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Graphene-chitin bio-composite polymer based mode locker at 2 micron region
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Abstract
In the field of pulsed fiber laser, graphene is a well-known two-dimensional (2D) material for its excellent optical properties. An alternative approach to the existing method, graphene based filament originally intended for 3-dimensional (3D) printing was used as starting material. Coupled with a newly introduced chitin nanofiber as the host polymer, it was demonstrated and reported as passive mode locker at 2-micron region. The conventional soliton operated at operating wavelength of 1982.7 nm with repetition rate of 11.35 MHz. The produced average output power, pulse width, time-bandwidth product (TBP) and signal to noise ratio (SNR) was 76.83 μW, 1.88 ps (HAC200), 0.416 and 43 dB, respectively. When the pulse was amplified with 5.4 dB of Thulium doped fiber amplifier (TDFA), the average output power increased to 3.43 mW and produced a broad operating wavelength around the 2-micron region. At the same repetition rate of 11.35 MHz, the measured pulse width, SNR, pulse energy and peak power of 7.033 ps (pulseCheck 150), 42.0 dB, 0.30 nJ, and 42.98 W, are obtained, respectively. High power laser operation in this region can find applications in medical field and sensors technology.

Author Keywords
Chitin; Graphene; Mode-locker; Thulium doped fiber

Index Keywords
3D printers, Chitin, Fiber amplifiers, Fiber lasers, High power lasers, Medical applications, Mode-locked fiber lasers, Optical properties, Pulse repetition rate, Pulsed lasers, Signal to noise ratio, Thulium; 2 micron, Average output power, Mode-locker, Noise ratio, Operating wavelength, Pulsewidths, Pulswidths, Repetition rate, Signal to noise, Thulium-doped fibers; Graphene

References

- Beyer, E., Mahrle, A., Lutke, M., Standfuss, J.
(2012), F. Brueckner Innovation in high power fiber laser applications. Proceedings of SPIE, 8237, 823717.

- Kujanp, V.
Review study on remote laser welding with fiber lasers
(2014) *J. Laser Appl.*, 25 (5).

- (2017), S. Taccheo Fiber laser for medical diagnostics and treatments: state of the art, challenges and future perspectives. Proceedings of SPIE 10058, Optical Fibers and Sensors for Medical Diagnostics and Treatment Applications XVII, 1005808.

- Pham, T.B., Bui, H., Le, H.T., Pham, V.H.
Characteristics of the fiber laser sensor system based on etched-bragg grating sensing probe for determination of the low nitrate concentration in water
(2017) *Sensors*, 17 (1), pp. 1-9.

- Bellemare, A.
  A broadly tunable erbium-doped fiber ring laser: experimentation and modeling
  (2001) *IEEE J. Sel. Top. Quantum Electron.*, 7 (1), pp. 22-29.

- Snitzer, E.
  Optical maser action of Nd⁺³ in a barium crown glass
  (1961) *Phys. Rev. Lett.*, 7 (12), pp. 444-446.

- Bremer, K., Pal, A., Yao, S., Lewis, E., Sen, R., Sun, T., Grattan, K.T.V.
  Sensitive detection of CO₂ implementing tunable thulium-doped all-fiber laser
  (2013) *Appl. Opt.*, 52, pp. 3957-3963.

- Hardy, L.A., Vinnichenko, V., Fried, N.M.
  High power holmium: YAG versus thulium laser treatment of kidney stones in dusting mode: ablation rate and fragment size studies
  (2019) *Lasers Surg. Med.*, p. 51.

- Wang, Z., Zhang, B., Liu, J., Song, Y., Zhang, H.
  Recent developments in mid-infrared fiber lasers: status and challenges
  (2020) *Opt. Laser Technol.*, 132.

- Li, Z., Heidt, A.M., Daniel, J.M.O., Jung, Y., Alam, S.U., Richardson, D.J.
  Thulium-doped fiber amplifier for optical communications at 2 µm
  (2013) *Opt. Express*, 21, pp. 9289-9297.

- Khushik, M.H.A.K., Jiang, C.
  Thulium-doped fiber amplifier for blue light signal amplification
  (2019) *China Commun.*, 16, pp. 181-188.

- Ahmad, H., Hassan, N.A., Aidit, S.N., Ooi, S.I., Harun, S.W., Tiu, Z.C.
  Q-switching pulse generation using black phosphorus tape saturable absorber
  (2017) *Optoelectron. Adv. Mater. Rapid Commun.*, 11, pp. 1-6.

- Ge, Y., Zhu, Z., Xu, Y., Chen, Y., Chen, S., Liang, Z., Song, Y., Fan, D.
  Broadband nonlinear photoresponse of 2D TiS₂ for ultrashort pulse generation and all-optical thresholding devices
  (2017) *Adv. Opt. Mater.*, 6 (4).

- Song, Y., Liang, Z., Jiang, X., Chen, Y., Li, Z., Lu, L., Ge, Y., Lu, Z.
  Few-layer antimonene decorated microfiber: ultra-short pulse generation and all-optical thresholding with enhanced long term stability
  (2017) *2D Mater.*, 4 (4).

- Rosdin, R.Z.R., Ahmad, M.T., Jusoh, Z., Arof, H., Harun, S.W.
  All-fiber Q-switched fiber laser based on silver nanoparticles saturable absorber
  (2018) *Dig. J. Nanomater. Biostr.*, 13, pp. 1159-1164.

- Jiang, T., Yin, K., Wang, C., Hou, J., Ouyang, H., Miao, R., Zhang, C., Zhang, H.
  Ultrafast fiber lasers mode-locked by two-dimensional materials: review and prospect
  (2020) *Photonics Res.*, 8 (1), p. 78.

- Li, P., Chen, Y., Yang, T., Wang, Z., Lin, H., Xu, Y., Li, L., Bao, Q.
  Two-dimensional CH₃NH₃PbI₃ perovskite nanosheets for ultrafast pulsed fiber lasers
  (2017) *ACS Appl. Mater. Interfaces*, 9 (14), pp. 12759-12765.

- Zhang, Y., Lim, C.K., Dai, Z., Yu, G., Haus, J.W., Zhang, H., Prasad, P.N.
  Photonics and optoelectronics using nano-structured hybrid perovskite media and their optical cavities
  (2019) *Phys. Rep.*, 795, pp. 1-51.

- Bianchi, V., Carey, T., Viti, L., Li, L., Linfield, E.H., Davies, A.G., Tredicucci, A., Vitiello, M.S.
  Terahertz saturable absorbers from liquid phase exfoliation of graphite
  (2017) *Nat. Commun.*, 8, p. 15763.

- Steinberg, D., Gerosa, R.M., Pellicer, F.N., Zapata, J.D., Domingues, S.H., Thoroh de Souza, E.A., Saito, L.
  Graphene oxide and reduced graphene oxide as saturable absorbers onto d-shaped fibers for sub 200fs EDFL mode locking
  (2018) *Opt. Mater. Express*, 8 (1), p. 144.

- Bao, Q., Zhang, H., Wang, Y., Ni, Z., Yan, Y., Shen, Z.X., Loh, K.P., Tang, D.Y.
  Atomic-layer graphene as a saturable absorber for ultrafast pulsed lasers
  (2009) *Adv. Funct. Mater.*, 19 (19), pp. 3077-3083.

- Bonaccorso, F., Sun, Z., Hasan, T., Ferrari, A.
  Graphene photonics and optoelectronics
  (2010) *Nat. Photonics*, 4 (9), pp. 611-622.

- Popa, D., Sun, Z., Hasan, T., Torrisi, F., Wang, F., Ferrari, A.
  Graphene Q-switched, tunable fiber laser
  (2011) *Appl. Phys. Lett.*, 98.

- Ugolotti, E., Schmidt, A., Petrov, V., Wan Kim, J., Yeom, D.I., Rotermund, F., Bae, S., Griebner, U.
  Graphene mode-locked femtosecond Yb: KLuW laser
  (2012) *Appl. Phys. Lett.*, 101 (16).

- Bhuyan, M.S.A., Uddin, M.N., Islam, M.M., Bipasha, F.A., Hossain, S.S.
  Synthesis of graphene
  (2016) *Int. Nano Lett.*, 6, pp. 65-83.

- Song, Y.
  Carbon nanotube and graphene photonic devices
  (2013) *Carbon Nanotubes and Graphene for Photonic Applications*, pp. 48-84.
  S. Yamashita Y. Saito J. Choi Woodhead Publishing Limited Cambridge

- Martinez, A., Fuse, K., Yamashita, S.
  Mechanical exfoliation of graphene for the passive mode-locking of fiber lasers
  (2011) *Appl. Phys. Lett.*, 99.

- Farmer, D.B., Chiu, H.Y., Lin, Y.M., Jenkins, K.A., Xia, F., Avouris, P.
  Utilization of a buffered dielectric to achieve high field-effect carrier mobility in graphene transistors
  (2009) *Nano Lett.*, 9 (12), pp. 4474-4478.

- Sobon, G., Sotor, J., Jagiello, J., Kozinski, R., Zdrojek, M., Holdynski, M., Paletko, P., Abramski, K.M.
  Graphene oxide vs. reduced graphene oxide as saturable absorbers for Er-doped passively mode-locked fiber laser
  (2012) *Opt. Express*, 20 (17), pp. 19463-19473.

- Wang, X.F., Zhang, J.H., Gao, Z.Y., Xia, G.Q., Wu, Z.M.
  Nanosecond mode-locked Tm-doped fiber laser based on graphene saturable absorber
  (2017) *Acta Phys. Sin.*, 66 (11).

- Tsao, H.X., Chang, C.H., Lim, S.T., Sheu, J.K., Tsai, T.Y.
  Passively gain-switched and self mode-locked thulium fiber laser at 1950 nm
  (2014) *Opt. Laser Technol.*, 56, pp. 354-357.

- Ahmad, H., Ramli, R., Monajemi, H., Reduan, S.A., Yusoff, N., Ismail, M.F.
  Soliton mode-locking in thulium-doped fibre laser by evanescent field interaction with reduced graphene oxide-titanium dioxide saturable absorber
  (2019) *Laser Phys. Lett.*, 16 (7).

- Wang, M., Huang, Y., Song, Z., Wei, J., Pei, J., Ruan, S.
  Two-micron all-fiberized passively mode-locked fiber lasers with high-energy nanosecond pulse
  (2020) *High. Power Laser Sci. Eng.*, 8, pp. 1-8.

- Sharbirin, A.S., Samion, M.Z., Ismail, M.F., Ahmad, H.
  Ultrafast mode-locked dual-wavelength thulium-doped fiber laser using Mach-Zehnder interferometric filter
  (2018) *Opto Electron. Rev.*, 26, pp. 312-316.

- Ahmad, H., Samion, M.Z., Sharbirin, A.S., Norian, S.F., Aidit, S.N., Ismail, M.F.
  Graphene-PVA saturable absorber for generation of a wavelength-tunable passively Q-switched thulium-doped fiber laser in 2.0 μm
  (2018) *Laser Phys.*, 28 (5).

- Rahman, M.F.A., Latiff, A.A., Zaidi, U.Z.M., Rusdi, M.F.M., Rosol, A.H.A., Bushroa, A.R., Dimyati, K., Harun, S.W.
  Q-switched and mode-locked thulium-doped fiber laser with pure antimony film saturable absorber
  (2018) *Opt. Commun.*, 421, pp. 99-104.

- Muhammad, A.R., Ahmad, M.T., Zakaria, R., Yupapin, P.P., Harun, S.W., Yasin, M.
  Mode-locked thulium doped fibre laser with copper thin film saturable absorber
  (2019) *J. Mod. Opt.*, 66 (13), pp. 1381-1385.

- Al-Hiti, A.S., Al-masoodi, A.H.H., Arof, H., Wong, W.R., Harun, S.W.
  Tungsten tri-oxide (WO₃) film absorber for generating Q-switched pulses in erbium laser
  (2020) *J. Mod. Opt.*, 67 (4), pp. 374-382.

- Park, M., Kim, H., Youngblood, J.P., Han, S.W., Verplogen, E., Hart, A.J.
  Excellent dispersion of MWCNTs in PEO polymer achieved through a simple and potentially cost-effective evaporation casting
  (2011) *Nanotechnology*, 22.

- Sobon, G., Sotor, J., Pasternak, I., Krajewska, A., Strupinski, W., Abramski, K.M.
  Thulium-doped all-fiber laser mode-locked by CVD-graphene/PMMA saturable absorber
  (2013) *Opt. Express*, 21 (10), p. 12797.

- Hasan, T., Scardaci, V., Tan, P.H., Bonaccorso, F., Rozhin, A.G., Sun, Z., Ferrari, A.C.
  Nanotube and graphene polymer composites for photonics ad optoelectronics
  (2011) *Molecular and Nanotubes*, pp. 304-307.
  A.C. Ferrari Springer Science Cambridge

- Babar, I.M., Paul, M.C., Das, S., Dhar, A., Ahmad, H., Harun, S.W.
  Mode-locked thulium ytterbium co-doped fiber laser with graphene saturable absorber
  (2016) *Photonics Lett. Pol.*, 8 (4), pp. 104-106.

- Zhang, M., Kelleher, E.J.R., Torrisi, F., Sun, Z., Hasan, T., Popa, D., Wang, F., Taylor, J.R.
  Tm-doped fiber laser mode-locked by graphene polymer composite
  (2012) *Opt. Express*, 20, pp. 25077-25084.

- Park, B.K., Kim, M.M.
  Applications of chitin and its derivatives in biological medicine
  (2010) *Int. J. Mol. Sci.*, 11, pp. 5152-5164.

- Song, Z., Li, G., Guan, F., Liu, W.
  Application of chitin/chitosan and their derivatives in the papermaking industry
  (2018) *Polymers*, 10, p. 389.

- Shervani, Z.
  Chitin-gold nanocomposite film and electro-optical properties
  (2017) *Front. Nanosci. Nanotechnol.*, 3 (3), pp. 2-4.

- Kokalis Burelle, N.
  Chitin amendments for suppression of plant nematodes and fungal pathogens
  (2001) *Phytopathology*, 91, pp. 5168-5175.

- Muzzarelli, R.A.A., Tubertini, O.
  Chitin and chitosan as chromatographic supports and adsorbents for from organic and aqueous solutions and seawater
  (1969) *Talanta*, 16, pp. 1571-1577.

- Jayakumar, R., Divya Rani, V.V., Shalumon, K.T., Sudheesh Kumar, P.T., Nair, S.V., Furuike, T.
  Bioactive and osteoblast cell attachment studies of novel α and β-chitin membranes for tissue engineering applications
  (2009) *Int J. Biol. Macromol.*, 45, pp. 260-264.

- Zuikafly, S.N.F., Nawawi, W.M.F., Ngee, L.H., Yahaya, H., Yahya, W.J., Ahmad, F.
  Graphene in chitin based passive Q-switcher
  (2019) *J. Phys. Conf. Ser.*, 1371.

- Wan Nawawi, W.M.F., Lee, K.Y., Kontturi, E., Murphy, R.J., Bismarck, A.
  Chitin nanopaper from mushroom extract: natural composite of nanofibers and glucan from a single biobased source
  (2019) *ACS Sustain. Chem. Eng.*, 7 (7), pp. 6492-6496.

- Escobar-Alarcon, L., Espinosa-Pesqueira, M.E., Solis-Casados, D.A., Gonzalo, J., Solis, J., Martinez-Orts, M., Haro-Poniatowski, E.
  Two-dimensional carbon nanostructures obtained by laser ablation in liquid: effect of an ultrasonic field
  (2018) *Appl. Phys. A*, 124, p. 141.

- Perumbilavil, S., Sankar, P., Thankamani, P.R., Philip, R.
  White light Z-scan measurements of ultrafast optical nonlinearity in reduced graphene oxide nanosheets in the 400–700 nm region
  (2015) *Appl. Phys. Lett.*, 107.

- Azzam, S.I., Kildishev, A.V.
  Time-domain dynamics of saturation of absorption using multilevel atomic systems
  (2018) *Opt. Mater. Express*, 8 (12), pp. 3829-3834.

- Li, L., Lu, R.D., Liu, S.C., Chen, Z.D., Wang, J., Wang, Y.G., Ren, W.
  Using reduced graphene oxide to generate Q-switched pulses in er-doped fiber laser
  (2018) *Chin. Phys. Lett.*, 35 (11).

- Jiang, X., Gross, S., Withford, M.J., Zhang, H., Yeom, D.I., Rottermund, F., Fuerbach, A.
  Low-dimensional nanomaterial saturable absorbers for ultrashort-pulsed waveguide lasers
  (2018) *Opt. Mater. Express*, 8 (10), p. 3055.

- Ahmad, H., Reduan, S.A., Ruslan, N.E., Lee, C.S.J., Zulkifli, M.Z., Thambiratnam, K.
  Tunable Q-switched erbium-doped fiber laser in the C-band region using nanoparticles (TiO2)
  (2019) *Optics Commun.*,

- Sun, Z., Hasan, T., Ferrari, A.C.
  Ultrafast lasers mode-locked by nanotubes and graphene
  (2012) *Phys. E*, 44, pp. 1082-1091.

- Ciplak, Z., Yildiz, N., Calimli, A.
  Investigation of graphene/Ag nanocomposites synthesis parameters for two different synthesis methods
  (2014) *Fuller., Nanotub. Carbon Nanostruct.*, 23, pp. 361-370.

- Lau, K.Y., Zainol Abidin, N.H., Abu Bakar, M.H., Latif, A.A., Muhammad, F.D., Huang, N.M., Omar, M.F., Mahdi, M.A.
  Passively mode-locked ultrashort pulse fiber laser incorporating multi-layered graphene nanoplatelets saturable absorber
  (2018) *J. Phys. Commun.*, 2.

- Richardson, D.J., Nilsson, J., Clarkson, W.A.
  High power fiber lasers: current status and future perspectives
  (2010) *J. Opt. Soc. Am. B Opt. Phys.*, 27, pp. B63-B92.

- Shen, D.Y., Sahu, J.K., Clarkson, W.A.
  High power widely tunable Tm:fibre lasers pumped by an Er, Yb co-doped fibre laser at 1.6 µm
  (2006) *Opt. Express*, 14, pp. 6084-6090.

- Sharbirin, A.S., Samion, M.Z., Ismail, M.F., Ahmad, H.
  Ultrafast mode-locked dual-wavelength thulium-doped fiebr laser using a Mach-Zehnder interferometric filter
  (2018) *Opto Electron. Rev.*, 26, pp. 312-316.

- Paschotta, R.
  Field Guide to Laser Pulse Generation
  (2008), SPIE Washington, USA

- Lin, G.R., Chiu, I.H., Wu, M.C.
  1.2 ps mode-locked semiconductor optical amplifier fiber laser pulses generated by 60 ps backward dark-optical comb injection and soliton compression
  (2005) *Opt. Express*, 13 (3), pp. 1008-1014.

- Lin, Y.H., Lin, G.R.
  Kelly sideband variation and self-four-wave-mixing in femtosecond fiber soliton laser mode-locked by multiple exfoliated graphite nano-particles
  (2013) *Laser Phys. Lett.*, 10 (4).

- Wang, Y., Fu, S., Tang, X., Kong, J., Lee, J.H., Zhao, L.
  Soliton distillation of pulses from a fiber laser
  (2021) *J. Light. Technol.*, 39 (8), pp. 2542-2546.

- Weill, R., Bekker, A., Smulakovsky, V., Fischer, B.
  Spectral sidebands and multi-pulse formation in passively mode-locked lasers
  (2011) *Phys. Rev. A*, 83.

- Wang, Y., Wang, S., Luo, J., Ge, Y., Li, L., Tang, D., Shen, D., Zhao, L.
  Vector soliton in a Tm fiber laser
  (2014) *IEEE Photonics Technol. Lett.*, 26 (8), pp. 769-772.

- Hsu, C.C., Lin, J.H., Hsieh, W.F.
  Pulse train modulation in a picosecond self-mode-locked laser
  (2009) *J. Phys. B Mol. Opt. Phys.*, 42 (14).

- Kolokolnikov, T., Bielawski, S.
  The Q-switching instability in passively mode-locked lasers
  (2006) *Phys. D*, 219, pp. 13-21.

- Honninger, C., Paschotta, R., Morier-Genoud, F., Moser, M., Keller, U.
  Q-switching stability limits of continuous-wave passive mode locking
  (1999) *J. Opt. Soc. Am. B*, 16 (1), pp. 46-56.

- Yang, G., Liu, Y.G., Wang, Z., Lou, J., Wang, Z., Liu, Z.
  Broadband wavelength tunable mode-locked thulium-doped fiber laser operating in the 2μm region by using a graphene saturable absorber on microfiber
  (2016) *Laser Phys. Lett.*, 13.

- Tsao, H.X., Chang, C.H., Lim, S.T., Sheu, J.K., Tsai, T.Y.
  Passively gain-switched and self mode-locked thulium fiber laser at 1950 nm
  (2014) *Opt. Laser Technol.*, 56, pp. 354-357.

- Wang, Q., Chen, T., Zhang, B., Li, M.S., Lu, Y.F., Cen, K.
  All-fiber passively mode-locked thulium-doped fiber ring laser using optically deposited graphene saturable absorbers

(2013) *Appl. Phys. Lett.*, 102.

- Sadeq, S.A., Harun, S.W., Al-Janabi, A.H.
  Ultrahsort pulse generation with an erbium-doped fiber laser ring cavity based on a copper oxide saturable absorber
  (2018) *Appl. Opt.*, 57 (18), pp. 5180-5185.
- Wang, J., Wang, X., Lei, J., Ma, M., Wang, C., Ge, Y., Wei, Z.
  Recent advances in mode-locked fiber lasers based on two-dimensional materials
  (2020) *Nanophotonics*, 9 (8), pp. 2315-2340.
- Ahmad, H., Ramli, R., Monajemi, H., Reduan, S.A., Yusoff, N., Ismail, M.F.
  Soliton mode-locking in thulium-doped fibre laser by evanescent field interaction with reduced graphene oxide-titanium dioxide saturable absorber
  (2019) *Laser Phys. Lett.*, 16 (7).
- Zhang, R., Li, X., Dai, S., Li, J., Cao, L., Wu, D., Dai, S., Nie, Q.H.
  All-fiber 2 μm mode-locked thulium-doped fiber laser with the graphene oxide film
  (2018) *Optik*, 157, pp. 1292-1299.
- Wang, X.F., Zhang, J.H., Peng, X.L., Ma, X.F.
  Generation and evolution of multiple operation states in passively mode-locked thulium-doped fiber laser by using a graphene-covered-microfiber
  (2018) *Chin. Phys. B*, 27 (8).
- , 3.
  Handbook of Graphene, Graphene-like 2D Materials M. Zhang Scrivener Publishing USA.

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