

International Journal of Physics and Applications

E-ISSN: 2664-7583
P-ISSN: 2664-7575
IJOS 2024; 6(2): 85-88
© 2024 IJPA
www.physicsjournal.in
Received: 01-05-2024
Accepted: 06-06-2024

Vikash Kumar Singh
Department of Physics,
Madhyanchal Professional
University, Bhopal,
Madhya Pradesh, India

Ghizal F Ansari
Department of Physics,
Madhyanchal Professional
University, Bhopal,
Madhya Pradesh, India

MY Lone
Department of Physics,
Madhyanchal Professional
University, Bhopal,
Madhya Pradesh, India

Investigation of frequency down-conversion in Terbium-Ytterbium ions co-doped Zinc-Tellurite glasses

Vikash Kumar Singh, Ghizal F Ansari and MY Lone

DOI: <https://doi.org/10.33545/26647575.2024.v6.i2b.103>

Abstract

Terbium-Ytterbium ions (Tb^{3+} - Yb^{3+}) co-doped zinc-tellurite glass specimens were prepared by melt quench process for the investigation of down-conversion phenomenon. Using energy level analysis, fluorescence spectroscopy, and absorption spectroscopy, the investigation verified that a down-conversion mechanism was present in the system. 325 nm and 448 nm were the two excitation wave lengths at which down-conversion was examined. High-energy photons can be absorbed by Terbium ions, which then efficiently transfer the energy to Ytterbium ions. Both the photoelectric conversion efficiency and the energy transfer efficiency of solar cells were altered. Our findings indicate that the Terbium-Ytterbium ions co-doped zinc-tellurite specimen exhibits frequency down-conversion and have considerable potential for use in solar cell applications.

Keywords: Melt quench method, down-conversion, photoelectric conversion

Introduction

In an effort to reduce the damaging effects of worldwide energy use on the atmosphere, there has been a surge in interest in justifiable energy production in recent times. Utilizing solar energy through solar cells is one option; however, the amount of energy these cells can produce is restricted due to their comparatively high cost per kilowatt-hour. However, there are two ways to cut a price: by boosting conversion efficiency or by decreasing production costs. The primary cause of the 30% efficiency limit for single junction solar cells is spectral mismatch losses, of which the majority is attributed to thermalization hole-electron pairs for the sub-band-gap input photons ^[1]. The goal of certain theoretical and experimental studies is to create solar energy converters that will increase the efficiency of photo-cells ^[2-4]. To enable a single junction crystalline silicon solar cell to have a major spectral response (10³ nm), it is extremely difficult to convert frequency from the visible area of the solar spectrum, which reaches its maximum intensity at 550 nm, to the near-infrared area efficiently ^[5]. It is commonly recognized that downconversion (DC) is an effective method for changing high-frequency photons into low-frequency photons, having been proposed as early as 1957 by Dexter ^[6]. The versatile energy levels of lanthanide ions offer a range of possibilities for spectral down-conversion realization. Numerous research on the down-conversion of lanthanide ions, including those on Cerium -Ytterbium ions ^[7], Praseodymium -Ytterbium ions ^[8, 9], Erbium-Ytterbium ions ^[10], Terbium-Ytterbium ions ^[11], and Thulium -Ytterbium ions ^[12], have been published in the last few years.

A crystal solar cell of single junction and a DC material are known to reduce energy drain caused by thermalization hole-electron pairs, with a potential conversion efficiency limit of up to 40% ^[5]. Furthermore, studies on DC using the cooperative energy transfer (CET) mechanism also referred as per quantum cutting and involving the frequency conversion of single visible photon to double NIR photons in various Terbium-Ytterbium ions co-doped materials have been conducted ^[4, 13]. An encouraging system to achieve VIS-NIR quantum cutting is one that combines one Terbium ions (sensitizer) and two Ytterbium ions (activator). This is due to the Terbium ions: 5D_4 - 7F_6 transition happens at about twice the energy of the Yb^{3+} : $^2F_{7/2}$ - $^7F_{5/2}$ absorption, it will produce a two photon emission at about 1000 nm. To obtain NIR emission from Ytterbium ions, there are other processes besides the CET procedure in Terbium-Ytterbium ions systems.

Corresponding Author:
Ghizal F Ansari
Department of Physics,
Madhyanchal Professional
University, Bhopal,
Madhya Pradesh, India

The CET mechanism is a second order energy transfer mechanism (low probability). One Ytterbium ions may also be excited by a Terbium-Ytterbium ions cross-relaxation mechanism after Terbium ions excitation, with a subsequent energy loss occurring from the multiphonon decay mechanism in Terbium ions. Interestingly, it has been observed by several publications [13-17] that the Ytterbium ions emission is caused by down conversion through the CET mechanism when examining the emission and excitation spectra in conjunction with lifetime measurements in Terbium-Ytterbium ions co-doped in various materials. Nevertheless, the authors neglected to conduct power-dependent luminescence experiments, an essential step in clarifying the DC process's genesis [17].

The down-conversion mechanism in Terbium-Ytterbium ions co-doped zinc tellurite glasses was examined in the current work. The Ytterbium ions emission is caused by a one-photon mechanism. Following the direct excitation of Terbium ions, an increased Yb^{3+} emission was noted with an increase in Ytterbium ions concentration. The cross-relaxation and multiphonon decay processes are used to analyze the mechanism of the non-resonant energy transfer from Terbium ions to Ytterbium ions. Our findings point to a possible NIR down-conversion material.

Experimental details

Glass samples with the compositions:

TNZZT = 69.5% TeO_2 - 10% Na_2CO_3 -20% ZnO -0.5% Tb_2O_3

TNZY = 69% TeO_2 - 10% Na_2CO_3 -20% ZnO -0.5% Yb_2O_3 and

TNZTY = 69% TeO_2 - 10% Na_2CO_3 -20% ZnO -0.5% Tb_2O_3 -0.5% Yb_2O_3

Were prepared by the conventional melt quenching method. A zinc-tellurite matrix was prepared using high-purity TeO_2 , Na_2CO_3 and ZnO , Tb_2O_3 and Yb_2O_3 was taken. The co-doped samples were grind well with help of pestle and mortar. For the melting the matrix were taken in alumina crucible and kept it in muffle Furnace at approximately 1000 °C for 50 to 55 minutes. In the melting process the samples were stir mechanically. For the removing the strain annealing have been done. The prepared samples are highly transparent and named as TNZZT, TNZY and TNZTY. The physical properties as densities, molar mass and volume, inter-ions separation, polaron radius, oxygen packing density were measured. The Perkin Elmer Lambda 900 spectrophotometer was utilized to obtain ground state absorption spectra within the wavelength range of 300 to 1250 nm. The visible and infrared portions of the emission spectra were acquired. Excitation measurements were performed by 488nm excitation 325 nm excitation.

Absorption Spectra

Research India Limited's spectrometer recorded the room-temperature absorption spectra of the Terbium-Ytterbium ions co-doped zinc-tellurite glasses in the region of 300-1250 nm (Figure 1). The transition of Terbium ions from the ground state 7F_6 was responsible for the absorption peaks in the range of 350 nm to 550 nm (sample TNZTY and TNZZT), and the transition of Ytterbium ions from $^2F_{7/2}$ to $^2F_{5/2}$ (978 nm) was also noted (sample TNZTY and TNZY). Only the absorption peaks in the 350-550 nm region were seen in the Terbium-singly-doped glass specimen (TNZZT). The only absorption peaks visible in the Ytterbium ions singly-doped glass specimen (TNZY) were those around 978 nm.

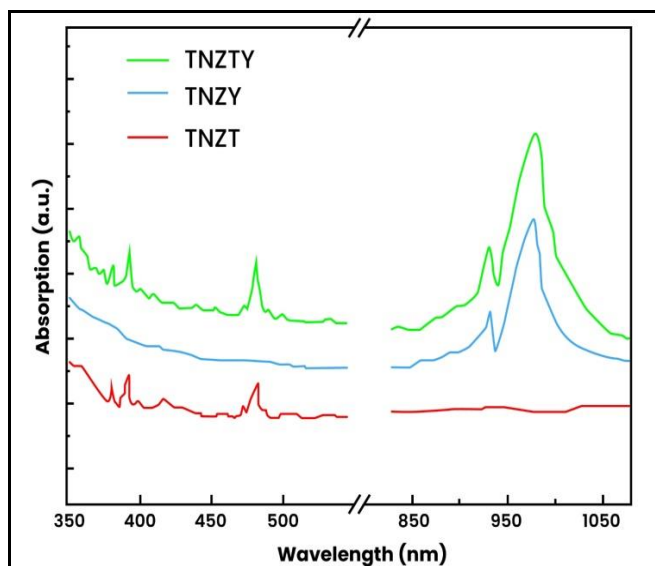


Fig 1: Absorption spectra of TNZZT, TNZY and TNZTY glasses

Fluorescence Spectra of TNZTY Glass at 448nm Excitation

The fluorescence spectra of the Terbium-Ytterbium ions co-doped glass sample TNZTY at 488 nm excitation are displayed in Figure 2. The emission peaks around 545 nm, 620 nm, and 622 nm were easily visible in the figures. It was determined that these peaks represented the change from 5D_4 to 7F_j ($j = 5, 4, 3$). Two emission peaks in the sample were also detected in the vicinity of 960 and 1080 nm in wavelength. These were caused by the change in Ytterbium ions from $^2F_{5/2}$ to $^2F_{7/2}$. The emission peaks of Terbium ions at 545, 620, and 622 nm in the visible light range became less intense as the concentration of Yb^{3+} ions increased steadily. Conversely, when concentration increased, the emission peak intensity of Ytterbium ions which are unable to absorb visible light grew, suggesting that Terbium ions transferred energy to Ytterbium ions. This outcome demonstrates that the down-conversion process is real. A sizable portion of the sun spectrum, which ranges from 300 to 900 nm, was not absorbed or used. The down-conversion method of Terbium-Ytterbium ions co-doped conversion materials allows for substantial adsorption capacity across the solar cell's spectrum region, indicating great potential.

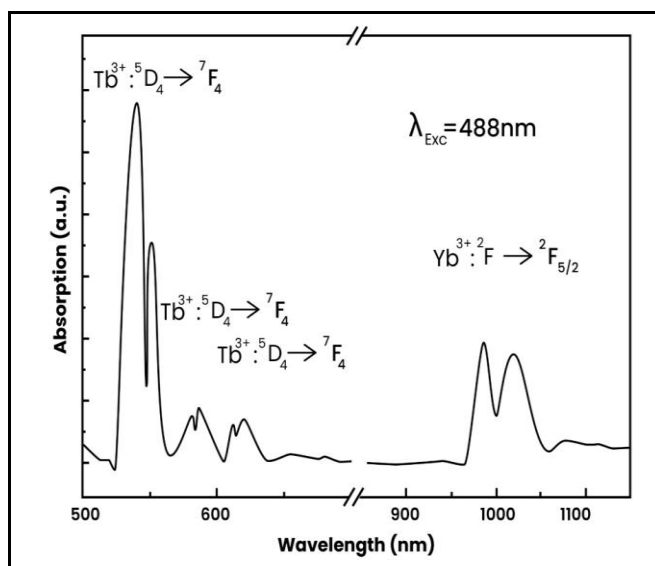


Fig 2: Fluorescence spectra of glass sample TNZTY at 488 nm excitation.

Figure 3 displays the results of correlation frequency conversion and analysis. The energy level association between Terbium and Ytterbium ions makes it simple to propose the down-conversion mechanism. Terbium ions absorbed incoming photons and were stimulated from ground state 7F_6 to excited state 5D_4 at 488 nm excitation energy. Red, blue, and green light are produced by Terbium ions transitions of $^5D_4 \rightarrow ^7F_5$ (545 nm), $^5D_4 \rightarrow ^7F_4$ (620 nm), and $^5D_4 \rightarrow ^7F_3$ (622 nm), respectively. It is estimated that the energy difference in Terbium ions between 5D_4 and 7F_6 is almost double that of Ytterbium ions between $^2F_{5/2}$ and $^2F_{7/2}$. Following Ytterbium ions doping, the electrons in the Terbium ions 5D_4 level can cooperatively transfer energy to two Yb^{3+} ions, allowing them to reach the $^2F_{5/2}$ level. Ytterbium ions then releases two near-infrared photons at a wavelength of 978 nm. The energy transfer mechanism is represented by the following expression: $^5D_4 + 2 ^2F_{7/2} \rightarrow 2 ^2F_{5/2} + ^7F_6$. Following conversion, the spectrum range that was left over was quite compatible with for absorption. These findings support the viability of using Terbium-Ytterbium ions co-doped glass as a down-conversion layer to raise solar cell efficiency.

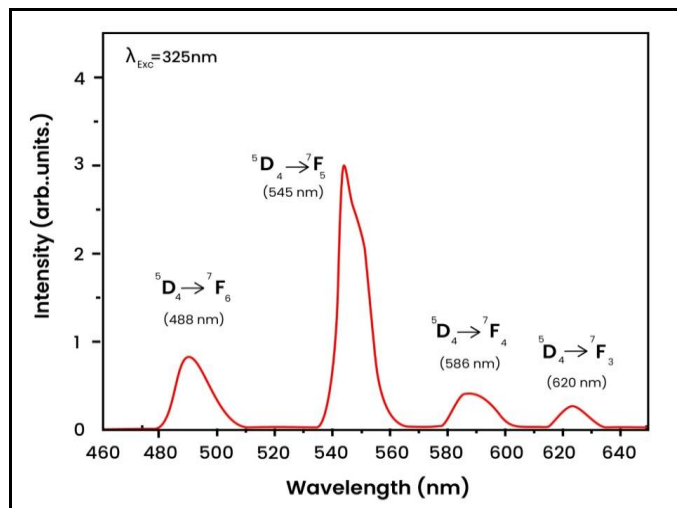


Fig 4: Fluorescence spectra of glass sample TNZTY at 325 nm excitation.

Furthermore, studies on DC using the cooperative energy transfer (CET) process also referred to as frequency down conversion and involving the frequency conversion of one visible photon to two NIR photons in various Terbium-Ytterbium ions co-doped materials have been conducted [4, 13]. Since the Terbium ions: $^5D_4 \rightarrow ^7F_6$ transition occurs at roughly twice the energy of the Ytterbium ions: $^2F_{7/2} \rightarrow ^2F_{5/2}$ absorption, combining one Terbium ions (sensitizer) and two Ytterbium ions (activator) ions is a promising system to achieve visible-NIR quantum cutting. This will result in a two photon emission at approximately 1000 nm. To create NIR emission from Ytterbium ions ions, there are other processes outside the CET process in Terbium-Ytterbium ions systems, which is a second order energy transfer process (low probability). One Ytterbium ions ion may also be excited by a Terbium-Ytterbium ions cross-relaxation mechanism after Terbium ions excitation, with a subsequent energy loss occurring from the multiphonon decay process in Terbium ions (refer to Fig. 5). It is interesting to note that many studies have determined that the Ytterbium ions emission is caused by quantum cutting through the CET process by evaluating the emission and excitation spectra in conjunction with lifetime measurements in Terbium-Ytterbium ions co-doped in different materials [13-17]. Nevertheless, the authors neglected to conduct power-dependent luminescence experiments, an essential step in clarifying the DC process's genesis [18].

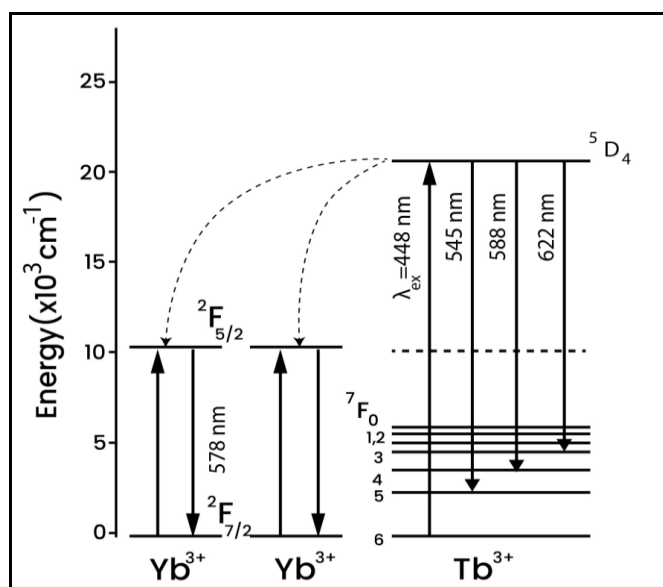


Fig 3: Energy levels mechanism of Terbium-Ytterbium ions in TNZTY glass at 488nm excitation

Fluorescence Spectra of TNZTY Glass at 325nm Excitation

Figure 4 displays the Terbium-Ytterbium ions co-doped TNZTY glasses' visible photoluminescence spectra at fixed Terbium ions concentrations as a function of Ytterbium ions concentrations and under 325 nm illumination. These spectra clearly show emission bands centered at 488, 545, 620, and 622 nm. The $^5D_4 \rightarrow ^7F_J$ ($J=6,5,4,3$) transitions of Terbium ions are responsible for these peaks, and elevating the Ytterbium ions concentration significantly lowers their intensities. Furthermore, the presence of OH in the samples contributed to the low UV emission intensity. These findings suggest that a down-conversion process is in progress. According to some publications [17], this mechanism in the Terbium-Ytterbium ions co-doped glasses is a quantum cutting because of a cooperative energy transfer process that turns one photon absorbed by the Terbium ion into two photons emitted by the Ytterbium ions ($Terbium\ ions: ^5D_4 \rightarrow Yb^{3+}: ^7F_{5/2} + Yb^{3+}: ^7F_{5/2}$).

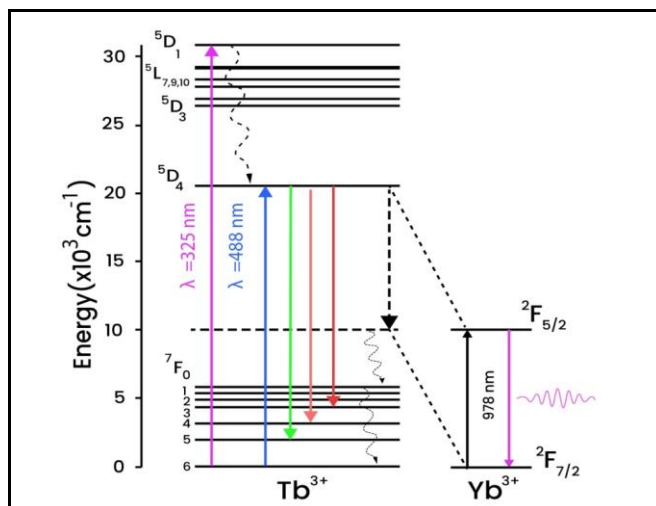


Fig 5: Mechanism of energy transfer in Terbium-Ytterbium ions at 325nm excitation

Conclusion

In this work, we synthesized Terbium-Ytterbium ions co-doped zinc-tellurite glasses using a melt-quench technique, and we investigated down-conversion using the glass samples. The absorption spectra, fluorescence spectrum, and energy levels of the materials were examined based on our findings. The two excitation powers used to study the fluorescence spectra were 488 nm and 325 nm. The mono-crystalline zinc-tellurite glass's conversion efficiency might be significantly increased by the down-conversion material. Using emission and excitation spectra in conjunction with time-resolved observations, the conversion of high-energy photons in the visible range to low-energy photons in the near-infrared was verified. When Terbium ions are directly excited, Ytterbium ions emission occurs through a one-photon mechanism, as demonstrated by the excitation power dependence of the emission intensity of Ytterbium ions. The one-photon energy transfer that facilitated the down-conversion process was described by a Terbium-Ytterbium ions cross-relaxation that was followed by multiphonon decay. Ultimately, all of the findings demonstrated that zinc-tellurite glass co-doped with Terbium and Ytterbium ions may find usage as a down-converter material in the near-infrared spectrum.

References

1. Van der Ende BM, Aarts L, Meijerink A. Photochemical & Photobiological Sciences. 2009;11:11081-1107.
2. Trupke T, Green MA, Wurfel P. Journal of Applied Physics. 2002;92:1668-1673.
3. Ansari GF, Parashar J, Mahajan SK. Journal of Physics: Conference Series. 2013;1913:012034.
4. Ye S, Zhu B, Chen J, Luo J, Qiu JR. Applied Physics Letters. 2008;92:141112.
5. Eilers JJ, Biner D, van Wijngaarden JT, Kramer K, Güdel HU, Meijerink A. Applied Physics Letters. 2010;96:151106.
6. Dexter DL. Physical Review. 1957;108:630-633.
7. Meijer JM, Aarts L, Ende M, *et al.* Physical Review B. 2010;81:035107.
8. Deng K, Wei X, Wang X, *et al.* Applied Physics B: Lasers and Optics. 2011;102:555-558.
9. Lin H, Yan XH, Wang XF, *et al.* Materials Science and Engineering B. 2011;176:1537-1540.
10. Ansari GF, Mahajan SK. Journal of Luminescence. 2014;156:97-101.
11. Liu X, Ye S, Qiao Y, Dong G, Zhu B, Chen D, *et al.* Applied Physics B: Lasers and Optics. 2009;96:51-55.
12. Xie LC, Wang YH, Zhang HJ. Applied Physics Letters. 2009;94:061905.
13. Zhang QY, Yang CH, Pan YX. Applied Physics Letters. 2007;90:021107.
14. Zhang QY, Yang CH, Jiang ZH, Ji XH. Applied Physics Letters. 2007;90:061914.
15. Yuan JL, Zeng XY, Zhao JT, Zhang ZJ, Chen HH, Yang XX. Journal of Physics D: Applied Physics. 2008;41:105406.
16. Liu X, Ye S, Qiao Y, Dong G, Zhu B, Chen D, Lakshminarayana G, Qiu J. Applied Physics B: Lasers and Optics. 2009;96:51.
17. Vergeer P, Vlugt T, Kox M, den Hertog M, van der Eerden J, Meijerink A. Physical Review B. 2005;71:014119.
18. Ye S, Katayama Y, Tanabe S. Journal of Non-Crystalline Solids. 2011;357:2268-2272.