chaos, twin-pulse emission etc., could appear in these mode locked lasers. The goal of laser mode locking is to generate optical pulses with possibly large energy and narrow pulse width. Experimentally we found that by operating a mode locked laser in the nonlinear regime, not only ultra-stable mode locked pulse train can be obtained, under suitable operation conditions, ultrashort pulses whose spectral bandwidth is far larger than the gain bandwidth can be formed. It could be an effective technique to generate ultra-stable and ultra-narrow optical pulses directly from a laser oscillator.

**BIOGRAPHY**

Prof. D. Y. Tang received his B.Sc. degree in physics from Wuhan University, China in 1983, M.Sc. degree in laser physics from Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Science in 1986 and Ph.D. degree in physics from Hannover University, Germany in 1993. From 1993 to 1994, he worked as a scientific employee at the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany. From 1994 to 1997 he was a university Postdoctoral Research Fellow, and from 1997 to 1999 an Australian Research Council (ARC) Postdoctoral Research Fellow at the University of Queensland, Australia. From 1999 to 2000 he was a Research Fellow in the Optical Fiber Technology Center (OFTC), University of Sydney, Australia. Since July 2000 he has been an Associate Professor in the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. Prof. Tang’s research interests are in the areas of laser physics and techniques, nonlinear optics, ultrafast optics, and ceramic laser materials. He has published over 300 international journal papers with an H-index of 47. He is an associate editor for the international journals of *Optical Engineering* and *Optics Express*. 
Binary Pixelated Beam Shapers for Laser Engineering and Wavefront Metrology

ABSTRACT

Binary pixelated beam shapers relying on distributions of small transparent or opaque pixels designed by spatial dithering algorithms allow for quasi-arbitrary continuous spatially varying transmission control. I will review the principle and application of metal-on-glass devices and variants based on binary phase modulation and binary polarization modulation to precise apodization and beam shaping in laser systems. Examples of applications to laser wavefront metrology will also be presented.

BIOGRAPHY

Christophe Dorrer received his PhD in Optics from the Ecole Polytechnique (France) in 1999. He was a post-doctoral fellow at the Institute of Optics (Rochester, NY, USA) from 1999 to 2001 and a member of technical staff at Bell Laboratories (Holmdel, NJ, USA) from 2001 to 2005. Since 2005, he is a scientist at the Laboratory for Laser Energetics (Rochester, NY, USA), where he works on the development of fiber front ends for laser systems, optical parametric chirped pulse amplification, temporal pulse characterization, techniques for temporal contrast characterization and improvement, wavefront sensing, and beam shaping. Since 2008, he is the chief technology officer at Aktiwave LLC, a company that specializes in metrology and beam shaping. He is a fellow of the Optical Society (OSA) and an associate editor for Optica.
Ultraclean Femtosecond Vortices Generation From A High-Order Transverse-Mode Femtosecond Mode-Locked Laser

ABSTRACT
Since the birth in the 1970s, the first generation of femtosecond laser, characterized by emitting Gaussian beam, has shown a wide range of applications from industry to scientific research. The second generation of femtosecond laser, characterized by structured beams with special spatial phase and intensity profiles, represented by femtosecond vortex beams, is reforming traditional ultrafast technology and has shown tremendous potential in a wide range of applications, including sub-wavelength nonlinear microscopy, femtosecond micro-nano manipulation, femtosecond special-structure micro-processing, filament optics, and vortex-based strong-field physics, etc.

However, the generation of high-quality clean femtosecond optical vortex is a challenge. The traditional vortex generation techniques based on phase or diffraction elements (spiral phase plate, hologram grating, etc.) work well for CW and picosecond lasers with a narrow spectral bandwidth, where the effect of dispersion can be ignored. However, femtosecond vortex has a wide spectral bandwidth. Therefore, the traditional vortex generation techniques based on phase or diffraction elements are intrinsically limited by dispersion, which will result in unclean or distorted femtosecond vortices generation.

Here, we report on ultraclean femtosecond vortex generation by a femtosecond mode-locked laser operating in a single high-order transverse mode. By controlling the oscillation thresholds of various-order transverse modes in a laser, a pure and mode-order-tunable femtosecond Hermite-Gaussian (HG) beam is generated from the mode-locked laser and subsequently is converted into the femtosecond vortex by a cylindrical lens converter. The obtained femtosecond vortex has an unprecedented ring-to-center intensity contrast of 36 dB measured with a near wavelength-spatial-resolution detecting device, which approaches to the theoretical limit of an ideal vortex beam. This work may open up a wide range of application prospects for femtosecond vortices and motivate novel femtosecond structured beam generation directly from mode-locked lasers.

BIOGRAPHY
Guoqiang Xie is currently a research professor at the School of Physics and Astronomy of Shanghai Jiao Tong University. He received the Ph.D. degree from Fudan University in 2008. From 2006 to 2009, he worked at Nanyang Technological University in Singapore as a Project Officer and then Research Fellow. In 2009, he joined in Shanghai Jiao Tong University as a Research Professor. He has published over 70 papers in international journals and conferences, and has a citation of more than 1300 times. He is the editorial board member (EBM) of Scientific Reports, guest editor of International Journal of Optics, Deputy Director of Youth Committee of Shanghai Laser Association, etc. His research interests include ultrafast laser, novel laser materials, and quadratic nonlinear optics, etc.
The Nonlinear and Laser Optics of Diamond

ABSTRACT

Many of diamond’s optical and thermal properties have been coveted in laser applications for many years, however, until recently these have not been exploited in applications due to its poor proclivity for hosting for fluorescent dopants. Our research has focused on the laser properties of diamond in its pure state by using Raman gain. Since our first demonstration of Raman laser using synthetic diamond in 2008, there has been rapid progress in using diamond to enhance the efficiency, wavelength range and output power of Raman lasers in temporal regimes spanning the ultrafast to cw. In this talk, I’ll review progress to date and highlight the directions in laser and nonlinear optics where it is well placed to make a substantial impact. Amongst a range of interesting advantages, its capacity for very high average power (>>kW) and high spectral brightness at traditionally difficult regions of the spectrum are areas that will be especially highlighted.

BIOGRAPHY

Rich Mildren (Australian Research Council Future Fellow in 2010-2014) is an Associate Professor in the Department of Physics and Astronomy. His research is in the development of novel and versatile photonic sources, instrumentation and applications. His PhD and early postdoctoral research was in the plasma kinetics of high power metal vapour lasers. He has studied ultrafast lasers at the National Research Council in Pisa, Italy. For 3 years (2005-2008) he led R&D for a University spin-off company in wavelength-switchable medical lasers, during which time he brought several medical laser products through to the stage of medical device regulatory approval. His most recent focus, conducted in the MQ Photonics Research Centre, is in the nonlinear optical properties of Group IV materials, particularly diamond.
Langasite Crystals: From Crystal Growth to Nonlinear Optical Applications

ABSTRACT

Langasite crystal is a multifunctional crystal material, and has important applications in the field of electro-optical, piezoelectric and nonlinear optics, etc. Compared with each other, we found that La$_2$Ga$_{5.5}$Nb$_{0.5}$O$_{14}$ (LGN) crystal satisfies the requirements of the mid-infrared lasers in transmission spectra, nonlinear coefficient and optical damage threshold. We studied the quadratic nonlinear optical properties of LGN crystal in mid-infrared range and realized the OPG generation. After particular calculations of the gain bandwidth of LGN, it is found that this crystal could be a qualified candidate in the field of mid-infrared amplification, especially in the aspects of mid-infrared CPA and/or OPCPA aiming to obtain high-peak-power few-cycle mid-IR pulses.

BIOGRAPHY

Haohai Yu was born in Jinan, China, on October 16, 1981. He received the Ph.D. degree from Shandong University, Jinan, in 2008. He is currently a scientist at the State Key Laboratory of Crystal Materials and Institute of Crystal Materials, Shandong University. His current research interests include crystal growth, diode-pumped solid-state lasers, and nonlinear optics based on the new crystals.
Recent Progress on High Power, Mid-IR, Ultra-Fast Fiber Lasers

ABSTRACT
The research on mid-infrared laser sources has attracted worldwide attentions because of their attractive applications in atmospheric gas detection, laser medicine, laser lidar, mid-infrared imaging and electro-optical countermeasure system. Due to its characteristics of high power, excellent beam quality and high temporal stability, 2 µm high average power, high peak power, and short pulsed thulium-doped fiber laser is considered to be a good candidate for implementing of 2~5 µm high power mid-infrared laser. Developing the 2 µm high power all-fiber thulium-doped fiber laser has become imperative to promote a new generation of mid-infrared laser system. Here, I will review our recent progress in developing 2 µm short pulsed thulium-doped fiber oscillator, 2 µm high power thulium-doped fiber amplifier and 2~5 µm supercontinuum generation. The recent progress on high power chirped pulse amplification Tm-doped femtosecond fiber lasers, and the high power tunable Raman solitons of 1.5 ~ 2.4 µm will also be presented.

BIOGRAPHY
Pu WANG received the Bachelor degree in Physics from Shandong University, Jinan, Shandong, P.R.China, in 1986 and the Ph.D. degree in Laser Physics from Macquarie University, Sydney, Australia, in 1999, respectively. He is now a professor in Institute of Laser Engineering, Beijing University of Technology. His current research interests include high power rare-earth-doped fiber lasers and amplifiers, ultrafast fiber lasers and amplifiers, nonlinear frequency conversion in fiber optics, etc. So far, he has published over 50 scientific papers.
ABSTRACT
The laser project of Shanghai Ultra-intense and Ultra-fast Laser Facility (SULF) is aimed to develop a laser with peak power of 10 PW which will be used for three intense physical experimental platform. The laser facility is based on the technology of chirped pulse amplification (CPA) and Ti:sapphire crystal. To suppress the parasitic lasing in large aperture Ti:sapphire amplifier for high energy output, we proposed a new method of temporal dual-pulse pumping. For a energy amplifier containing a 150mm diameter Ti:sapphire, energy of 202.8 J was obtained with pump of 320 J corresponding the conversion efficiency of 49.3%. The compressed pulse duration of 24.0 fs was measured with a throughput efficiency of 64%, leading to a peak power of 5.4 PW. For the next step, we will improve the amplified energy with a 200 mm Ti:sapphire amplifier to support the peak power of 10 PW.

BIOGRAPHY
Xiaoyan Liang is currently a professor in Shanghai Institute of Optics and Fine Mechanics (SIOM), China. She received the B.S. degree in physics from Shanxi University in China in 1988, and the Ph.D. in Laser Optics in 2001 from Institute of Physics, Chinese Academy of Science. From 2001 to 2003 she was a postdoctoral fellow in department of physics, University of Kaiserslautern in Germany, where her research was on solid state lasers and widely tunable optical parametric oscillator. She joined SIOM in 2003, and her current research interests involve exploring of ultra-intense and ultra-fast petawatt lasers. Her work mainly focuses on petawatt (PW) femtosecond laser based on chirped pulse amplification (CPA) and optical parametric chirped pulse amplification (OPCPA). At the moment, she is engaged in build of the SULF 10 PW laser.
Temporal Contrast Enhancement for LFEX Petawatt Laser

ABSTRACT
LFEX is the recent strongest petawatt (PW, \(10^{15}\) W) laser which could support a 3 kJ, 1.5 ps, and accordingly 2 PW output. The temporal contrast, defined as the intensity ratio between the signal and the pre-noise, is a key parameter for a PW laser which directly determines the applications of such lasers. The temporal contrast of LFEX in the picosecond range is \(10^8\), and then peak power of the noise would reach to around \(10^7\) W, which is powerful enough to generate low-density plasma and destroy the experimental target before the real signal arriving. In this talk, we investigated the influence factors and proposed corresponding methods for temporal contrast enhancement. The proposed theory models and theoretical predictions were verified by experimental demonstrations. We believe this work is expected to further optimize PW-class lasers with high temporal contrasts.

BIOGRAPHY
Zhaoyang Li received his B.S. degree from Beijing Institute of Technology in 2005, M.S. degree from China Academy of Engineering Physics in 2008, and Ph.D. degree from Nanjing University of Science and Technology in 2015. From 2006 to 2014 he worked as a research associate for Chinese first PW laser (ShenGuang-II petawatt facility), from 2014 to 2016 he worked as a research associate for Chinese first 10-PW laser (Shanghai Super-intense Ultra-fast Laser Facility, SULF), and from 2016 he worked as an assistant professor for the recent strongest PW laser (LFEX at Institute of Laser Engineering, Osaka University, Japan). His recent research interests include ultrahigh ultrafast lasers, high average power lasers, fiber lasers, and nonlinear optics.
Generation of Ultrashort Dissipative Soliton Pulses in Solid-State Lasers

ABSTRACT

The generation of ultrashort optical pulses has been one of the hottest research topics in the laser physics and engineering due to their widespread applications in modern science and technology. In this talk, we will present our recent progress on generation of ultrashort sub-100 fs even sub-50 fs dissipative soliton pulses, whose dynamics are governed by the complex Ginzburg-Landau Equation, in different Yb-doped and Nd-doped mode-locked solid-state lasers. Ultrashort soliton pulses of 30 fs and 79 fs were obtained from Yb:CaYAlO₄ and Nd:Ca₃La₂(BO₃)₄ lasers, respectively, which is the shortest pulse for Yb-doped and Nd-doped solid-state oscillators up to now. The experimental results demonstrated ultrashort soliton pulses shorter than that allowed by the net gain bandwidth could be achieved if the various pulse-shaping mechanisms, including cavity dispersion, nonlinear phase modulation, laser gain and losses, and the gain bandwidth, could be appropriately balanced.

BIOGRAPHY

Jie Ma received his B.S. degree from Shandong University, China, in 2007, and Ph.D. degree in physics from Shanghai Jiao Tong University, China, in 2013. After that, he worked as a postdoctoral research fellow in National University of Singapore during 2014 to 2015. In 2015, he joined in School of Electrical and Electronic Engineering, Nanyang Technological University in Singapore as a research fellow. His research interests include ultrafast laser, novel optical materials, and nonlinear optics.
Laser Beam Combination Based on Brillouin Serial Amplification

ABSTRACT

Laser beam combination is an effective method to generate high power laser and avoid the thermal damage and the limitation of energy capacity of a single laser beam. The serial laser beam combination based on stimulated Brillouin scattering (SBS), compared to other laser beam combination technology, is close to one completely coherent laser beam. Its advantages have been confirmed that the phase controlling is unnecessary, and the high-quality laser beam is coherent with high stability and significant scalability. Two pivotal difficulties have been discussed. One is the amplification of the strong Stokes seed, and the other is phase matching for non-collinear Brillouin amplification.

BIOGRAPHY

Yulei Wang is Professor of physical electronics at Harbin Institute of Technology. He received the B.S. degree and Ph.D. degree from Harbin Institute of Technology, Harbin, China, in 2001 and 2007 respectively. He worked at Imperial College London as a visiting scholar from 2011 to 2012. His research interests are high power solid-state lasers, stimulated Brillouin scattering (SBS) and its applications in high-power lasers. He worked as a leadership to build the high power hundred-Joule laser facility with the extremely excellent quality. He holds 15 patents, has authored and co-authored 76 papers in peer-reviewed journals, including APL, OL, OE, etc. He gained the National Science Foundation for Excellent Young Scholars in 2016.
Temperature-Insensitive Parametric Amplification and Pulse-Contrast Characterization for Ultrafast Intense Lasers

ABSTRACT
Noncollinearity provides an effective design freedom for the nonlinear three-wave interactions. Two applications of the noncollinear configuration in ultrafast intense lasers will be presented. The first example is the noncollinear achromatic phase matching scheme, in which the noncollinearity is employed to eliminate the first derivative of phase-mismatch with respect to temperature. By combining an angularly dispersed seed, this scheme can support simultaneous temperature- and wavelength-insensitive amplification for high-average-power ultrafast lasers. The second example is the noncollinear cross-correlator, in which the noncollinearity is employed to realize time-to-space encoding for enabling the single-shot characterization of pulse contrast of intense lasers. Recent pulse-contrast measurement results for several petawatt-class laser facilities in China will be reported.

BIOGRAPHY
Dr. Ma, born in 1986, received his B.S. in Optics at Shandong University in 2009 and his Ph.D. in Optics at Fudan University in 2014. He worked in Shanghai Jiao Tong University for his postdoc research from 2014-2016. He is now a lecturer in School of Physics and Astronomy, SJTU. Research interests include nonlinear optics, ultrafast lasers and intense lasers. He has published over 20 papers, including 1 in Nature Communications, 1 in Optica and 7 in Optics Letters/Express. He has obtained 8 licenses of invention patents, including 4 United States Patents.
High Power Kerr-Lens Mode-Locked Yb-Bulk Oscillators

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Yb doped gain media have attracted numerous interests in high-power ultrashort pulse generation due to their excellent spectroscopic and thermal conductivity for decades. In particular, sub-50 fs pulses can be obtained from some specific Yb-doped materials by using Kerr-lens mode-locking technique. However, most of them suffered from limited output average power of less than 100 mW due to the limited power of single mode laser diodes (LDs) which are essential for pure Kerr-lens mode-locking operation. To increase the average power of the ultrafast Kerr-lens mode-locked Yb: lasers, either using high-power single-mode fiber laser as the pump source or utilizing multi-mode LD to implement Kerr-lens mode-locking operation with hard aperture is needed. With the previous method, we demonstrated a bright fiber laser pumped Kerr-lens mode-locked Yb:GSO oscillator, which delivered 4-W, 249-fs pulses at the repetition rate of 92 MHz. The corresponding optical-to-optical efficiency with respect to the absorbed pump power was as high as 54%. This is, to the best of our knowledge, the highest optical-to-optical efficiency ever achieved from a Kerr-lens mode-locked solid-state oscillator. In addition, we also demonstrated a high power Kerr-lens mode-locked Yb:YSO laser with as high as 2 W average power and 95 fs pulse duration for the first time. By employing the second methods, an additional Kerr medium is introduced to enhance the Kerr effect as well as a small pinhole acts as the hard aperture. As a result, a LD pumped Kerr-lens mode-locking Yb:CYA laser is demonstrated for the first time. Output power up to 1.5 W is obtained at a repetition rate of 50 MHz. The corresponding signal pulse energy is as high as 30 nJ, which is the highest single pulse energy ever achieved from the Yb:CYA lasers. With optimized intra-cavity dispersion compensation, the pulse duration of the KLM pulses is 68 fs, corresponding to the peak power of 0.44 MW. By better thermal management and cavity dispersion compensation, multi-watt, sub-100 fs pulses could be produced from the solid-state Yb-based oscillators by these simple architectures and will have wide applications in many fields.

Key words: Kerr-lens mode-locking; all-solid-state laser; diode-pumping; femtosecond; high power

Diode-pumped cesium-vapor laser and blue-violet laser by frequency doubling

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The diode-pumped alkali-vapor lasers (DPALs) have the preferred properties of solid-state lasers and gas lasers, such as high quantum efficiency, large stimulated emission cross-section, easy heat elimination and good optical characteristics. The DPALs are expected to obtain near-infrared laser output with high power, high efficiency and high beam quality, which has potential applications in military and civilian. Therefore, it has attracted more and more attention in recent years. In addition, it is a new way to achieve blue-violet laser by frequency doubling of DPALs, which has important applications in scientific research, medical treatment, laser displays and underwater communication.

In this paper, the experimental investigations on a diode-pumped cesium-vapor laser (Cs-DPAL) and its frequency doubling to obtain blue-violet laser are carried out. First of all, a Cs-DPAL is constructed. By optimizing the parameters, the CW Cs laser with fundamental transverse mode is obtained, and the center wavelength and the line width are 894.57 nm and 0.032 nm, respectively. When the operating temperature of the Cs vapor cell is 107.6°C, the maximum stable CW power of Cs-DPAL is 1.74 W and the optical-optical efficiency is 17.3%. Under the condition of pulsed operation, the maximum stable power of Cs-DPAL is about 3 W and the efficiency is 14.6%. And then the researches on blue-violet laser by extra-cavity and intra-cavity frequency doubling are presented by using the type I phase matching method with LBO crystal. By extra-cavity frequency doubling, the highest power of the 447.3 nm pulsed blue-violet laser reaches to 0.01 mW. With intra-cavity frequency doubling, the CW and pulsed powers of blue-violet laser are 0.22 mW and 0.36 mW, respectively.

Key words: diode-pumped alkali-vapor laser; cesium-vapor laser; frequency doubling

Calculation of Laser Transverse Modes in Stable Cavities Using Mode Coupling Matrix

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We propose a method to calculate laser transverse modes in stable cavities using mode coupling matrix. Asymmetrical optical elements can lead to the couplings of orthogonal eigenmodes. The couplings are measured by the overlap integrals of eigenmodes after the optical elements. Using the overlap integrals as matrix elements, we construct a transverse mode coupling matrix. Fields on the transverse planes in laser cavities can be expressed as the linear superposition of eigenmodes and thus are written as vectors whose elements are the superposition coefficients. The field-propagation in stable laser cavities is simulated by the multiplication of the vector with the coupling matrixes. We can know the eigenmodes in an oscillation mode from the simulation. A stable end-pumped solid-state laser model is constructed to study our method. The calculation results have an overlap of over 99% with the desired modes. This indicates asymmetrical optical elements can lead to the couplings of orthogonal eigenmodes.

Key words: laser coupling; stable cavity; solid-state
Reconfigurable Dynamic All-Optical Chaotic Logic Operations in an Optically Injected VCSEL

ZhongDong Zhou, XuGe Liang, LuoWei, XiaoZhen Zhen
The Department of Information Engineering, Wuyi University

By using the polarization bistability characteristics and the threshold mechanism, we propose a novel implementation scheme for reconfigurable dynamic all-optical chaotic logic operations in a chaotic system of vertical cavity surface emitting laser (VCSEL) with external optical-injection. Here, two logic inputs are encoded by the optically injected amplitude. One of logic outputs is decoded from the difference between the mean square error (MSE) of the x-polarization component emitted by VCSEL and its threshold, the other is decoded from the difference between the MSE of y-polarization component and its threshold. We explore the dynamic polarization bistability evolutions of VCSEL caused by the external injection amplitude under the conditions of different key parameters, such as the bias current, the injection strength and frequency detuning between the tunable distributed feedback laser and the VCSEL. Based on the evolution laws, here we consider the frequency detuning as the control logic signal, and the conversion among different logic functions such as AND, NAND, OR, NOR, XOR, XNOR can be realized in different time periods in the case that the frequency detuning logic meets corresponding logic operation with the two logic inputs.

Key words: vertical cavity surface emitting laser (VCSEL); semiconductor logic devices; polarization switching; chaos; logic design
Multi-Target Ranging by Using Chaotic Laser Radar Based on the Complete Chaotic Synchronizations of the Polarization Components in the Drive-Response VCSELs

Wei Luo, Zhongdong Zhou
Wayi University

According to the principle of complete chaos synchronization and the theory of Hilbert phase transformation, we propose a novel real-time multi-target ranging scheme by using chaotic radar in the drive-response vertical-cavity surface-emitting lasers (VCSELs). In the scheme, to ensure each polarization component (PC) of the master VCSEL (M-VCSEL) to be synchronized steadily with that of the slave VCSEL, the output x-PC and y-PC from the M-VCSEL in the drive system and those in the response system are modulated by linear electro-optic effect simultaneously. Under this condition, by simulating the influence of the bias current, the applied electric field and the propagating delay time on the synchronization quality, related operating parameters can be optimized. The x-PC and the y-PC, as two chaotic radar sources, are used to be implemented the real-time ranging for two targets. It is found that the measured distances of the two targets at arbitrary position exhibit a slight jitter. Their resolutions are up to millimeters, and their relative errors are very small, less than 2.7%.

Key words: chaotic laser radar; real-time ranging; complete chaotic synchronization; the drive-response VCSELs

An Identification Technology for Crude Oil and Lubricant on Simulated Sea Surface

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Xidian University

A recognition technology for crude oil and lubricant is described by use of back-scattering fluorescence. It is shown that when the fluorescence intensity reaches the maximum peak, its attenuation ratio has no obvious dependence on laser power, incident angle and thickness of oil film during a fixed wavelength interval. An algorithm is presented to reflect the fluorescence intensity decay rate and considering the distinction and stability, two relatively constant wavelength regions for the algorithm are selected. Then the two coefficients are fused in a two-dimensional spectrum. Then two areas which represent the two kinds of oil are identified in the two-dimensional spectrum, and the oil type can be determined according to which area the measurement data lies in. The experimental results show that the correct identification probabilities for crude oil and lubricant can reach 96% and 98%, respectively. It is expected that this can be a useful method for oil type recognition.

Key words: laser-induced fluorescence; spectroscopy; crude oil; lubricant; oil type recognition

Output Characteristics of Actively Q-switched Ho:CYA Laser

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High power solid-state lasers emitting in the 2.1 μm wavelength region are of great interest for eye-safe applications, such as medical surgery, light detection and ranging (LIDAR), and interferometric sensing. In particular, high energy 2.1 μm Q-switched lasers are effective pump sources for frequency conversion in the 3-12 μm range. Since the holmium has a large emission cross section in the 2.1 μm region and a long upper-state fluorescence lifetime among various earth ions, Ho3+-doped laser materials are important candidates to produce high energy Q-switched laser around 2.1 μm. Here, in this paper, we report on an actively Q-switched Ho:CYA laser in band pumped (5I8→5I7) by a homemade Tm:fiber laser at the wavelength of 1922 nm. With the incident pump power of 40.1 W, a maximum average output power of 8.1 W was achieved at the pulse repetition frequency (PRF) of 50 kHz. Shortest pulse duration of 20.5 ns with peak power of 60.6 kW has been obtained at 2 kHz PRF under 19.7 W of incident pump power. Our experimental results indicated that Q-switched Ho:CYA laser, which has high peak power and short pulse duration, will provide an excellent pump source for mid-IR optical parametric oscillators.

Key words: lasers, q-switched; lasers, solid-state; rare earth and transition metal solid-state lasers

Graphene Binary/Ternary-Nanocomposites: Synthesis, Characterization and Their Application to Ultrafast Soliton Lasers

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Since firstly reported in 2009, the research on graphene and its derivatives as a saturable absorber in the field of ultrafast photonics is booming. Here, we experimentally demonstrate a switchable single-, and dual-wavelength soliton fiber laser based on graphene binary/ternary-nanocomposite, that is, graphene/polyaniline (G/PANI) and graphene/tin oxide/polyaniline (G/SnO2/PANI), respectively. In experiment, we firstly synthesized the G/PANI and G/SnO2/PANI nanocomposites by using the liquid-phase ultrasonic method and studied their nonlinear optical properties by using the z-scan technology.
Then, they are transferred into the laser cavity by the polymer-film method. The experimental results show that the as-prepared graphene device not only can act as an excellent saturable absorber for mode-locking, but also induces a highly third-order nonlinear optical effect to form a filter for dual-wavelength pulse generation in the laser. By exploiting the dual-function of this device, the switchable dual-wavelength soliton operation of the fiber laser is stably initiated with a minimum pulse width of 1.25 ps, a fundamental repetition rate of 2.13 MHz, pulse energy of 1.51 nJ and peak power of 1.2 kW.

Key words: graphene composite; fiber laser; soliton laser; mode-locking; multiwavelength

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**Novel Tm: CaYAlO₄ Mode-Locked Laser at 2 μm Water Absorption Band**

Wei Zhou, Xiaodong Xu, Rui Xu, Xuliang Fan, Yongguang Zhao, Deyuan Shen, Dingyuan Tang

*Key Laboratory of Advanced Laser Materials and Devices, School of Physics and Electronic Engineering, Jiangsu Normal University*

We report on stable passively harmonic mode-locking dissipative pulses with high repetition rate and narrow bandwidth in 2 μm Tm: CaYAlO₄ laser. At the large intracavity intensity, the laser generated 1st-order to 5th-order passively harmonic solitons with fundamental repetition rate of about 198 MHz and 5th-order repetition rate up to 0.98 GHz, which was mainly caused by the peak power clamp effect. Employed a simple quartz plate, the fundamental mode-locked solitons demonstrated a wide tunable wavelength from 1874 nm to 1973 nm, a narrow optical spectrum bandwidth of 60 pm and the maximum output average power up to 1.2 W. To our knowledge, this is the first observation of passively harmonic mode locking in 2 μm solid laser system, and also the first Watt-level wavelength tunable mode-locked laser in this laser system.

**Key words:** Tm: CaYAlO₄; mode-locking; 2 μm; water absorption band

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**Characterization of Chaotic Brillouin Dynamic Grating**

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*Institute of Optoelectronic Engineering, College of Physics and Optoelectronics, Taiyuan University of Technology*

The Brillouin dynamic grating (BDG) based on chaotic laser has particular advantages over the conventional BDG, for example, the creation of single and permanent BDG. To gain insight into the chaotic BDG, we theoretically investigate the reflection and gain spectra characteristics of the chaotic BDG generated in the polarization maintaining fiber. We find that the reflection spectral width of the chaotic BDG is inversely proportional to the effective grating length and the variation in the gain spectral width is negligible with respect to the effective grating length. The widths of the reflection and gain spectra are not affected by the power of the chaotic pump wave. Besides, in the generation process of the chaotic BDG, the occurrence of the weak BDGs resulted from the time-delay signature of the chaotic laser is further analyzed, which leads to the side-lobe of the reflected pulse. In order to improve the reflection characterization of the chaotic BDG, the chaotic laser subject to filtered optical feedback is utilized to generate the chaotic BDG. The results indicate that the weak BDGs can be effectively suppressed under the proper filter parameters. When the spectral width of the filter is 4 GHz and its detuning from the laser frequency is 5.02 GHz, the side-lobes of the reflected plus can be almost completely suppressed.

**Key words:** Brillouin dynamic grating; chaotic laser; reflection spectrum; gain spectrum; filtered optical feedback; reflection characterization

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**Dynamic Characteristics of Packaged Chaotic Semiconductor Laser**

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Chaotic signal has attracted considerable research interest owing to its many potential applications, including high-speed random bit generation, secure communication, chaotic radar, and distributed optical sensor. However, most of the chaotic lasers are fabricated by the discrete optical components in lab, the stability and size are common issues for the practical application. In order to solve these problems, many research groups have put forward the integrated chaotic semiconductor lasers.

In this paper, an integrated chaotic semiconductor laser with short-cavity optical feedback is proposed. The middle part between the semi-reflective mirror and the front face of the chaotic semiconductor laser chip (CSLC) works as an external feedback cavity. In particular, the strong optical feedback makes it possible to generate chaos. The dynamic characteristics of this integrated chaotic semiconductor laser are investigated by a rate equation model. The simulating results show period-doubling route to chaos when \( \text{fext}/\text{fr} > 5.2 \) and the system shows chaotic state when the Kap > 0.12. In order to make the simulating results more accurate, the internal parameters of the CSLC are extracted by experiment. This research will provide a theoretical foundation for the further production of this integrated chaotic semiconductor laser.

**Key words:** Integrated chaotic semiconductor laser; short-cavity optical feedback; chaotic dynamic characteristics; extract the internal parameters extraction
A Short-Cavity Integrated Chaotic Semiconductor Laser Packaged by a Butterfly Package

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Chaotic light is of great interest owing to its important roles in both basic science and applied technology. Research on generation of chaotic light usually uses semiconductor laser with various separate external optical components. It is huge, environmental sensitive and instable. Therefore researchers have done lots of effort to develop a small, stable and low-cost photonic integrated chaotic semiconductor laser. However, we have noticed that the most relevant investigations only focus on solitary monolithically integrated semiconductor laser and pay little attention to component integration.

In this letter, a short-cavity integrated chaotic semiconductor laser packaged by a butterfly package is designed and fabricated for chaos generation. A distributed feedback laser chip, a collimator lens, a transflective mirror, a focus lens and an optical fiber are coupled, so chaotic laser can be generated. It should be point out that a short external straight feedback cavity is formed by the transflective mirror. All these sections above together with chip submount, heat sink and thermoelectric cooler are packaged by a commercial 14-pin butterfly package. After several trial productions, the perfect reflectivity of the transflective mirror is 5%, and the perfect external cavity length which is the distance between the transflective mirror and the distributed feedback laser chip is 2 mm. The bandwidths of power spectra of the chaotic signal generated by the chaotic semiconductor laser are wider than 4.5 GHz under multiple currents when the temperature is maintained at 18.5°C.

Key words: chaos; short-cavity; integration; laser; butterfly package

Continuous-Wave Brightness Enhancement in an External Cavity Diamond Raman Laser

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MQ Photonics Research Centre, Department of Physics and Astronomy, Macquarie University

Demonstrations of high power continuous-wave (CW) lasers with high brightness have been key solutions to remote sensing and defense. A significant amount of effort has been devoted to improve the laser brightness, however, the extreme thermal load in the active medium has been a primary challenge for currently available high power lasers due to the intrinsic thermal properties of suitable laser materials. At present, diamond possesses record-high thermal conductivity, which makes diamond a promising crystal to withstand extremely high power operation. The high Raman gain coefficient and broad transparency make diamond Raman laser (DRL) a method for extending the wavelength coverage of mature high-power laser sources with high efficiency. Moreover, Raman lasers are capable of beam cleanup that lead to output Stokes beam near-diffraction-limited with a Gaussian shape and enhance beam brightness. Here, we report frequency conversion in an external cavity DRL using highly multi-spatial mode pumping in the continuous wave regime. Brightness enhancement was investigated as a function of input beam quality in the range $M_2$ of 2.3-3.3 for pumping durations of 0.25 ms, sufficient for steady-state thermal gradients. Up to 389 W pump-limited 1240 nm output is generated with a brightness enhancement factor of 2.7 and $M_2$ of 1.25. Much higher brightness enhancement factors are predicted for lower beam quality pumps which foreshadows a scalable approach to high brightness continuous wave lasers of Raman-shifted frequency.

Key words: Raman laser; diamond; brightness enhancement; continuous-wave

Modelling End-Pumped Electro-Optic Q-Switching Lasers with the Influences of Thermal Effects and Spatial Mode Matching

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National Key Laboratory of Science and Technology on Tunable Laser, Harbin Institute of Technology

Spatial mode matching between the pump and lasing modes and the thermal effects within the laser crystal have important effects on output parameters of diode-end-pumped laser oscillator. A theoretical model for the electric-optic Q-switched operation which includes spatial mode matching under thermal effects like thermal lensing effect and thermally induced diffraction loss is developed to directly determine the critical parameters such as pulse energy, peak power and pulse width. A computational approach has been employed by introducing the dimensionless parameters for practical design and analyses of diode-end-pumped lasers. An actively Q-switched system with asymmetrical flat-flat dynamically stable resonators which can acquire fairly stable Q-switched pulse is exploited to manifest the proposed theoretical model. The experimental results agree well with the theoretical predictions showing that the high accuracy of the proposed model for designing actively Q-switched lasers in consideration of both the spatial mode matching and thermal effects.

Key words: lasers; Q-switched; spatial mode matching; thermal effects
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An External-Cavity Faraday Laser at Rb 1529 nm Transition

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External-cavity diode lasers are increasingly popular in fundamental research and practical applications due to their compactness and reliability. For various laser spectroscopic measurements and metrological applications, frequency-stabilized lasers are essential and frequency stabilization with long-term stability is very important. In particular, much effort is presently devoted toward the realization of practical laser frequency standards in the telecommunication region (1528 -1563 nm) for the field of multi-wavelength optical communications. However, in conventional 1529 nm optical wavelength standards, the method of utilizing an optically pumped rubidium vapor cell which exhibits resonances at 1529 nm made the whole system costly, bulky and complex. It is highly desirable to devise an approach where excited-state frequency standard do not depend on a frequency-stabilized laser. One promising solution to this problem is by using a Rb electrodeless discharge lamp (EDL)-based excited-state Faraday anomalous dispersion optical filter (LESFADOF), which has many advantages such as high transmission, ultranarrow bandwidth, and high noise rejection. In this work, we experimentally demonstrated a Faraday laser at 1529 nm by using a performance-improved LESFADOF. A cavity mirror provides optical feedback with free spectrum range of 300 MHz, and the LESFADOF successfully limits the laser frequency to the excited-state $5P_{3/2}-4D_{5/2}$ of Rb 1529 nm transition. The peak transmission assigned to the transition in the LESFADOF is 46% with a filter bandwidth of 800 MHz. The Allan deviation of the Faraday laser is around $3\times10^{-10}$ at 100s. Laser frequency is always kept in the center of the transmitted peak assigned to $5P_{3/2}-4D_{5/2}$ of Rb 1529 nm transition. The external-cavity Faraday laser is highly appreciated for its frequency corresponding to Rb atom excited-state 1529 nm transition while utilizing a EDL instead of a frequency-stabilized laser as a prerequisite to preparing Rb atom from 5S to 5P excited state. Hence the light emitted by the Faraday laser can be used for further research on metrology, microwave photonics and optical communication systems. In addition, this method does not employ any electrical locking schemes, thus, it is small in size and greatly low in complexity. Furthermore, due to the extraordinarily rich spectra of the EDL, this scheme provides a highly novel approach for laser frequency stabilization.

Key words: Faraday filters; external-cavity diode lasers; Faraday laser

CIOP-2017-1943

Mode-Locking of Tm:Lu$_2$O$_3$ Laser at 1943 nm with GaSb-Based SESAM

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Using GaSb-based semiconductor saturable absorber mirror (SESAM), a diode-pumped self-starting continuous-wave mode-locked crystalline Tm:Lu$_2$O$_3$ laser was realized. Ultra-short pulses with a minimum duration of 14.3 ps, a repetition rate of 90 MHz and a maximum average output power of 115 mW were obtained. The central wavelength of the output laser was 1943 nm.

Key words: mode-locked lasers; ultrafast lasers; infrared and far-infrared lasers

CIOP-2017-1949

RFA-Based 589 nm Guide Star Laser Pulsed at Larmor Frequency

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Obtaining high resolution images of astronomical objects with ground-based large aperture telescopes is limited by image distortion induced by atmospheric turbulence. Adaptive optics (AO) system can sense and correct atmospheric aberrations in real time. Sodium guide star, generated at ~90 km altitude by 589 nm laser irradiation, is considered as the best choice of AO beacons. It has been widely used in astronomical telescopes. Many works had been done to develop robust 589 nm guide star laser to excite the sodium layer and generate guide star efficiently. The presence of geomagnetic field reduces the brightness of sodium guide star, because the sodium atoms precess along the magnetic field. Guide star laser pulsed at the Larmor frequency was proposed to improve the brightness, because it allows the laser light to interact with the atoms at a fixed point in the precession cycle. But sodium guide star lasers pulsed at this frequency range with enough output power are technically challenging to develop and have not been reported yet. Here we report our recent advancement in developing fiber based guide star laser pulsed at Larmor frequency. A continuous wave 1064 nm and 1120 nm double wavelength laser is modulated at 350 kHz repetition rate with an AOM, and seeds an Yb-Raman integrated fiber amplifier to generate high power pulsed linearly polarized 1120 nm laser. By pulse shaping of the seed laser, the amplifier emits close-to-rectangular pulses at 1120 nm. The high power pulsed 1120 nm fiber laser pumps an 1178 nm narrow linewidth Raman fiber amplifier at backward direction. The generated high power 1178 nm laser is then coupled into a frequency doubling resonator locked with the PDH method. A pulsed 589 nm laser with 17 W average power is demonstrated at a duty cycle of 20 % and a repetition rate of 350 kHz, which is suitable for a geomagnetic field of 0.5 G. The demonstrated laser is an important new development in guide star lasers. Detailed laser design and system performance will be presented at the conference.

Key words: fiber lasers; Raman laser; frequency conversion
CIOP-2017-2016

**Generation of Cylindrical Vector Beams in Mode-Locked Fiber Laser Using Mode Selective Coupler**

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We experimentally obtained cylindrical vector beams in a passively mode-locked fiber laser based on nonlinear polarization rotation. A mode selective coupler composed of both single-mode fiber (SMF) and two-mode fiber (TMF) is incorporated into the cavity to act as a mode converter from LP01 mode to LP11 mode with broad spectral bandwidth. Cylindrical vector beams in different mode-locked states including single-pulse, multipulse and bound pulse states have been obtained.

**Key words:** cylindrical vector beams; mode-locked fiber laser; mode selective coupler; different mode-locked states

CIOP-2017-2030

**Direct generation of OAM-Tunable Vortex Laser**

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Direct generation of vortex laser with tunable OAM state was researched in an Er:YAG solid-state laser. Based on mode-matching principle, the targeted Laguerre-Gaussian (LG) beams was designed having the largest overlapping efficiency with pump beam through adjusting the cavity parameters. Then effective methods of handedness control for vortex were further explored due to the degeneration always happening between opposite-handed modes. We successfully obtained laser beams with five OAM states, i.e., 0, ±ħ, and ±2ħ, which was expected to offer a new degree of freedom for light source in optical communication systems. Additionally, a reflective volume Bragg grating (VBG) was used as one folding mirror in this Er:YAG laser, and it was found that VBG could be an effective wavelength selector for vortex beams without deteriorating the OAM integrity. Such property opens the possibility of multiplexing information channels simultaneously with OAM and the conventionally used wavelength domains in packaged and robust resonant cavity.

**Key words:** vortex; OAM; solid-state laser; optical communication

CIOP-2017-2128

**The Time Resolved SBS and SRS Research in Heavy Water and Its Application in CARS**

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We present the time resolved character of stimulated Brillouin scattering (SBS) and backward stimulated Raman scattering (BSRS) in heavy water and its application as a robust laser source in Coherent Anti-Stokes Raman Scattering (CARS) technique. A nanosecond laser pulse from a frequency-doubled Nd: YAG laser was introduced into a cell filled with heavy water that with SRS and SBS activity, to generate SBS and BSRS beams. The SBS and BSRS beams are excellent collinear, and their time resolved property are studied by streak tube, experimental results show that the stimulated scattering beams generated by this method is ideally compact, low-cost and robust source for the CARS system, possible method to improve the system is also discussed.

**Key words:** stimulated Brillouin scattering; stimulated Raman scattering; coherent anti-stokes Raman scattering

CIOP-2017-2150

**A Tunable Long-Cavity Passive Mode-Locked Fiber Laser Based on Nonlinear Amplifier Loop Mirror**

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In this paper, we demonstrate long-cavity passive mode-locked fiber laser. The mode locker is a nonlinear amplifying loop mirror (NALM). The cavity frequency of the laser is 465 kHz because that 404 m SMF is inserted in the cavity. A tunable bandpass filter with ~1 nm 3 dB bandwidth is inserted into the cavity to realize tunable mode locking. The passive mode-locked laser at a fixed wavelength is investigated in detail. The experimental results indicate that the laser operates in dissipative soliton resonance (DSR) region. When the pump power is 400 mW, the laser generates the rectangular pulses with 10.58 ns pulse duration, 70.28 nJ single-pulse energy. When the pump power is 400 mW, the laser keeps stable mode locking status in the range from 1523.4 nm to 1575 nm. During the whole tuning range, the SNR, the pulse duration, the output power and single pulse energy have a little fluctuation because that the gain of the EDF changes with the wavelength.

**Key words:** mode-locked laser; tunable filter; dissipative soliton resonance
CIOP-2017-2254

Efficient Yb:LuYAG Mixed Crystal Microchip Laser

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Ytterbium-doped crystals have been intensely investigated for generating short pulses and high peak power in solid-state laser around 1 μm. Yb:YAG and Yb:LuAG crystals are two dominant laser gain media used for solid-state lasers owing to the excellent optical, thermal, chemical, and mechanical properties. Mixing Lu$^{3+}$ and Y$^{3+}$ compositions to form Yb:(Lu,$_{x}$Y,$_{1-x}$)Al$_{5}$O$_{12}$ (Yb:LuYAG) mixed crystal is extremely attractive to be gain medium. The disordered crystal structure resulting from the mixing of the two compositions could induce a spectral broadening of the absorption band, providing a broader range well suited for laser diode pumping; the melting point of the LuYAG is lower than LuAG by several tens of K, resulting in an easier crystal growth; the preparation of LuYAG in comparison with LuAG requires a smaller amount of high purity Lu$_2$O$_3$ powder, which is very expensive. On the other hand, LuAG has a high thermal conductivity, similar to LuAG, which should be almost unaffected by Yb$^{3+}$ doping, providing an advantage over YAG at high doping levels. In this work, optical properties and laser performance of Yb:LuYAG mixed crystal were investigated and compared to Yb:YAG single crystal. There are four absorption peaks centered at 916 nm, 938.7 nm, 958 nm, and 1030 nm, respectively. The absorption band-width of Yb:LuYAG mixed crystal centered at 938.7 nm was measured to be 2.2×10$^{-20}$ cm$^2$, which is comparable to that of Yb:YAG single crystal (2.2×10$^{-20}$ cm$^2$). The excellent optical properties of the Yb:LuYAG mixed crystal show that the Yb:LuYAG mixed crystal is very suitable for laser diode pumping and huge-pulses laser generation in passively Q-switched lasers. Continuous-wave laser operation of the Yb:LuYAG mixed crystal pumped by high -brightness single emitter laser diode has been demonstrated at room temperature for the first time. A 0.7-mm-thick Yb:LuYAG crystal plate doped with 10% Yb$^{3+}$-ions was used as the gain medium, four plane-parallel 2 mm-thick BK7 with different reflectivity (ROC) of 80%, 85%, 90%, 95% at 1030 nm were used as output couplers to compare the laser performance. The optimal reflectivity of the output coupler has been found to be 90% for achieving highly efficient laser performance. The output power increases linearly with the absorbed pump power and the slope efficiency was 73.7%. The maximum output power of 1.2 W was measured at the absorbed pump power of 1.65 W. The corresponding optical-to-optical efficiency was as high as 67.6%, which is the highest efficiency achieved in microchip laser with rare-earth ions doped LuYAG materials as gain medium to our best knowledge. The Yb:LuYAG laser oscillates in multi-longitudinal modes owing to the broad emission spectrum of Yb:LuYAG mixed crystal. Excellent laser performance of Yb:LuYAG mixed crystal indicates that Yb:LuYAG mixed crystal could be a potential candidate for high power and high energy solid state lasers.

Key words: Yb:LuYAG; mixed crystal; microchip laser; optical properties

CIOP-2017-2255

Bundle Multi-FM Beam Smoothing by Spectral Dispersion Technology

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In research of inertial confinement fusion, laser plasma interaction (LPI) problem is a key issue that affects ignition. Many beam smoothing technologies were proposed and adopted to suppress laser plasma instabilities. Smoothing by spectral dispersion (SSD) combined with continuous phase plate (CPP) and polarization smoothing (PS) is the mainstream beam smoothing technology at present. Single-beam smoothing technologies were widely studied both theoretically and experimentally. However, actual laser drivers may adopt a bundle of beams focusing on one point. Additionally, adding more laser beams into a bundle is a development trend of high power laser drivers. Besides, LPI is still one of the most important problems in the ignition process, eager for new beam smoothing technology. To obtain a smoother focal spot, bundle Multi-FM SSD were proposed and studied. Traditional Multi-FM SSD adopts multi-frequency...
Shaped vortex beams with orbit angular momentum (OAM) have vast potential applications in the fields of optical manipulation, quantum and optical information, optical detection. Since the Laguerre-Gaussian (LG) beam was demonstrated to possess OAM, the generation methods, propagation characteristics and application of light beams with OAM have been attracting great attention of many scholars. The interaction of light beams with different media is an important topic that has been extensively studied in the past several decades. As a typical vortex beam, characteristics of the high-order Bessel beam have been developed widely. With the increasing applications of anisotropic media in optical signal processing, optical fiber designing, radar cross section controlling, interactions between anisotropic media and beams have been intensively investigated. Understanding the effects of various media on vortex beam propagation is an important premise to study their potential applications. The reflection and transmission of vector Bessel vortex beams from a uniaxial anisotropic slab are investigated in this work. Based on the cylindrical vector wave function expansion and Fourier transform method, the reflection and transmission characteristics of vector Bessel vortex beam incident on a homogeneous uniaxial anisotropic slab are studied. Firstly, making use of the relationship between spherical vector wave functions and cylindrical vector wave functions, the beam coefficients of arbitrary polarized vector Bessel vortex beams are deduced, and their applicable conditions are checked. Secondly, the electromagnetic fields of the incident vector Bessel vortex beam, the reflected beam and the transmitted beam are expressed by cylindrical vector wave functions directly. With the help of Fourier transform method, the electromagnetic fields of the internal beam in the uniaxial anisotropic media are also expressed in detail. Then, according to the boundary conditions of electromagnetic fields on the dielectric interfaces, equations of all the unknown coefficients of the reflected beam, the transmitted beam and the internal beam are given. The unknown coefficients are obtained by solving these equations. Finally, the complete expressions of fields for all spaces can be obtained. Numerical results of the intensity magnitude distributions of the reflected beam, the transmitted beam and the internal beam are simulated. The effects of beam’s half-cone angle, the incident angle, the topological charge, the thickness of the slab, and the dielectric tensor of the uniaxial anisotropic media are discussed. The methods we provide here can be applied to the propagation of vector Bessel vortex beam in other kinds of anisotropic media conveniently. The results presented in this work are important for the propagation of vector Bessel vortex beams in uniaxial anisotropic media and provide the opportunity for a wide application of the Bessel vortex beams in areas such as optical information, optical detection, and vortex wave communication.

Key words: uniaxial anisotropic slab; vector Bessel vortex beam; reflection and transmission

CIOP-2017-2480

Reflection and Transmission of Vector Bessel Vortex Beam from Uniaxial Anisotropic Slab

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As an attractive platform for investigating solitary wave dynamics, ultrafast fiber lasers have drawn numerous interests. The potential applications of vector solitons in nanophotonics, high precision spectroscopy, and expanding the optical communication capacity based on polarization division multiplexing (PDM) and polarization switch are stirring up more and more explorations. We report on polarization locked vector solitons generation in a linear thulium-doped fiber laser. The fiber laser was made of all-anomalous-dispersion fibers and passively mode locked with a semiconductor saturable absorber mirror. Extra “peak-dip” spectral sidebands were clearly visible on the polarization resolved optical spectra, indicating coherent energy exchange between the two polarization components of vector solitons.

Key words: polarization-locked; vector solitons; four-wave-mixing; birefringence
Influence of Deposition Parameter on Structures and Nonlinear Optical Properties of IB Group Elements Doped ZnO Nanostructures

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IB group elements doped ZnO nanostructures with different deposition parameter were grown using magnetron sputtering technique. The detailed study has been carried out for the effect on the film properties comes from the component, substrate temperature, annealed temperatures, and annealed atmosphere. The structural and morphological of samples are systematically investigated by X-ray diffraction (XRD) and scanning electronic microscopy (SEM), respectively. The results show that the Ag- doped ZnO (AZO) and Cu- doped ZnO (CZO) films can maintain a wurtzite structure. Moreover, the optical transmittance spectra of AZO and CZO films show a transmittance of 70%~80% within the visible wavelength region. The Ag and Cu atoms exert a significant impact on emission by creating the localized energy levels inside the ZnO band gap. Furthermore, the open-aperture Z-scan measurements of the film were realized by nanosecond laser pulse. These samples show two-photon absorption behavior, and the two-photon absorption coefficient of AZO and CZO films is higher than that of pure ZnO film. Our results show that AZO and CZO films are promising candidates in further opto-electronic device applications.

Key words: nano-films materials; semiconductor materials; nonlinear optical properties