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Exploring the Impact of Plasmonic Nanoparticles on Photoluminescence of Er^{3+} -Doped Sodium Zinc Tellurite Glass for Solid-State Laser Applications

[1*]Nur Nabihah Yusof, [2]Muhammad Noorazlan Abd Azis, [3]Nurulhuda Mohammad Yusoff

[1]Universiti Sains Malaysia, 11800 USM, Penang, Malaysia
[2]Sultan Idris Education University, 35900, Tanjung Malim, Perak, Malaysia
[3] Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia

*Corresponding author email: nurnabihah7@usm.my

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ABSTRACT

The present work compares the impact of embedding silver (Ag), gold (Au), titanium (Ti), and titanium nitride (TiN) nanoparticles (NPs) on the absorption, photoluminescence, and Judd Ofelt properties of erbium-doped sodium zinc tellurite glass (TNZE), known as reliable solid-state laser media. Ten absorption bands of Er^{3+} ions in the range of 400–1600 nm are attainable where their bands correspond to their own *4f* transitions. Three prominent photoluminescence (PL) bands of Er^{3+} ions were observed at approximately 525 nm, 545 nm, and 630 nm, corresponding to the transitions $^2H_{11/2}\rightarrow{}^4I_{15/2}$, $^4S_{3/2}\rightarrow{}^4I_{15/2}$ and $^4F_{9/2}\rightarrow{}^4I_{15/2}$, respectively. TZNE with 0.15 mol% of TiN NP inclusion showed the highest PL enhancement factor about 35 times, followed by Ti (17 times), Ag (10 times), and Au NPs (5 times), accordingly. This enhanced PL can be attributed to the strong local field induced by the localized surface plasmon resonance (LSPR) of the plasmonic NPs lies within 490–630 nm, which assists the transitions of Er^{3+} ions. The Judd Ofelt parameter was calculated and the TNZE glass with 0.15 mol% of TiN NPs inclusion disclosed the highest spectroscopic quality with a value of 3.57, compared to the TNZE glass with Ti (1.19), Au (0.59), and Ag NPs (0.90) inclusions. This research revealed several potential glass compositions with plasmonic nanoparticles that are attractive for the development of solid-state laser materials.

Keywords: Nanoparticles, Titanium, Tellurite, Photoluminescence.

Information about authors:

Nur Nabihah Yusof	*Dr., School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia. E-mail: nurnabihah7@usm.my*
Muhammad Noorazlan Bin Abd Azis	*Dr., Prof., Physics Department, Faculty of Science and Mathematics, Sultan Idris Education University, 35900, Tanjung Malim, Perak, Malaysia. E-mail: azlanmn@fsmt.upsi.edu.my*
Nurulhuda Mohammad Yusoff	*Dr., UniSZA Science and Medicine Foundation Centre, Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia. E-mail: nurulhudamy@unisza.edu.my*

Introduction

Plasmonic nanoparticles (NPs) such as gold [1], silver [2], titanium [3] and titanium nitride [[4], [5], [6]] exhibit unique optical properties by enhancing the local field proximity rare earth ions (REI) doped glass whenever their natural frequency matched with excitation frequency. This phenomenon is known as local surface plasmon resonance (LSPR). It may alter the optical properties of the REIs doped glass for various applications, such as fiber optics, passive solar covers, photonic devices, and optical data storage [[1], [2]]. The tunability of glass properties based on composition makes them versatile as hosts for solid-state lasers. Comparing the effects of different metal NPs on REI luminescence within the same host would offer a systematic approach to navigate the effective plasmonic sensitizer to enhance the photoluminescence (PL) of REIs doped glass.

Sodium zinc tellurite glass doped with erbium (Er^{3+}) ions (TNZE) is an attractive candidate as a host for solid-state lasers. TNZE exhibits photoluminescence (PL) that extends from the visible to the mid-infrared (MIR) region (450–3000nm), making it suitable for a wide range of photonic applications [[7], [8]]. It has a high refractive index (>2.3) and a low phonon energy

(~780 cm−1). TNZE also shows strong up-conversion (UC) emission intensities due to its distinct energy level spacing and sharp spectral features in the *4f* electronic transitions [9]. The spectroscopic quality of sodium zinc tellurite glass doped with erbium (Er^{3+}) is calculated using Judd Ofelt simulations. To determine the most suitable plasmonic nanoparticle (NP) as a sensitizer, various types of NPs such as silver (Ag), gold (Au), titanium (Ti), and titanium nitride (TiN) are incorporated into the system. The main objective is to investigate the influence of these NPs on the laser properties of the glass and identify the most effective plasmonic sensitizer.

Sample Preparation and Characterizations

Composition of the glass with formula 68.85-TeO_2-20ZnO-10Na_2O-1Er_2O_3-0.15 MNPs in mol% is prepared using melt quenching technique. The corresponding glass codes for the MNPs are TNZEAg, TNZEAu, TNZETi, and TNZETiN. High purity analytical grade powders (≈99%) of TeO_2, ZnO, Na_2O, Er_2O_3, Ag, Au, Ti, and TiN NPs from Sigma Aldrich were utilized. Additionally, four MNPs-based glasses without REIs were prepared and coded as Ag_{SPR}, Au_{SPR}, Ti_{SPR}, and TiN_{SPR}, representing glass compositions with Ag, Au, Ti, and TiN NP inclusions, accordingly. These glass is prepared to probe LSPR bands within the host glass. The constituents were placed in an alumina crucible and melted in an electrical furnace at 1000°C for 30 minutes. The liquid-melt was then poured onto a stainless-steel plate and annealed for three hours at 300°C. After cooling to room temperature, the samples were stored in closed containers to prevent moisture attack. Finally, the samples were polished to obtain a smooth surface for luminescence measurement. The room temperature absorption spectra in the range of 400-1600 nm were recorded using a Shimadzu UV-3600PC scanning spectrophotometer (Kyoto, Japan), while the photoluminescence (PL) was measured using a Hitachi F850 Fluorescence spectrometer (Tokyo, Japan). The Judd-Ofelt analysis was performed where their equations are referring to previous published articles [[7], [8]].

Results and Discussion

The UV-Vis-NIR absorption spectra of prepared sample is displayed in in Figure 1. It shown ten absorption bands centred at 407, 444, 452, 489, 522, 653, 800, 976 and 1532 nm which corresponding to transition from the Er^{3+} ions ground state ($^4I_{15/2}$) to excited states of $^2G_{9/2}$, $^4F_{3/2}$, $^4F_{5/2}$, $^4F_{7/2}$, $^4H_{11/2}$, $^4S_{3/2}$, $^4F_{9/2}$, $^4I_{9//2}$, $^4I_{11/2}$ and $^4I_{13/2}$, accordingly [1]. The absorbance bands disclosed almost similar pattern from previous work [1]. These data were used to perform Judd Ofelt (JO) calculations.

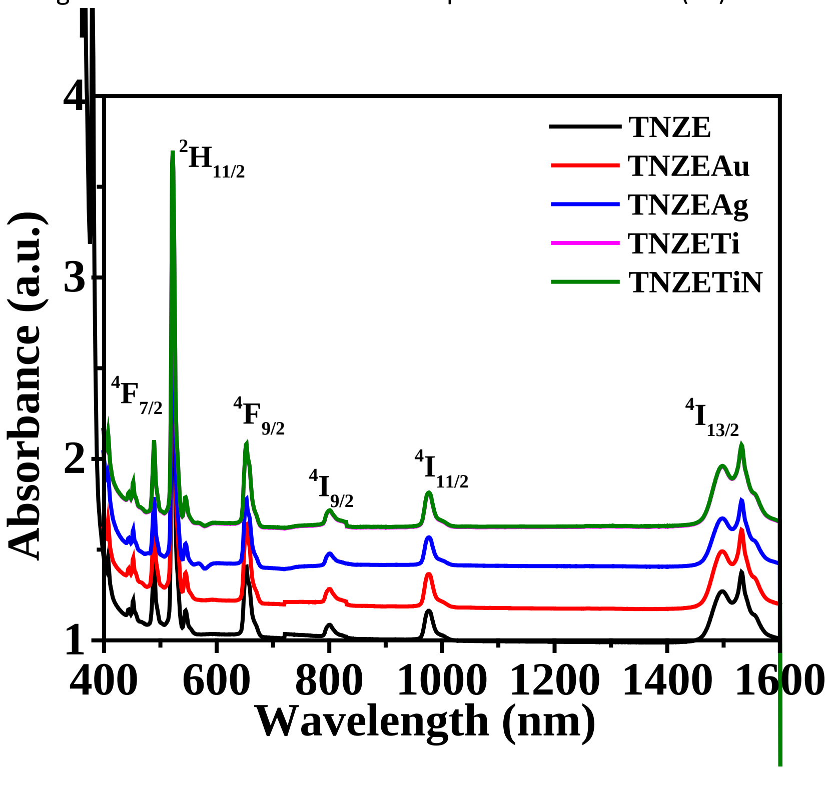

Figure 1 - UV-Vis-NIR absorption spectra of glasses

Table 1 - The JO intensity parameters $(\Omega_2, \Omega_4, \Omega_6)$ and spectroscopic quality factors $\chi = (\Omega_4 / \Omega_6)$ of the glasses

Glass code	Metallic NPs used	Contents (mol%)	Ω_2	Ω_4	Ω_6	Trends of Ω_λ	χ	LSPR band (nm)	Ref.
TNZEAu	Au	0.15	3.38	1.19	2.02	$\Omega_2 > \Omega_6 > \Omega_4$	0.59	630	Present
TNZEAg	Ag	0.15	3.74	2.63	2.93	$\Omega_2 > \Omega_6 > \Omega_4$	0.90	492	Present
TNZETi	Ti	0.15	3.11	2.23	1.88	$\Omega_2 > \Omega_4 > \Omega_6$	1.19	553, 581	Present
TNZETiN	TiN	0.15	4.70	2.71	0.77	$\Omega_2 > \Omega_4 > \Omega_6$	3.57	564	Present
TPBFErAu 2	Au	0.2	10.39	2.55	4.98	$\Omega_2 > \Omega_6 > \Omega_4$	0.51	599.652	[12]
TZEAg	Ag	0.5	6.54	2.36	2.82	$\Omega_2 > \Omega_6 > \Omega_4$	0.82	500	[13]
TNZETi	TiO_2	0.1	3.08	2.15	1.88	$\Omega_2 > \Omega_4 > \Omega_6$	1.14	580	[14]

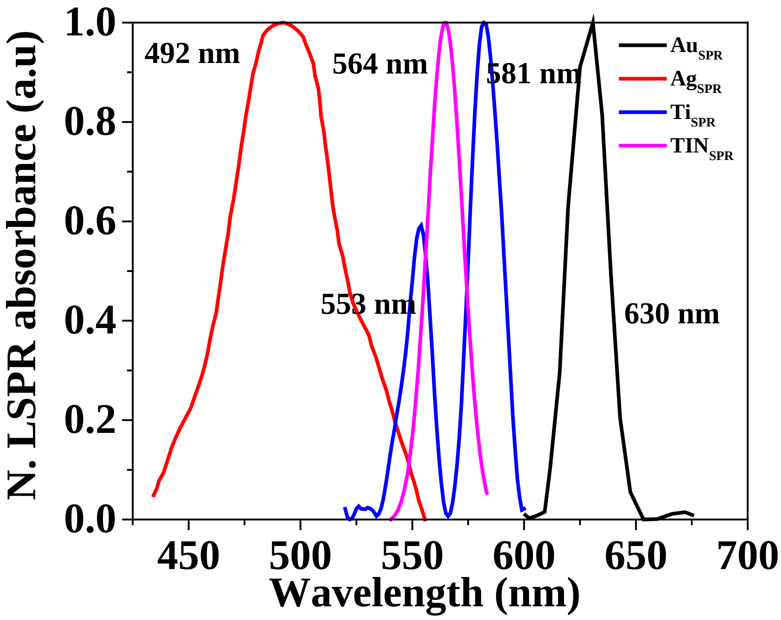

Figure 2 - Normalize LSPR band of plasmonic NPs in host glass

The values of JO intensity parameters $(\Omega_2, \Omega_4, \Omega_6)$ and spectroscopic quality factors $\chi = (\Omega_4 / \Omega_6)$ of prepared samples are summarized in. Glass with 0.15 mol% of Ti NPs shows lowest value of Ω_2 which indicates high symmetrical around Er^{3+} ion. The low Ω_2 value disclosed ionic characteristic of the glass. Meanwhile its lowest Ω_6 values revealed by glass contains TiN NPs indicate its weakest rigidity. The laser strength of the REIs is access through spectroscopic quality parameter, χ. In present case, χ shows highest in TNZETiN follow by TZNETi, TZNEAg and TZNEAu, accordingly.

Figure 2 displayed normalize LSPR bands of Ag, Au and Ti NPs as incorporated into TNZE. The LSPR of Ag, TiN, Ti and Au NPs shows highest peak around 490, 564, 581, and 630 nm, respectively. The Ti NPs exhibit additional LSPR band around 553 due to slight different aspect ratio causes by irregular shape/size [[2], [15]]. This irregular shape tailor different plasma mode and frequency. According to, the localized surface plasmon resonance (LSPR) bands of the plasmonic NPs in present work is comparable with other glass system.

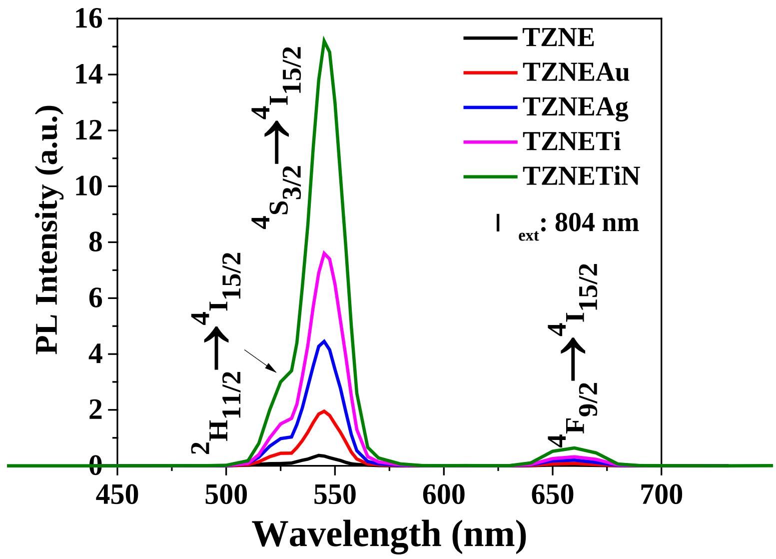

Figure 3 - PL spectra of the glasses with different plasmonic NPs, excited at 804

Figure 3 shows the up-conversion (UC) photoluminescence spectra of Er^{3+} ion as pumped with 804 nm. The photoluminescence (PL) spectra of Er^{3+} ion revealed three prominent bands centred at 525, 545 and 660 nm assigning to $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ transitions, respectively. The PL enhancement factor (η_E) was calculate by dividing the highest PL area of each emission band (525, 545, 660 nm) that incorporated with plasmonic NPs with glass with NPs-free. The highest η_E is revealed by TNZETiN which is about 43, 32, 29 times corresponding to emission band around 525 ($^2H_{11/2} \rightarrow {}^4I_{15/2}$), 545 ($^4S_{3/2} \rightarrow {}^4I_{15/2}$) and 660 nm ($^4F_{9/2} \rightarrow {}^4I_{15/2}$), respectively. Then followed by sample TZNETi (22, 16, 14 times), TNZEAg (13, 10, 9 times), and TNZEAu (6, 5, 3) tally with transitions $^2H_{11/2} \rightarrow {}^4I_{15/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ and $^4F_{9/2} \rightarrow {}^4I_{15/2}$ accordingly. The enhancement is response to local field enlargement that is proximity Er^{3+} ion. The green band at 525 and 545 nm present highest intensification due to overlap TiN and Ti NPs band LSPR band located around 564 and (553 and 581 nm) with the PL bands [[16], [17], [18], [19], [20]] . Ti and TiN NPs reflect potential as new plasmonic sensitizers replacing Au and Ag NPs.

Conclusion

The impact of Ag, Au, Ti, and TiN NPs on the photoluminescence (PL) of TNZE was examined. The localized surface plasmon resonance (LSPR) of the plasmonic NPs was observed in the range of 490-630 nm. The glass with TiN NPs inclusion exhibited the highest spectroscopic quality among other REI-doped hosts in present work, with a value of 3.57. It also demonstrated the most significant enhancement, averagely 35 times for all observed PL bands. The LSPR bands of Ti and TiNPs about 550-580 nm that is overlapped with the Er^{3+} emission (525-545 nm) could be main cause for the utmost PL enhancements where the energy transfer is possible. Present work revealed that different plasmonic NPs able to modify the luminescence intensity of Er^{3+} ions doped sodium zinc tellurite glass. The prepared glass shown potential as a new gain medium for solid-state laser applications.

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Қатты күйдегі лазерлерде пайдалануға арналған Er^{3+}-легирленген натрий мырыш теллюрит әйнегінің фотолюминесценциясына плазмалық нанобөлшектердің әсерін зерттеу

[1*]Nur Nabihah Yusof, [2]Muhammad Noorazlan Abd Azis, [3]Nurulhuda Mohammad Yusoff

[1] Universiti Sains Malaysia, 11800 USM, Пенанг, Малайзия
[2]Сұлтан Ыдырыс білім университеті, 35900, Танджунг Малим, Перак, Малайзия
[3]Сұлтан Зайнал Абидин университеті, Гонг Бадак кампусы, 21300 Куала Нерус, Теренгану, Малайзия

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ТҮЙІНДЕМЕ

Бұл жұмыс күміс (Ag), алтын (Au), титан (Ti) және титан нитриді (TiN) (NPs) нанобөлшектері кірінділерінің эрбиймен легрленген қатты күйдегі лазерлік тасымалдағыш ретінде белгілі шыны (TNZE) натрий мырыш теллуритінің сіңіру, фотолюминесценция және Judd Ofelt қасиеттеріне әсерін салыстырады. Er^{3+} иондарының он жұту жолағы 400-1600 нм диапазонында қол жетімді, мұнда олардың жолақтары өздерінің 4f өтулеріне сәйкес келеді. $^2H_{11/2}\rightarrow{}^4I_{15/2}$, $^4S_{3/2}\rightarrow{}^4I_{15/2}$ and $^4F_{9/2}\rightarrow{}^4I_{15/2}$ өтулеріне сәйкес шамамен 525, 545 және 630 нм-де Er3+ иондарының үш байқалатын фотолюминесценция (PL) жолағы байқалды. Er^{3+} иондарының үш көрнекті фотолюминесценция (PL) жолағы $^2H_{11/2}\rightarrow{}^4I_{15/2}$, $^4S_{3/2}\rightarrow{}^4I_{15/2}$ және $^4F_{9/2}\rightarrow{}^4I_{15/2}$, тиісінше, өтулеріне сәйкес шамамен 525 nm, 545 nm және 630 nm аралығында байқалды. TiN NP қосындысының 0,15 моль% TZNE ең жоғары PL күшейту коэффициентін шамамен 35 есе көрсетті, одан кейін тиісінше Ti (17 есе), Ag (10 есе) және Au NPs (5 есе) болады. Бұл күшейтілген PL 490–630 нм диапазонында жатқан плазмоникалық NP-лердің локализацияланған беттік плазмонды резонансы (LSPR) арқылы индукцияланған күшті жергілікті өріске жатқызылуы мүмкін, бұл Er^{3+} иондарының ауысуларына ықпал етеді. Judd Ofelt параметрі есептелді және Ti (1,19), Au (0,59) және Ag (0,90) қосындылары бар TNZE шынысымен салыстырғанда 0,15 моль% TiN NPs қосылған TNZE шынысы 3,57 мәнімен ең жоғары спектроскопиялық сапаны көрсетті. Бұл зерттеу қатты күйдегі лазерлік материалдарды әзірлеу үшін тартымды болып табылатын плазмоникалық нанобөлшектері бар бірнеше әлеуетті шыны формулаларын анықтады.

Түйін сөздер: нанобөлшектер, титан, теллурит, фотолюминесценция.

Авторлар туралы ақпарат:

Nur Nabihah Yusof — *Доктор, Физика мектебі, Universiti Sains Malaysia, 11800 USM, Пенанг, Малайзия. E-mail: nurnabihah7@usm.my*

Muhammad Noorazlan Abd Azis — *Доктор, профессор, Сұлтан Ыдырыс білім университеті, жаратылыстану-математика факультетінің физика бөлімі, 35900, Танджунг Малим, Перак, Малайзия. E-mail: azlanmn@fsmt.upsi.edu.my*

Nurulhuda Mohammad Yusoff — *Доктор, UniSZA ғылым және медицина қорының орталығы, Сұлтан Зайнал Абидин университеті, Гонг Бадак кампусы, 21300 Куала Нерус, Теренгану, Малайзия. E-mail: nurulhudamy@unisza.edu.my*

Исследование влияния плазмонных наночастиц на фотолюминесценцию натриево-цинкового теллуритного стекла, легированного Er^{3+}, для применения в твердотельных лазерах

[1*]Nur Nabihah Yusof, [2]Muhammad Noorazlan Abd Azis, [3]Nurulhuda Mohammad Yusoff

[1]Университет Сайнс Малайзия, 11800 USM, Пенанг, Малайзия
[2]Образовательный университет Султана Идриса, 35900, Танджунг-Малим, Перак, Малайзия
[3]Университет Султана Зайнала Абидина, кампус Гонг Бадак, 21300 Куала Нерус, Теренггану, Малайзия

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АННОТАЦИЯ

В настоящей работе сравнивается влияние внедрения наночастиц (NPs) серебра (Ag), золота (Au), титана (Ti) и нитрида титана (TiN) на поглощение, фотолюминесценцию и свойства Judd Ofelt легированного эрбием теллурита натрия-цинка стекло (TNZE), известное как надежный твердотельный лазерный носитель. Достижимы десять полос поглощения ионов Er^{3+} в диапазоне 400-1600 nm, где их полосы соответствуют их собственным 4f-переходам. Наблюдались три заметные полосы фотолюминесценции (PL) ионов Er^{3+} примерно при 525, 545 и 630 nm, соответствующие переходам $^2H_{11/2}\rightarrow{}^4I_{15/2}$, $^4S_{3/2}\rightarrow{}^4I_{15/2}$ and $^4F_{9/2}\rightarrow{}^4I_{15/2}$, соответственно. TZNE с 0,15 mol% включения TiN NP показал самый высокий коэффициент усиления PL примерно в 35 раз, за ним следуют Ti (17 раз), Ag (10 раз) и Au NPs (5 раз) соответственно. Эту усиленную PL можно объяснить сильным локальным полем, индуцированным локализованным поверхностным плазмонным резонансом (LSPR) плазмонных NPs, лежащим в пределах 490-630 nm, что способствует переходам ионов Er^{3+}. Был рассчитан параметр Judd Ofelt, и стекло TNZE с включением TiN NPs 0,15 mol% показало самое высокое спектроскопическое качество со значением 3,57 по сравнению со стеклом TNZE с Ti (1,19), Au (0,59) и Ag (0,90) включения. Это исследование выявило несколько потенциальных составов стекла с плазмонными наночастицами, которые привлекательны для разработки твердотельных лазерных материалов.

Ключевые слова: наночастицы, титан, теллурит, фотолюминесценция.

Информация об авторах:

Nur Nabihah Yusof	*Доктор, Школа физики, Университет Сайнс Малайзия, 11800 USM, Пенанг, Малайзия. E-mail: nurnabihah7@usm.my*
Muhammad Noorazlan Abd Azis	*Доктор, профессор, Физический факультет, факультет естественных наук и математики, Образовательный университет Султана Идриса, 35900, Танджунг Малим, Перак, Малайзия. E-mail: azlanmn@fsmt.upsi.edu.my*
Nurulhuda Mohammad Yusoff	*Доктор, Центр Фонда науки и медицины UniSZA, Университет Султана Зайнала Абидина, кампус Гонг Бадак, 21300 Куала Нерус, Теренггану, Малайзия. E-mail: nurulhudamy@unisza.edu.my*

References

[1] Awang A, Ghoshal SKK, Sahar MRR, Arifin R. Gold nanoparticles assisted structural and spectroscopic modification in Er^{3+}-doped zinc sodium tellurite glass, Optical Materials. 2015; 42:495-505. https://doi.org/10.1016/j.optmat.2015.02.009

[2] Fares H, Elhouichet H, Gelloz B, Férid M. Silver nanoparticles enhanced luminescence properties of Er^{3+} doped tellurite glasses: Effect of heat treatment, Journal of Applied Physics. 2014; 116:123504. https://doi.org/10.1063/1.4896363

[3] Yusof NN, Ghoshal SK, Jupri SA. Spectroscopic properties of neodymium doped magnesium zinc sulfophosphate glass: Synergistic effects of titanium and silver nanoparticles embedment, Optical Materials. 2020; 109:110266. https://doi.org/10.1016/j.optmat.2020.110266

[4] Huang J, Li J, Xiao Y, Li J. Broadband nonlinear optical response of titanium nitride in the visible spectral range, Optical Materials. 2023; 136:113375. https://doi.org/10.1016/j.optmat.2022.113375

[5] Guo WP, Mishra R, Cheng CW, Wu BH, Chen LJ, Lin MT, Gwo S. Titanium Nitride Epitaxial Films as a Plasmonic Material Platform: Alternative to Gold, ACS Photonics. 2019; 6:1848-1854. https://doi.org/10.1021/acsphotonics.9b00617

[6] Xu C, Qiu G, Ng SP, Lawrence Wu CM. Nanostructured titanium nitride for highly sensitive localized surface plasmon resonance biosensing, Ceramics International. 2020; 46:20993-20999. https://doi.org/10.1016/j.ceramint.2020.05.163

[7] Li C, Zhu L, Zhao D, Li J, Zhou Y. Broadband NIR radiative transitions in Er^{3+}/Tm^{3+} co-doping tellurite glass material, Materials Research Bulletin. 2023; 158:112042. https://doi.org/10.1016/j.materresbull.2022.112042

[8] Zhao D, Zhu L, Li C, Ding J, Li J, Zhou Y. Broadband near-infrared luminescence property in Nd^{3+}/Tm^{3+} co-doped tellurite glass, Journal of Alloys and Compounds. 2023; 937:168384. https://doi.org/10.1016/j.jallcom.2022.168384

[9] Zhang L, Hu H. The fluorescence properties of highly-doped erbium fluoroaluminate glass pumped at 800 and 980 nm, Journal of Non-Crystalline Solids. 2003; 326–327:353-358. https://doi.org/10.1016/S0022-3093(03)00433-2

[10] Yusof NN, Ghoshal SK, Arifin R, Awang A, Hamzah K. Self-cleaning and spectral attributes of erbium doped sodium-zinc-tellurite glass: role of titania nanoparticles, Journal of Non-Crystalline Solids. 2018; 48:225-238. https://doi.org/doi.org/10.1016/j.jnoncrysol.2017.10.044

[11] Ahmadi F, Hussin R, Ghoshal SK. On the optical properties of Er^{3+} ions activated magnesium zinc sulfophosphate glass: Role of silver nanoparticles sensitization, Journal of Luminescence. 2018; 204:95-103. https://doi.org/10.1016/j.memsci.2015.12.065

[12] Sajna MS, Sanu MS, Vimal G, Prakashan VP, Biju PR, Joseph C, Pillai VPM, Unnikrishnan NV. SPR coupled luminescence enhancement of Er^{3+}/Au NPs - doped multicomponent tellurite glasses, Optical Materials. 2022; 131:112637. https://doi.org/10.1016/j.optmat.2022.112637

[13] Torquato A, de Oliveira RA, Sales TO, Jacinto C, Dousti MR. Enhanced thermometry parameters in Er^{3+}-doped zinc tellurite glasses containing silver nanoparticles, Optik. 2021; 240:166929. https://doi.org/10.1016/j.ijleo.2021.166929

[14] Yusof NN, Ghoshal SK, Azlan MN. Optical properties of titania nanoparticles embedded Er^{3+} -doped tellurite glass: Judd-Ofelt analysis, Journal of Alloys and Compounds. 2017; 724:1083-1092. https://doi.org/10.1016/j.jallcom.2017.07.102

[15] Guillot N, de la Chapelle ML. The electromagnetic effect in surface enhanced Raman scattering: Enhancement optimization using precisely controlled nanostructures, Journal of Quantitative Spectroscopy and Radiative Transfer. 2012; 113:2321-2333. https://doi.org/10.1016/j.jqsrt.2012.04.025

[16] Som T, Karmakar B. Nanosilver enhanced upconversion fluorescence of erbium ions in Er^{3+}: Ag-antimony glass nanocomposites, Journal of Applied Physics. 2009, 105. https://doi.org/10.1063/1.3054918

[17] Yusof NN, Hashim S, Ghoshal SK, Azlan MN, Zaid MHM, Boukhris I, Kebaili I. Spectrographic analysis of zinc-sulfate magnesium-phosphate glass containing neodymium ions: Impact of silver–gold nanoparticles plasmonic coupling, Journal of Luminescence. 2021; 242:118571. https://doi.org/10.1016/j.jlumin.2021.118571

[18] Yusof NN, Ghoshal SK, Jupri SA. Luminescence of Neodymium Ion-Activated Magnesium Zinc Sulfophosphate Glass: Role of Titanium Nanoparticles Sensitization, Optical Materials. 2020; 109:110390. https://doi.org/10.1016/j.optmat.2020.110390

[19] Azlan MN, Hajer SS, Halimah MK, et al. Comprehensive comparison on optical properties of samarium oxide (micro/nano) particles doped tellurite glass for optoelectronics applications. J Mater Sci: Mater Electron. 2021; 32:14174-14185. https://doi.org/10.1007/s10854-021-05961-z

[20] Azlina Y, Azlan MN, Boukhris I, et al. Polarizability of erbium-doped zinc-tellurite glasses coated with graphene oxide for telecommunication devices. Chalcogenide Letters. 2021; 18(9):525-534.