



High performance GaSb based digital-grown InGaSb/AlGaAsSb mid-infrared lasers and bars

Sheng-Wen Xie(谢圣文), Yu Zhang(张宇), Cheng-Ao Yang(杨成奥), Shu-Shan Huang(黄书山), Ye Yuan(袁野), Yi Zhang(张一), Jin-Ming Shang(尚金铭), Fu-Hui Shao(邵福会), Ying-Qiang Xu(徐应强), Hai-Qiao Ni(倪海桥), Zhi-Chuan Niu(牛智川)

Citation: Chin. Phys. B . 2019, 28(1): 014208. **doi:** 10.1088/1674-1056/28/1/014208

Journal homepage: <http://cpb.iphy.ac.cn>; <http://iopscience.iop.org/cpb>

What follows is a list of articles you may be interested in

Room-temperature continuous-wave interband cascade laser emitting at 3.45 μm

Yi Zhang(张一), Fu-Hui Shao(邵福会), Cheng-Ao Yang(杨成奥), Sheng-Wen Xie(谢圣文), Shu-Shan Huang(黄书山), Ye Yuan(袁野), Jin-Ming Shang(尚金铭), Yu Zhang(张宇), Ying-Qiang Xu(徐应强), Hai-Qiao Ni(倪海桥), Zhi-Chuan Niu(牛智川)

Chin. Phys. B . 2018, 27(12): 124207. **doi:** 10.1088/1674-1056/27/12/124207

Semiconductor photonic crystal laser

Wanhua Zheng(郑婉华)

Chin. Phys. B . 2018, 27(11): 114211. **doi:** 10.1088/1674-1056/27/11/114211

Electrically pumped metallic and plasmonic nanolasers

Martin T Hill

Chin. Phys. B . 2018, 27(11): 114210. **doi:** 10.1088/1674-1056/27/11/114210

Surface plasmon polariton nanolasers: Coherent light sources for new applications

Yu-Hsun Chou(周昱薰), Chia-Jui Chang(張家睿), Tzy-Rong Lin(林資榕), Tien-Chang Lu(盧廷昌)

Chin. Phys. B . 2018, 27(11): 114208. **doi:** 10.1088/1674-1056/27/11/114208

Thermal analysis of GaN-based laser diode mini-array

Jun-Jie Hu(胡俊杰), Shu-Ming Zhang(张书明), De-Yao Li(李德尧), Feng Zhang(张峰), Mei-Xin Feng(冯美鑫), Peng-Yan Wen(温鹏雁), Jian-Pin Liu(刘建平), Li-Qun Zhang(张立群), Hui Yang(杨辉)

Chin. Phys. B . 2018, 27(9): 094208. **doi:** 10.1088/1674-1056/27/9/094208

CPB

Chinese Physics B

Volume 28 January 2019 Number 1

TOPICAL REVIEW

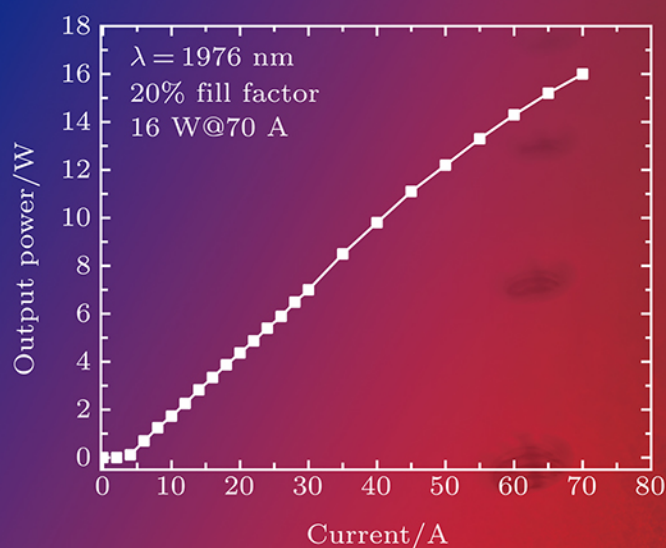
- Magnetism, magnetic materials, and interdisciplinary research
- Fundamental research under high magnetic fields

SPECIAL TOPIC

- Photodetector: Materials, physics, and applications

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

iopscience.org/cpb | cpb.iphy.ac.cn

**Featured Article**

High performance GaSb based digital-grown InGaSb/AlGaAsSb mid-infrared lasers and bars

Sheng-Wen Xie, Yu Zhang, Cheng-Ao Yang, Shu-Shan Huang, Ye Yuan, Yi Zhang,

Jin-Ming Shang, Fu-Hui Shao, Ying-Qiang Xu, Hai-Qiao Ni, Zhi-Chuan Niu

Chin. Phys. B, 2019, 28(1): 014208

High performance GaSb based digital-grown InGaSb/AlGaAsSb mid-infrared lasers and bars*

Sheng-Wen Xie(谢圣文)^{1,2}, Yu Zhang(张宇)^{1,2,†}, Cheng-Ao Yang(杨成奥)^{1,2}, Shu-Shan Huang(黄书山)^{1,2},
Ye Yuan(袁野)^{1,2}, Yi Zhang(张一)^{1,2}, Jin-Ming Shang(尚金铭)^{1,2}, Fu-Hui Shao(邵福会)^{1,2},
Ying-Qiang Xu(徐应强)^{1,2}, Hai-Qiao Ni(倪海桥)^{1,2}, and Zhi-Chuan Niu(牛智川)^{1,2,‡}

¹ State Key Laboratory for Superlattices and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

² Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China

(Received 27 August 2018; published online 12 December 2018)

InGaSb/AlGaAsSb double-quantum-well diode lasers emitting around 2 μm are demonstrated. The AlGaAsSb barriers of the lasers are grown with digital alloy techniques consisting of binary AlSb/AlAs/GaSb short-period pairs. Peak power conversion efficiency of 26% and an efficiency higher than 16% at 1 W are achieved at continuous-wave operation for a 2-mm-long and 100- μm -wide stripe laser. The maximum output power of a single emitter reaches to 1.4 W at 7 A. 19-emitter bars with maximum efficiency higher than 20% and maximum power of 16 W are fabricated. Lasers with the short-period-pair barriers are proved to have improved temperature properties and wavelength stabilities. The characteristic temperature (T_0) is up to 140 $^{\circ}\text{C}$ near room temperature (25–55 $^{\circ}\text{C}$).

Keywords: mid-infrared laser diode, digital alloys, characteristic temperature, bars

PACS: 42.55.Px, 78.55.Cr, 78.67.De, 42.60.Pk

DOI: 10.1088/1674-1056/28/1/014208

1. Introduction

GaSb based InGaSb/AlGaAsSb multi-quantum well structures are recognized as the most suitable structures for lasers emitting around 2 μm in terms of output power and power conversion efficiency (PCE).^[1,2] However, the structure has serious flaws in the energy band design.^[3] The valence band offset is no more than 0.1 eV even if between an $\text{In}_{0.4}\text{Ga}_{0.6}\text{Sb}$ well and an $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ barrier, a limiting quantum well structure which actually may not be used in practice. With the increased In composition (InGaSb) in the well, however, the valence band offset becomes smaller. The poor offset means poor hole confinement, leading to increased thermionic emission of carriers from quantum wells, and the increased thermionic emission leads to an increase of the threshold current because of the leakage current, which would lead to poor device performance eventually.

Therefore, we involved digital alloys^[4] as the barriers of active layers in the band design to increase the effective barrier height. Quantum well lasers with digital alloy as barriers have improved temperature stability, namely, higher characteristic temperature.^[5] It is mainly attributed to the less thermionic emission of carriers because of the good carrier confinement.

In this article, we report results on diode lasers and bars emitting around 2 μm , part structure of which were grown with digital alloys. The AlGaAsSb barriers and gradient layers were digital alloys (DA), and the remaining structures includ-

ing InGaSb wells were random alloys (RA).

2. Device design

The partial digital-grown lasers discussed in this paper were grown on Te-doped GaSb substrates by Gen-II molecular beam epitaxy (MBE) system. 500 nm Te-doped GaSb buffer was firstly grown after the deoxydation of the substrate, followed by 2000 nm N-type $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}_{0.04}\text{Sb}_{0.96}$ cladding layer. Two quantum wells were grown between 500 nm undoped $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ waveguide layers. And the structure was ended with a 250 nm p^+ GaSb cap. Between the claddings of high Al component (0.5) and the waveguides of low Al component (0.25) were 39 nm gradient layers grown via digital alloy technique. The 20 nm $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ barriers on both sides of the 9 nm InGaSb wells were designed to be digital alloys too.

The AlGaAsSb digital alloy barriers are grown with pairs of short superlattices of 3 nm as a cycle. One circle is grown with the sequence of AlSb (t_1)/AlAs (t_2)/AlSb (t_1)/GaSb (t_3). The total growth time ($2t_1 + t_2 + t_3$) of a circle is about 20 s. Digital alloys also bring benefits to the epitaxial growth.^[6] The As vapor pressure is too low to be stable when growing lattice-matched $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ barriers using traditional MBE technique. As a result, it is difficult to control the Sb/As ratio to grown perfectly lattice-matched crystals. However, the component of AlGaAsSb digital alloys is decided by

*Project supported by the National Natural Science Foundation of China (Grant Nos. 61790580 and 61435012), the National Basic Research Program of China (Grant No. 2014CB643903), and the Scientific Instrument Developing Project of the Chinese Academy of Sciences (Grant No. YJKYYQ20170032).

[†]Corresponding author. E-mail: zhangyu@semi.ac.cn

[‡]Corresponding author. E-mail: zcnui@semi.ac.cn

© 2019 Chinese Physical Society and IOP Publishing Ltd

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

the shutter time of the binary materials ($(2t_1 + t_2)/t_3$) instead of the V group ratio, which perfectly solves the problem of instability of the As vapor pressure.

The schematic shutter sequences during the gradient layers growth from $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}_{0.04}\text{Sb}_{0.96}$ to $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ are shown in Fig. 1. Figure 2 depicts the energy-band structures of the broadened-waveguide InGaSb (RA)/AlGaAsSb (DA) double-quantum-well laser. The wafer then was processed into 2-mm-long, 100- μm -wide stripe chips with standard contact optical lithography in combination with etching process.^[7] 250 nm SiO_2 was deposited to be used as insulation after the 2 μm ridge was etched. The wafer was thinned to 130 nm. 50 nm/50 nm/300 nm Ti/Pt/Au and 50 nm/50 nm/300 nm-1000 nm AuGeNi-Au were used as P-contact metals and N-contact metals respectively deposited by thermal evaporation equipment. Then the wafer was cleaved into bars and chips. The chip facets were

high ($> 95\%$)/anti ($< 5\%$)-reflection coated targeting the lasing wavelength, and the devices were indium-soldered p-side down on C-mount heatsinks and characterized. The bars including 19 single HR/AR coated emitters were mounted on CS heatsinks and characterized.

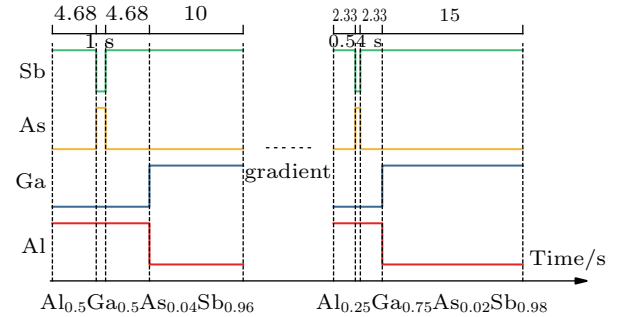


Fig. 1. Schematic time shutter sequence utilized during gradient layers growth from $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}_{0.04}\text{Sb}_{0.96}$ to $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ via digital alloy technique.

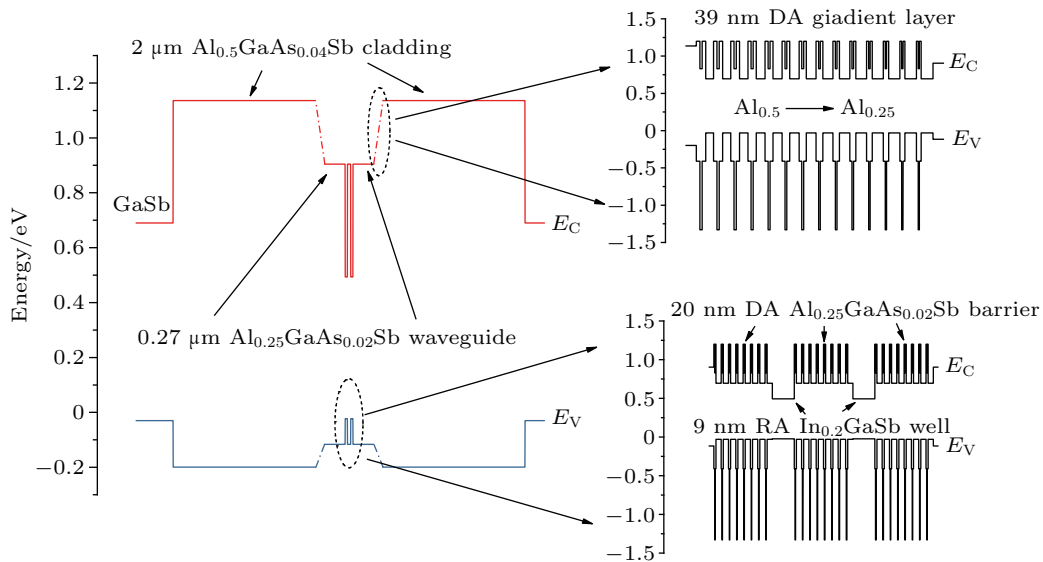


Fig. 2. Schematic energy-band diagram of the broadened-waveguide diode laser. The insets show the energy band of digital alloys varying from $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}_{0.04}\text{Sb}_{0.96}$ to $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ and the energy band of InGaSb (RA)/ $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}_{0.02}\text{Sb}_{0.98}$ (DA) quantum wells.

3. Results

The power conversion efficiency η is a significant parameter to characterize the overall performance^[8] of a diode laser, which is defined as $\eta = P_{\text{out}}/(IV)$, where P_{out} is the output power, and I and V are the operating current and voltage. The power conversion efficiency along with the optical output power versus the injection current of our partial digital-grown laser is plotted in Fig. 3. The measurement for the single 2000 $\mu\text{m} \times 100 \mu\text{m}$ laser was performed under TEC-cooling at 290 K. In the extrapolation of the I - V characteristic back to $I = 0$, the laser turn-on voltage $V_0 = 0.672 \text{ V}$ is obtained. One of the empirical terms reducing PCE is the voltage waste, which is a combination of the voltage drop of junction interface and electrical resistance. The turn-on voltage 0.672 V is basically the same as the photon energy, which means that the

short period superlattices (digital alloys) do not increase the voltage wastes in consideration of the voltage drop between the waveguides and cladding layers. The measured maximum power is 1.4 W at 7 A under continuous-wave (CW) operation with PCE higher than 10%. The low calculated series resistance of 158 m Ω results in the maximum efficiency 27% at 0.7 A. And higher than 15% PCE at 1 W output is achieved, which is remarkable for lasers emitting around 2 μm .^[9,10] Another remarkable characteristic of the partial digital-grown emitter is the threshold current density (J_{th}), which is as low as 52 A/cm². Judging from the output power and efficiency of a diode laser, the partial digital-grown laser is no worse than that without digital alloys.^[2,10]

Many studies have focused on diode lasers with digital alloy structures for their advantages of improving the device

temperature properties (high T_0).^[11] However, most of them focused on the 1.3–1.5 μm wavelength range^[12,13] and we have not found any research on this technique involving mid-infrared lasers emitting around 2 μm . To make it clear, lasers without digital alloy but had the same structures with the lasers described in this paper were fabricated for comparison. Figure 4 shows the threshold current density ($\ln(J_{\text{th}})$) in pulse operation versus heatsink temperature (25–95 °C) for a partial digital-grown InGaSb/AlGaAsSb quantum well laser (type A). The inset shows the temperature characteristic of an InGaSb/AlGaAsSb quantum well laser without digital alloy in its structures (type B). The stripe width and cavity length of type A and type B are the same, both 100 μm and 2 mm, respectively.

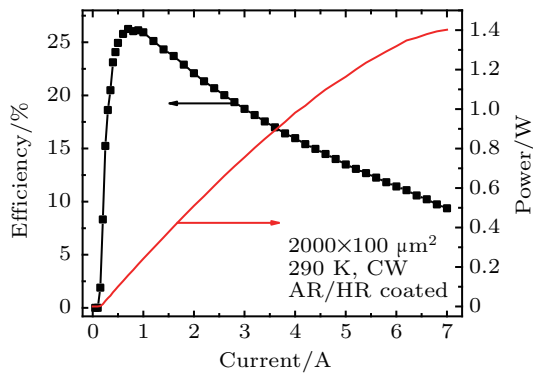


Fig. 3. Output power and power efficiency versus laser current for a 2000 $\mu\text{m} \times 100 \mu\text{m}$ single emitter emitting around 2 μm . The facets were AR/HR coated and the device was mounted p-side down. Maximum CW power and power efficiency were 1.4 W and 26%, respectively.

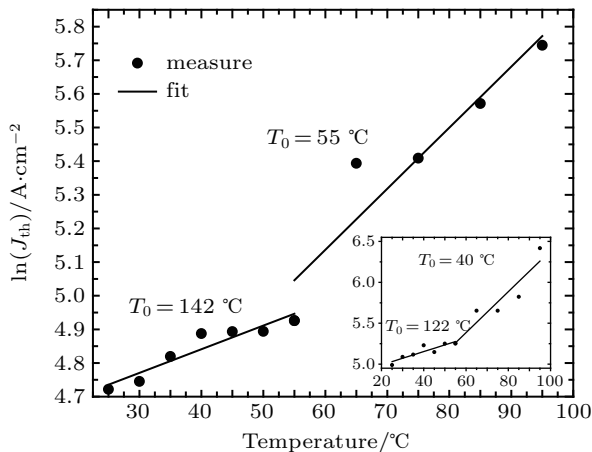


Fig. 4. Threshold current density versus heatsink temperature (25–95 °C) for a partial digital-grown InGaSb/AlGaAsSb quantum well laser. The inset shows the temperature characteristic of an InGaSb/AlGaAsSb quantum well laser without digital alloy in its structure.

The equation $J_{\text{th}} = J_0 \exp(T/T_0)$ is used to calculate the characteristic temperature T_0 . Near room temperature (25–55 °C), the characteristic temperature T_0 for type A is 142 °C, compared with 122 °C for type B. At a temperature higher than 55 °C, the T_0 for type A decreases to 55 °C and for type B decreases to 40 °C. The decrease in T_0 for both types is mainly

due to the increase in Auger recombination and current leakage with increasing temperature.

By comparison, the characteristic temperature T_0 of type A is larger than that of type B. Thus, we come to a conclusion that a laser with AlGaAsSb digital-alloy barriers has higher T_0 than that with AlGaAsSb random-alloy barriers. In conclusion, the short-period superlattices could also raise lasers' temperature properties at 2 μm wavelength range. The improvement in T_0 is attributed to the reduced thermionic emission of carriers out of the quantum wells because of the increased barrier height after using digital alloys as barriers.

For a given diode laser device, the wavelength increases with the operating current because of the chip core area temperature rise and the gap decrease in the InGaSb band. The normalized lasing spectra at different currents of a partial digital-grown laser at CW operation with natural heat dissipation are shown in Fig. 5. The inset shows the linear relationship between the lasing wavelengths and operating currents of the laser. Most electroluminescence measurements in Fig. 5 were performed on the Bruker Fourier transform infrared spectrometer with TE-InGaAs detector and the spectrum at 0.35 A with full-width at half-maximum (FWHM) only 1.8 nm was measured by Yokogawa OSA equipment with better accuracy.

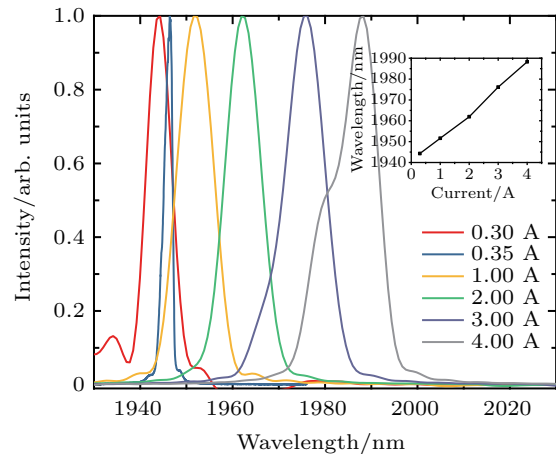


Fig. 5. Emission wavelengths at different injection currents for the partial digital-grown device at 290 K. The inset shows the relationship between lasing wavelengths and operating currents.

From the data, the emission wavelength shifts from 1951.62 nm to 1988.29 nm with the injection current increased from 1 A to 4 A because of the drifting of the gain peak. The slope is estimated to be 10 nm/A when the current is lower than 2 A. The slope increases to 13 nm/A after 2 A due to the thermal influence on mode selection, and the emitting spectra of a laser device without digital alloys were also measured and the red shift slope was about 20.14 nm/A which was two times as much as that of a partial digital-grown laser. The significant reduction in red shift slope for the partial digital-grown laser, which has not been mentioned in any paper before, may be attributed to the difference of thermal effect for digital alloys

and random alloys. The difference of thermal expansion coefficient between digital alloy barriers and random alloy barriers would cause different lattice mismatch between InGaSb wells and AlGaAsSb barriers. The different thermal conductivities of the two alloys might also be one of the causes.

High performance laser bars were also fabricated. Figure 6 shows the optical power for a 0.95 cm laser bar with 20% fill factor under CW operation. The bar contains 19 emitters including digital alloy as barriers and gradient layers in its structures, and is mounted on a CS heatsink. A peak power of 16 W is achieved at 70 A with water cooling systems at 290 K. The maximum power efficiency is higher than 26%, which is almost equal to that of a single emitter and higher than 20% efficiency is reached at 11 W, meeting the requirements of commercial product considerations.^[14] The high performance of the 19-emitter-bar is a good proof that the optimization of the growth technique does not sacrifice the infrared laser performance and also a good proof of emitter uniformity around the whole wafer.^[15]

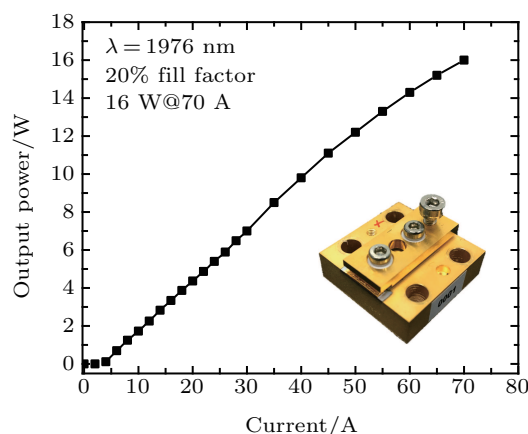


Fig. 6. Output power of a 0.95 cm diode laser bar emitting at 1976 nm.

4. Conclusion

In summary, we have investigated the influence of the digital alloys in diode laser emitting around 2 μm . By using digital alloys as the barriers and gradient layers in laser structures, an improved temperature property (higher T_0) is achieved, which is 142 °C near room temperature. It is also proved that the laser has better wavelength stability by comparison with lasers without digital alloys. The maximum power 1.4 W and the maximum efficiency 27% under CW operation are obtained from a single partial digital-grown emitter, which is a good result at present. A peak power of 16 W is also achieved at 70 A with a high performance 19-emitter-bar.

References

- [1] Scholle K, Lamrini S, Koopmann P and Fuhrberg P 2010 *2 μm Laser Sources and Their Possible Applications*
- [2] Peters M, Rossin V, Everett M, et al. 2007 *Proc. SPIE* **6456**
- [3] Peters M, Rossin V and Zucker E 2007 *High-Power Diode Laser Technology and Applications V* p. 1217
- [4] Lyu Y, Han X, Sun Y, Jiang Z, Guo C, Xiang W, Dong Y, Cui J, Yao Y, Jiang D, Wang G, Xu Y and Niu Z 2018 *J. Cryst. Growth* **482** 70
- [5] Schafer F, Mayer B, Reithmaier J P and Forchel A 1998 *Appl. Phys. Lett.* **73** 2863
- [6] Mourad C, Gianardi D, Malloy K J and Kaspi R 2000 *J. Appl. Phys.* **88** 5543
- [7] Yang C, Zhang Y, Liao Y, Xing J, Wei S, Zhang L, Xu Y, Ni H and Niu Z 2016 *Chin. Phys. B* **25** 24204
- [8] Li H, Chyr I, Srinivasan R, et al. 2007 *Proc. of SPIE* **6456** 64560C
- [9] Shterengas L, Belenky G, Kisin M V and Donetsky D 2007 *Appl. Phys. Lett.* **90** 11119
- [10] Chen J, Kipshidze G and Shterengas L 2010 *IEEE J. Quantum Electron.* **46** 1464
- [11] Postigo P A, Golmayo D, Gomez H, Rodriguez D and Dotor M L 2002 *Jpn. J. Appl. Phys. Pt Lett.* **41** L565
- [12] Liu G T, Stintz A, Pease E A and Newell T C 2000 *Photon. Technol. Lett. IEEE* **12** 4
- [13] Heo D, Song J D, Han I K, Choi W J and Yong T L 2013 *IEEE J. Quantum Electron.* **49** 24
- [14] Stickley C M and Hach E E 2006 *Proc. of SPIE* **6104** 610405
- [15] Kelemen M T, Rattunde M and Wagner J 2010 *Proc. SPIE* **7583** 758300

Chinese Physics B

Volume 28

Number 1

January 2019

TOPICAL REVIEW — Magnetism, magnetic materials, and interdisciplinary research

017501 Sm–Co high-temperature permanent magnet materials

Shiqiang Liu

TOPICAL REVIEW — Fundamental research under high magnetic fields

017106 Heavy fermions in high magnetic fields

M Smidman, B Shen, C Y Guo, L Jiao, X Lu and H Q Yuan

TOPICAL REVIEW — Photodetector: Materials, physics, and applications

017103 Photodetectors based on two-dimensional materials and organic thin-film heterojunctions

Jiayue Han and Jun Wang

017104 Optical characterization of defects in narrow-gap HgCdTe for infrared detector applications

Fang-Yu Yue, Su-Yu Ma, Jin Hong, Ping-Xiong Yang, Cheng-Bin Jing, Ye Chen and Jun-Hao Chu

017105 Review of gallium oxide based field-effect transistors and Schottky barrier diodes

Zeng Liu, Pei-Gang Li, Yu-Song Zhi, Xiao-Long Wang, Xu-Long Chu and Wei-Hua Tang

017302 Room-temperature infrared photodetectors with hybrid structure based on two-dimensional materials

Tiande Liu, Lei Tong, Xinyu Huang and Lei Ye

017803 Photodetectors based on inorganic halide perovskites: Materials and devices

Ying Li, Zhi-Feng Shi, Xin-Jian Li and Chong-Xin Shan

018103 A review on MBE-grown HgCdSe infrared materials on GaSb (211)B substrates

Z K Zhang, W W Pan, J L Liu and W Lei

018501 Review of deep ultraviolet photodetector based on gallium oxide

Yuan Qin, Shibing Long, Hang Dong, Qiming He, Guangzhong Jian, Ying Zhang, Xiaohu Hou, Pengju Tan, Zhongfang Zhang, Hangbing Lv, Qi Liu and Ming Liu

018502 Metal halide perovskite photodetectors: Material features and device engineering

Ye Wang, Meng-Lei Gao, Jin-Liang Wu and Xing-Wang Zhang

SPECIAL TOPIC — Photodetector: Materials, physics, and applications

017305 Synthesis of free-standing Ga_2O_3 films for flexible devices by water etching of $\text{Sr}_3\text{Al}_2\text{O}_6$ sacrificial layers

Xia Wang, Zhen-Ping Wu, Wei Cui, Yu-Song Zhi, Zhi-Peng Li, Pei-Gang Li, Dao-You Guo and Wei-Hua Tang

(Continued on the Bookbinding Inside Back Cover)

- 018504 Preparation of Ga₂O₃ thin film solar-blind photodetectors based on mixed-phase structure by pulsed laser deposition**

Y M Lu, C Li, X H Chen, S Han, P J Cao, F Jia, Y X Zeng, X K Liu, W Y Xu, W J Liu and D L Zhu

RAPID COMMUNICATION

- 017301 Pressure-mediated contact quality improvement between monolayer MoS₂ and graphite**
Mengzhou Liao, LuoJun Du, Tingting Zhang, Lin Gu, Yugui Yao, Rong Yang, Dongxia Shi and Guangyu Zhang

- 017304 Electronic synapses based on ultrathin quasi-two-dimensional gallium oxide memristor**
Shuopei Wang, Congli He, Jian Tang, Rong Yang, Dongxia Shi and Guangyu Zhang

GENERAL

- 010201 A nonlocal Burgers equation in atmospheric dynamical system and its exact solutions**
Xi-Zhong Liu, Jun Yu, Zhi-Mei Lou and Xian-Min Qian
- 010203 Stationary response of stochastic viscoelastic system with the right unilateral nonzero offset barrier impacts**
Deli Wang, Wei Xu and Xudong Gu
- 010301 Direct measurement of the concurrence of hybrid entangled state based on parity check measurements**
Man Zhang, Lan Zhou, Wei Zhong and Yu-Bo Sheng
- 010302 Noiseless linear amplification for the single-photon entanglement of arbitrary polarization-time-bin qudit**
Ling-Quan Chen, Yu-Bo Sheng and Lan Zhou
- 010303 Current-phase relations of a ring-trapped Bose-Einstein condensate with a weak link**
Xiu-Rong Zhang and Wei-Dong Li
- 010304 Average fidelity estimation of twirled noisy quantum channel using unitary 2t-design**
Linxi Zhang, Changhua Zhu and Changxing Pei
- 010305 Finite-size analysis of continuous-variable quantum key distribution with entanglement in the middle**
Ying Guo, Yu Su, Jian Zhou, Ling Zhang and Duan Huang
- 010306 Analytical treatment of Anderson localization in a chain of trapped ions experiencing laser Bessel beams**
Jun Wen, Jian-Qi Zhang, Lei-Lei Yan and Mang Feng
- 010307 Periodically modulated interaction effect on transport of Bose-Einstein condensates in lattice with local defects**
Kun-Qiang Zhu, Zi-Fa Yu, Ji-Ming Gao, Ai-Xia Zhang, Hong-Ping Xu and Ju-Kui Xue
- 010308 Ground-state vortex structures of a rotating binary dipolar Bose-Einstein condensate confined in harmonic plus quartic potential**
Guang-Ping Chen, Chang-Bing Qiao, Hui Guo, Lin-Xue Wang, Ya-Jun Wang and Ren-Bing Tan
- 010501 Solitons in nonlinear systems and eigen-states in quantum wells**
Li-Chen Zhao, Zhan-Ying Yang and Wen-Li Yang

- 010502 Attractors with controllable basin sizes from cooperation of contracting and expanding dynamics in pulse-coupled oscillators**
Hai-Lin Zou and Zi-Chen Deng
- 010503 Evacuation simulation considering action of guard in artificial attack**
Chang-Kun Chen and Yun-He Tong
- 010504 Formation mechanism of asymmetric breather and rogue waves in pair-transition-coupled nonlinear Schrödinger equations**
Zai-Dong Li, Yang-yang Wang and Peng-Bin He
- 010505 Effect of exit location on flow of mice under emergency condition**
Teng Zhang, Shen-Shi Huang, Xue-Lin Zhang, Shou-Xiang Lu and Chang-Hai Li
- 010701 Simulation of SiC radiation detector degradation**
Hai-Li Huang, Xiao-Yan Tang, Hui Guo, Yi-Men Zhang, Yu-Tian Wang and Yu-Ming Zhang
- 010702 Standing-wave spectrometry in silicon nano-waveguides using reflection-based near-field scanning optical microscopy**
Yi-Zhi Sun, Wei Ding, Bin-Bin Wang, Rafael Salas-Montiel, Sylvain Blaize, Renaud Bachelot, Zhong-Wei Fan and Li-Shuang Feng
- 010703 \mathcal{H}_∞ couple-group consensus of stochastic multi-agent systems with fixed and Markovian switching communication topologies**
Muyun Fang, Cancan Zhou, Xin Huang, Xiao Li and Jianping Zhou

ATOMIC AND MOLECULAR PHYSICS

- 013101 First-principles study of structural, electronic, elastic, and thermal properties of *Imm2-BC***
Qiang Li, Zhen-Ling Wang, Yu-Cheng Yu, Lan Ma, Shao-Li Yang, Hai-Bo Wang and Rui Zhang
- 013201 Validity of extracting photoionization time delay from the first moment of streaking spectrogram**
Chang-Li Wei and Xi Zhao
- 013202 Properties of collective Rabi oscillations with two Rydberg atoms**
Dan-Dan Ma, Ke-Ye Zhang and Jing Qian
- 013203 Accurate calculation of electron affinity for S_3**
Xue Yang, Haifeng Xu and Bing Yan
- 013301 Novel infrared differential optical absorption spectroscopy remote sensing system to measure carbon dioxide emission**
Ru-Wen Wang, Pin-Hua Xie, Jin Xu and Ang Li
- 013701 Momentum-space crystal in narrow-line cooling of ^{87}Sr**
Jian-Xin Han, Ben-Quan Lu, Mo-Juan Yin, Ye-Bing Wang, Qin-Fang Xu, Xiao-Tong Lu and Hong Chang
- 013702 Effect of external magnetic field on the shift of resonant frequency in photoassociation of ultracold Cs atoms**
Pengwei Li, Yuqing Li, Guosheng Feng, Jizhou Wu, Jie Ma, Liantuan Xiao and Suotang Jia

ELECTROMAGNETISM, OPTICS, ACOUSTICS, HEAT TRANSFER, CLASSICAL MECHANICS, AND FLUID DYNAMICS

- 014201 Propagation characteristics of oblique incidence terahertz wave through non-uniform plasma**
Antao Chen, Haoyu Sun, Yiping Han, Jiajie Wang and Zhiwei Cui
- 014202 Effects of the Casimir force on the properties of a hybrid optomechanical system**
Yi-Ping Wang, Zhu-Cheng Zhang, Ya-Fei Yu and Zhi-Ming Zhang
- 014203 Wavefront evolution of the signal beam in Ti:sapphire chirped pulse amplifier**
Zhen Guo, Lianghong Yu, Wenqi Li, Zebiao Gan and Xiaoyan Liang
- 014204 Multiple Fano resonances in nanorod and nanoring hybrid nanostructures**
Xijun Wu, Ceng Dou, Wei Xu, Guangbiao Zhang, Ruiling Tian and Hailong Liu
- 014205 Controllable transmission of vector beams in dichroic medium**
Yun-Ke Li, Jin-Wen Wang, Xin Yang, Yun Chen, Xi-Yuan Chen, Ming-Tao Cao, Dong Wei, Hong Gao and Fu-Li Li
- 014206 Experimental determination of distributions of soot particle diameter and number density by emission and scattering techniques**
Huawei Liu and Shu Zheng
- 014207 Mode-locked fiber laser with MoSe₂ saturable absorber based on evanescent field**
Ren-Li Zhang, Jun Wang, Xiao-Yan Zhang, Jin-Tian Lin, Xia Li, Pei-Wen Kuan, Yan Zhou, Mei-Song Liao and Wei-Qing Gao
- 014208 High performance GaSb based digital-grown InGaSb/AlGaAsSb mid-infrared lasers and bars**
Sheng-Wen Xie, Yu Zhang, Cheng-Ao Yang, Shu-Shan Huang, Ye Yuan, Yi Zhang, Jin-Ming Shang, Fu-Hui Shao, Ying-Qiang Xu, Hai-Qiao Ni and Zhi-Chuan Niu
- 014301 Theoretical prediction of the yield of strong oxides under acoustic cavitation**
Jing Sun, Zhuangzhi Shen and Runyang Mo
- 014302 Effects of rough surface on sound propagation in shallow water**
Ruo-Yun Liu and Zheng-Lin Li
- 014701 Derivation of lattice Boltzmann equation via analytical characteristic integral**
Huanfeng Ye, Bo Kuang and Yanhua Yang
- 014702 Double-slit interference of a relativistic vortex laser**
Hao Zhang, Bai-Fei Shen and Lin-Gang Zhang
- 014703 Molecular-dynamics investigation of the simple droplet critical wetting behavior at a stripe pillar edge defect**
Xiaolong Liu, Chengyun Hong, Yong Ding, Xuepeng Liu, Jianxi Yao and Songyuan Dai

PHYSICS OF GASES, PLASMAS, AND ELECTRIC DISCHARGES

- 015201 Plasma shape optimization for EAST tokamak using orthogonal method**
Yuan-Yang Chen, Xiao-Hua Bao, Peng Fu and Ge Gao
- 015202 Damped electrostatic ion acoustic solitary wave structures in quantum plasmas with Bohm potential and spin effects**
S Hussain, H Hasnain and Mahnaz Q. Haseeb

015203 Effects of resonant magnetic perturbation on the instability of single tearing mode with non-shear flow

Le Wang, Ming Yang and Wen-Bin Lin

CONDENSED MATTER: STRUCTURAL, MECHANICAL, AND THERMAL PROPERTIES

016101 Photoluminescence of SiV centers in CVD diamond particles with specific crystallographic planes

Ying-Shuang Mei, Cheng-Ke Chen, Mei-Yan Jiang, Xiao Li, Yin-Lan Ruan and Xiao-Jun Hu

016102 Effect of substrate type on Ni self-assembly process

Xuzhao Chai, Boyang Qu, Yuechao Jiao, Ping Liu, Yanxia Ma, Fengge Wang, Xiaoquan Li, Xiangqian Fang, Ping Han and Rong Zhang

016103 Effects of deuteration on the structure of $\text{NH}_4\text{H}_2\text{PO}_4$ crystals characterized by neutron diffraction

Baoan Liu, Lili Zhu, Fafu Liu, Xun Sun, Xiping Chen, Lei Xie, Yuanhua Xia, Guangai Sun and Xin Ju

016104 High-pressure-induced phase transition in cinchomeronic acid polycrystalline form-I

Ting-Ting Yan, Dong-Yang Xi, Jun-Hai Wang, Xu-Feng Fan, Ye Wan, Li-Xiu Zhang and Kai Wang

016105 Versatile GaInO_3 -sheet with strain-tunable electronic structure, excellent mechanical flexibility, and an ideal gap for photovoltaics

Hui Du, Shijie Liu, Guoling Li, Liben Li, Xueshen Liu and Bingbing Liu

016301 Electronic structures and optical properties of Si- and Sn-doped $\beta\text{-Ga}_2\text{O}_3$: A GGA+ U study

Jun-Ning Dang, Shu-wen Zheng, Lang Chen and Tao Zheng

016401 Equation of state for aluminum in warm dense matter regime

Kun Wang, Dong Zhang, Zong-Qian Shi, Yuan-Jie Shi, Tian-Hao Wang and Yue Zhang

016402 Equation of state of LiCoO_2 under 30 GPa pressure

Yong-Qing Hu, Lun Xiong, Xing-Quan Liu, Hong-Yuan Zhao, Guang-Tao Liu, Li-Gang Bai, Wei-Ran Cui, Yu Gong and Xiao-Dong Li

016501 Alkyl group functionalization-induced phonon thermal conductivity attenuation in graphene nanoribbons

Caiyun Wang, Shuang Lu, Xiaodong Yu and Haipeng Li

016801 Approximate expression of Young's equation and molecular dynamics simulation for its applicability

Shu-Wen Cui, Jiu-An Wei, Wei-Wei Liu, Ru-Zeng Zhu and Qian Ping

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

017101 Photoluminescence in fluorescent 4H-SiC single crystal adjusted by B, Al, and N ternary dopants

Shi-Yi Zhuo, Xue-Chao Liu, Wei Huang, Hai-Kuan Kong, Jun Xin and Er-Wei Shi

- 017102 Tunable magnetic orders in $\text{UAu}_{1-x}\text{Sb}_2$**
Wen Zhang, Qiu-Yun Chen, Dong-Hua Xie, Yi Liu, Shi-Yong Tan, Wei Feng, Xie-Gang Zhu, Qun-Qing Hao, Yun Zhang, Li-Zhu Luo and Xin-Chun Lai
- 017107 Exploration of the structural and optical properties of a red-emitting phosphor $\text{K}_2\text{TiF}_6\text{:Mn}^{4+}$**
Xi-Long Dou, Xiao-Yu Kuang, Xin-Xin Xia and Meng Ju
- 017201 Inverse spin Hall effect in ITO/YIG excited by spin pumping and spin Seebeck experiments**
Kejian Zhu, Weijian Lin, Yangtao Su, Haibin Shi, Yang Meng and Hongwu Zhao
- 017202 Semi-analytic study on the conductance of a lengthy armchair honeycomb nanoribbon including vacancies, defects, or impurities**
Fateme Nadri, Mohammad Mardaani and Hassan Rabani
- 017203 Current diffusion and efficiency droop in vertical light emitting diodes**
R Q Wan, T Li, Z Q Liu, X Y Yi, J X Wang, J H Li, W H Zhu, J M Li and L C Wang
- 017204 Generation of valley pump currents in silicene**
John Tombe Jada Marcellino, Mei-Juan Wang and Sa-Ke Wang
- 017303 Investigation and active suppression of self-heating induced degradation in amorphous InGaZnO thin film transistors**
Dong Zhang, Chenfei Wu, Weizong Xu, Fangfang Ren, Dong Zhou, Peng Yu, Rong Zhang, Youdou Zheng and Hai Lu
- 017401 Synthesis, physical properties, and annealing investigation of new layered Bi-chalcogenide LaOBiHgS_3**
Yi Yu, Chunchang Wang, Liang Li, Qiuju Li, Chao Cheng, Shuting Wang and Changjin Zhang
- 017402 Quantum critical duality in two-dimensional Dirac semimetals**
Jiang Zhou, Ya-Jie Wu and Su-Peng Kou
- 017701 Harvesting base vibration energy by a piezoelectric inverted beam with pendulum**
Jia-Nan Pan, Wei-Yang Qin, Wang-Zheng Deng and Hong-Lei Zhou
- 017801 Light absorption coefficients of ionic liquids under electric field**
Ji Zhou, Shi-Kui Dong, Zhi-Hong He, Ju-Lius Caesar Paoza and Yan-Hu Zhang
- 017802 First-principles study on optic-electronic properties of doped formamidinium lead iodide perovskite**
Xin-Feng Diao, Yan-Lin Tang and Quan Xie

INTERDISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

- 018101 Criteria for Beverloo's scaling law**
Sheng Zhang, Ping Lin, Guanghui Yang, Jiang-Feng Wan, Yuan Tian and Lei Yang
- 018102 High-performance $\text{InAlGaN}/\text{GaN}$ enhancement-mode MOS-HEMTs grown by pulsed metal organic chemical vapor deposition**
Ya-Chao Zhang, Zhi-Zhe Wang, Rui Guo, Ge Liu, Wei-Min Bao, Jin-Cheng Zhang and Yue Hao
- 018104 Influence of wall friction on granular column**
Yang-Yang Yang, Sheng Zhang, Ping Lin, Jiang-Feng Wan, Lei Yang and Shurong Ding

018201 Exploring the effect of aggregation-induced emission on the excited state intramolecular proton transfer for a bis-imine derivative by quantum mechanics and our own n -layered integrated molecular orbital and molecular mechanics calculations

Huifang Zhao, Chaofan Sun, Xiaochun Liu, Hang Yin and Ying Shi

018503 Efficiency enhancement of ultraviolet light-emitting diodes with segmentally graded p-type AlGaIn layer

Lin-Yuan Wang, Wei-Dong Song, Wen-Xiao Hu, Guang Li, Xing-Jun Luo, Hu Wang, Jia-Kai Xiao, Jia-Qi Guo, Xing-Fu Wang, Rui Hao, Han-Xiang Yi, Qi-Bao Wu and Shu-Ti Li

018505 Optimization of ambipolar current and analog/RF performance for T-shaped tunnel field-effect transistor with gate dielectric spacer

Ru Han, Hai-Chao Zhang, Dang-Hui Wang and Cui Li

018701 Entrainment range affected by the heterogeneity in the amplitude relaxation rate of suprachiasmatic nucleus neurons

Chang-Gui Gu, Ping Wang and Hui-Jie Yang

COMMENT

010202 A note on “Lattice soliton equation hierarchy and associated properties”

Xi-Xiang Xu and Min Guo

JUST FOR AUTHORS
— CHINESE PHYSICS B