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Optical properties of chemically synthesized nanostructured strontium tungstate

Ananda Kumar V M
Associate Professor
Nanomaterials Lab, Department of Physics and Research Centre
Mahatma Gandhi College, Pattom Palace P O, Thiruvananthapuram, Kerala PIN 695004

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Abstract

Nanostructured materials differ from conventional materials in terms of its tunable physical properties. The optical properties of nanostructured materials are grain size dependent and this gives an opportunity to engineer these properties to develop materials to suit specific needs. Strontium tungstate ($SrWO_4$) is employed as solid state scintillators and in optoelectronic devices. In the present study, nanocrystalline $SrWO_4$ of three different grain sizes were synthesized using chemical precipitation technique. The crystal structure, phase and the grain size of the samples were found from X-ray diffraction spectra. The Fourier transform Infrared spectra of the sample was recorded and analysed for phase purity. The UV-Visible absorption, photoluminescence and Raman spectra of the samples were recorded and the features of the spectra are discussed in detail.

Key words: Nanostructured materials, Optical absorption spectra, Photoluminescence, Raman spectra, Strontium tungstate.

Introduction

Nanostructured materials are new class of materials that have properties often superior compared to conventional bulk solid. Unique properties exhibited by these materials have attracted extensive studies and find potential applications in different fields of science and technology (L. Tian et. al., 2018 and A. M. Abadalla et. al., 2018) . The reduction of crystalline size to nanoscale often involves spectacular changes in optical properties of materials through charge and phonon confinement (D.M. Sagar et. al., 2015 and E. Nazek et. al., 2016) One of the distinct features of nanostructured materials is that a large percentage of atoms are associated with interface such as surfaces and grain boundaries. Therefore with the decrease in average particle size, the characteristics of surface atoms will become increasingly sharper and contribution from these atoms should be taken into account when attempting to describe strange properties exhibited by materials with nanograin size (C. Zhou et. al., 2012 and MD. P Ahmaed et. al., 2019).

Metal tungstates and molybdates are two important families of inorganic materials that have high application potential in various fields, such as in photoluminescence, microwave applications, optical fibers, scintillator materials, humidity sensors, magnetic properties and catalysis (W. Van Loo, 1975, T.T. Basiev et. al., 2000, D. Chen et. al., 2003, M.A.M. A. Maurera et. al., 2004, G. Jia et. al., 2004,

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S.K. Arora and B. Chudasama, 2006, L. Sun et. al., 2007, J.C. Sczancoski et. al., 2015, H. Hossainian et. al., 2016, E. A. Potanina et. al., 2019). Strontium tungstate crystal belongs to the tungstate family. Alkaline-earth tungstates, MWO_4 (M = Ba, Ca, Sr, Pb) are important because of their scientific and technological applications. These compounds are employed as solid-state scintillators and optoelectronic devices. Tungstate divalent scheelite compound strontium tungstate ($SrWO_4$) finds use in solid state laser applications and various other technological applications. Strontium Tungstate crystallizes in a tetrahedral structure with four molecules in each crystallographic unit. Several reports of synthesis and characterization of crystals of $SrWO_4$ are available in the literature (W. Van Loo, 1975, T.T. Basiev et. al., 2000, M.A.M. A Maurera et. al., 2004, G. Jia et. al., 2004, S.K. Arora and B. Chudasama, 2006, L. Sun et. al., 2007, J.C. Sczancoski et. al., 2015, H. Hossainian et. al., 2016, E. A. Potanina et. al., 2019). Rare-earth doped strontium tungstate crystals and their optical properties were also reported in the literature (S. K. Gupta et. al., 2016, Y. Zhang et. al., 2018). In the present work, the synthesis and evolution of optical properties of nanostructured SrWO4 are attempted. The structural characterization of the samples were done using x-ray diffraction, Fourier transform Infrared spectroscopy, UV-Visible spectroscopy, photoluminescence spectroscopy and Fourier transform Raman spectroscopy.

Materials and Methods

Nanocrystalline $SrWO_4$ was synthesized by chemical precipitation technique. Strontium chloride hexahydrate ($SrCl_2.6H_2O$) and Sodium Tungstate dehydrate ($Na_2WO_4.2H_2O$) are the reactants. The equation for the reaction could be given as

$$Na_2WO_4.2H_2O + SrCl_2.6H_2O \rightarrow SrWO_4 + NaCl_2 + 8H_2O$$

Aqueous solutions of the reactants were added to the reaction medium under rigorous stirring. The resulting precipitate is washed and dried. Three different samples of strontium tungstate were prepared by changing the reaction medium, pH and the preparation conditions. The samples were given codes ST1, ST2 and ST3. The powder samples were then characterized using X-ray diffraction technique to identify crystal structure, phase and grain size. The X-ray diffraction patterns of all the powder samples were recorded using Philips XPERT PRO diffractometer with Cu $K_{\square}$ radiation ($\square$ = 1,5406 Å) source. Fourier transform Infrared (FTIR) spectrum of the sample was recorded in the range 400 to 1200 cm^{-1} using Brucker IFS FTIR spectrometer. 10 mg of each powder sample is finely dispersed in ethanol using ultrasonicator and the absorption spectra of the dispersed sample were recorded in the UV-Visible range using CARY 100 BIO UV-Visible spectrometer from 200 – 700 nm range, The photoluminescence (PL) spectra of the dispersed samples in ethanol medium were recorded for an excitation wavelength of 240 nm using SPEX Fluorolog Spectrometer. The Fourier Transform Raman spectrum of the sample with smaller grain size (Sample Code:ST2) was recorded using Brucker FT Raman spectrometer.

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Results and Discussion

Figure 1 shows the X-ray diffraction (XRD) spectrum of one of the as prepared sample of nanocrystalline SrWO4 (sample code: ST1). The XRD spectrum showed distinct peaks indicating that the samples are crystalline in nature. The 2θ values of three major peaks are 27.8°, 45.3° and 55.9° correspond respectively to the three crystal planes (112) (204) (312) of crystalline $SrWO_4$. All the diffraction peaks in the spectrum can be indexed to ICDD data file 85-0587 which corresponds to $SrWO_4$ belonging to scheelite structure. The average grain size of the sample was determined from the broadening of diffraction peaks using Debye - Scherrer equation

$$D = k\lambda / \beta \cos\theta \qquad (1)$$

where, k is a constant equal to 0.9, λ is the wavelength of X-rays equal to 1.5406 Å, β is the full width at half maximum of the diffraction peak and θ is the diffraction angle. The sizes calculated by using Debye - Scherrer equation for the samples ST1, ST2 and ST3 are 21, 16 and 25 nm respectively.

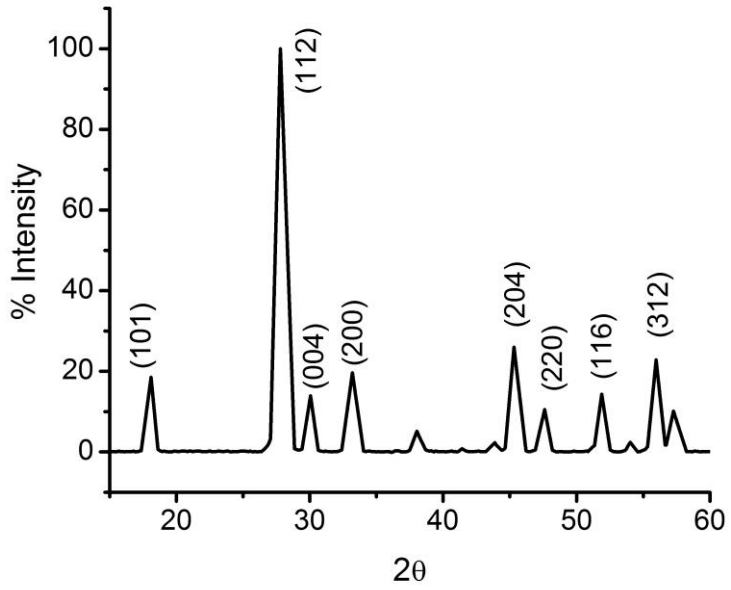

Figure 1 XRD spectrum of nanostructured $SrWO_4$ (sample code: ST1)

Figure 2 shows the Fourier Transform Infrared (FTIR) spectrum of nanocrystalline $SrWO_4$ recorded in the range 400 to 1200 cm^{-1}. The spectrum showed a sharp absorption peak at 410 cm−1 and a broad peak around 820 cm^{-1}. Out of the 8 allowed modes only two modes are recorded in this range. Tungstates of scheelite type has allowed 8 stretching and bending vibrations in the IR region. The strong and sharp absorption band seen at 410 nm can be attributed to the $\upsilon_2(A_u)$ mode of vibration of

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WO_4^{2-} tetrahedra corresponding to bending vibrations. The strong and broad band found around 820 cm^{-1} may be related to the anti-symmetric stretching vibrations inside WO_4^{2-} clusters belonging to $\upsilon_3(A_u)$ mode. Both these peak agree well with that reported for $SrWO_4$ earlier indicating that the synthesized samples are pure (J.C. Sczancoski et. al., 2015).

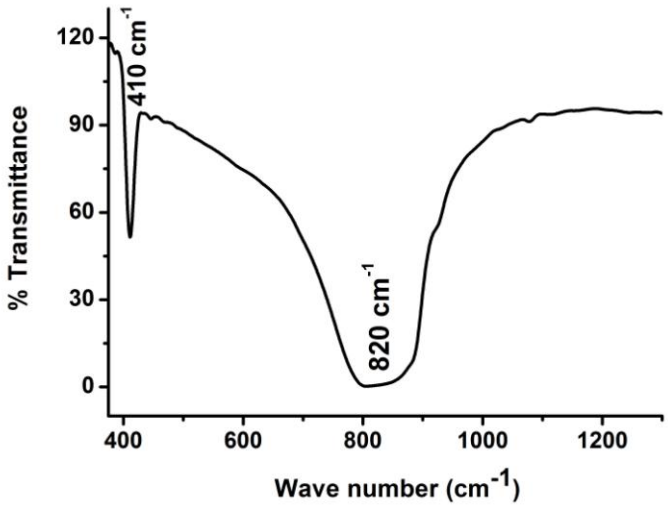

Figure 2 IR spectrum of nanocrystalline $SrWO_4$ (Sample Code:ST2)

Optical absorption spectra of as prepared nanocrystalline samples of $SrWO_4$ dispersed in ethanol medium are shown in figure 2. The samples ST1 and ST2 showed absorption onset at around 500 nm and showed a sharp peak around 250 nm. In the case of sample ST3 the absorption becomes significant around 325 nm and showed a peak around 275 nm. The optical properties of single crystals and thin films of $SrWO_4$ are widely reported in literature (Z. Lou and M. Cocivera, 2002, D. Chen et. al., 2003, G. Jia et. al., 2004, L. Sun et. al., 2007, A. Wang et. al., 2010, J.C. Sczancoski et. al., 2015, E.A. Potanina et. al., 2019). Single crystals of $SrWO_4$ were synthesized using Czochralski method and pure crystals are found to be transparent up to 2700 nm and has an ultraviolet absorption edge around 300 nm (G. Jia et. al., 2004). Thin films of $SrWO_4$ were fabricated on glass substrates using spray pyrolysis and study of their optical absorption properties revealed an absorption edge around 255 nm (Z. Lou and M. Cocivera, 2002). Thin films of $SrWO_4$ were deposited on glass substrates using chemical solution method and the transmittance of these films dropped significantly at around 260 nm (M.A.M. A Maurera et. al., 2004). It was reported that $SrWO_4$ powders synthesized using co-precipitation method and processed microwave-hydrothermal methods showed absorption maximum around 270 nm (J.C. Sczancoski et. al., 2009). The as prepared nanocrystalline $SrWO_4$ samples with average grain size 21 and 16 nm showed absorption peak around 250 nm and there is

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no significant variation is found in the absorption peak. The early onset of absorption in these samples may be attributed to the defect levels present in the band. But in the case of nanocrystalline sample with average grain size 25 nm, the absorption peak was found to be at around 275 nm. All these samples showed significant blue shift compared to bulk crystals of $SrWO_4$. Nanostructured systems are confined systems in which the charge carriers get themselves confined. This is manifested as a blue shift in the absorption maximum well reported in semiconductor and ceramic nanoparticles (K. Lin et. al., 2005, I.A. Rahman et. al., 2008, D. Segets et. al., 2009, C. Xia et. al., 2018). In nanocrystalline $SrWO_4$ also it is observed that the absorption maximum gets blueshifted with reduction in grain size. Thus tuning of grain size can result in blue shift of absorption maxima in the UV-Visible spectra of nanocrystalline $SrWO_4$.

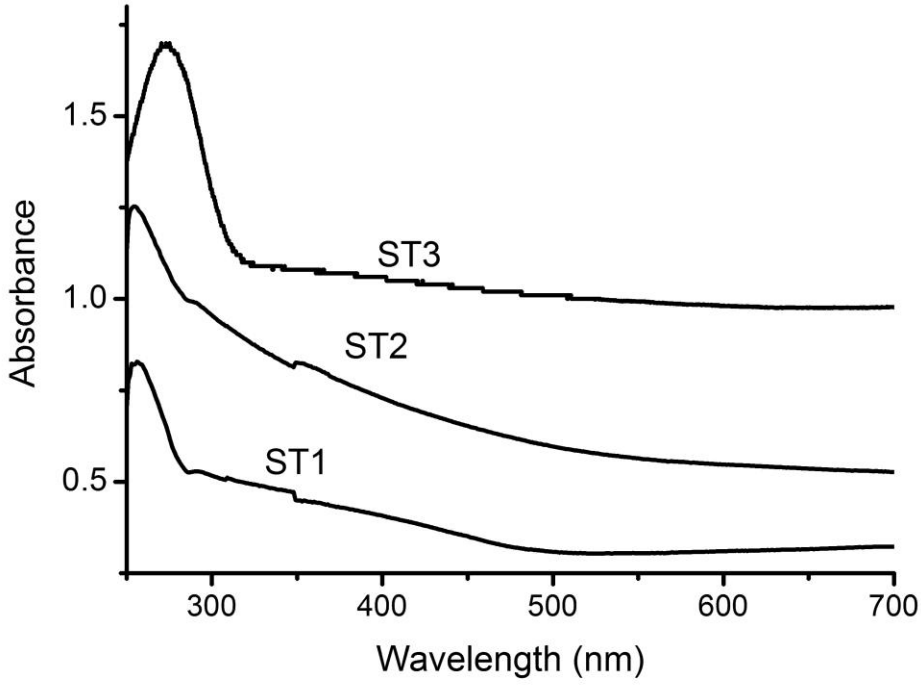

Figure 3 UV-Visible absorption spectra of nanocrystalline $SrWO_4$
(Sample code: ST1, ST2, ST3)

The room-temperature photoluminescence spectra for an excitation wavelength of 240 nm of nanocrystalline $SrWO_4$ samples (ST-1, ST-2 and ST-3) are shown in figure 2. The samples ST1 and ST2 showed a sharp peak near 420 nm while the peak shifted to higher wavelength of 430 nm for sample ST3. Hence it is seen that for sample with larger grain size the peak got shifted towards the longer wavelength side. The photoluminescence spectra of as prepared 3D microcrystals of $SrWO_4$

showed strong emission peaks at 432 and 505 nm (G. Tian et. al., 2014). Photoluminescence emission originates from the radiative return to the ground state upon excitation. The peaks recorded in photoluminescence spectra of SrWO4 was attributed to the existence of distorted WO_4 clusters within $SrWO_4$ lattice which create intermediate energy levels in the band gap (J.C Sczancoski et. al., 2015). Thin films of $SrWO_4$ prepared by spray pyrolysis exhibited a cathodoluminescence at 447 and 487 nm. These peaks were ascribed to the electronic transitions happening within the WO_4^{2-} ions (Z. Lou and M. Cocivera, 2002). Photoluminscent properties of different nanostructures with different morphologies of $SrWO_4$ prepared using solvothermal mediated microemulsion technique showed peaks at 501 and 468 nm (L. Sun et. al., 2007). Photoluminescence spectrum of nanosized particles in irregular clusters of $SrWO_4$ using cyclic microwave radiation showed a prominent peak around 420 nm. This peak was attributed to $^1T_2 \rightarrow {}^1A_1$ transitions of electrons within WO_4^{2-} ions. This transition is ascribed to be a possible exciton formation (T. Thongtem et. al., 2008 , J.C. Sczancoski et. al., 2009) It may be observed that for the sample with average grain size 25 nm the photoluminescence peak got shifted towards higher wavelength. The shape of the nanoparticles, degree of crystallinity, excitation wavelength, presence of impurities, defects and many other factors contribute to emission. The shift of emission maximum to lower wavelength or higher energy may be attributed to quantum confinement effect. As the grain size is reduced to nanosize the charge carriers get confined to nanograins resulting in modification of their energy bands. Usually the band gap widening occurs as a result of lowering of grain size. Hence the emission peak also get shifted towards higher energy side with reduction in grain size.

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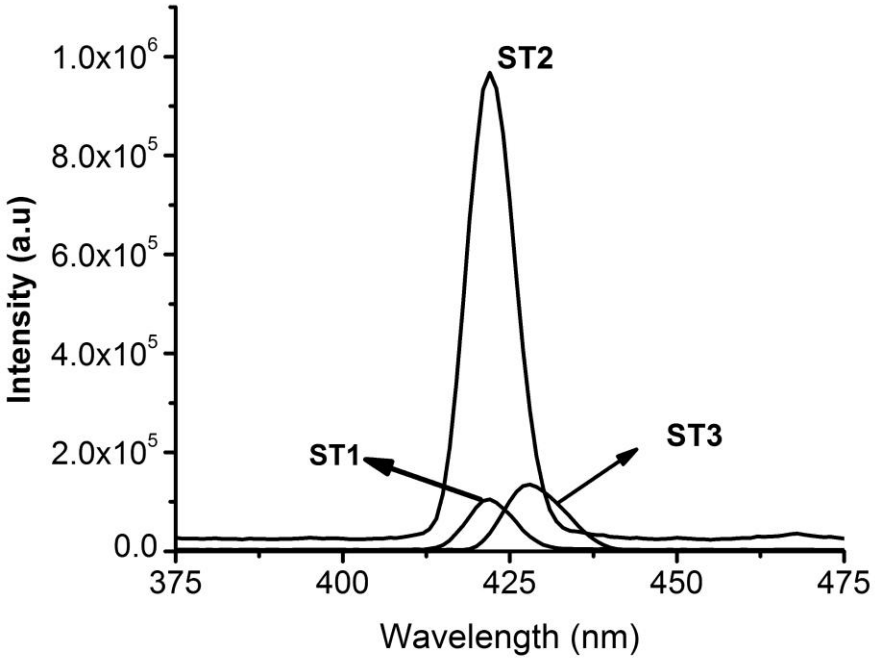

Figure 4 Photoluminescence spectra of nanocrystalline $SrWO_4$
Excitation wavelength : 240 nm

The figure 5 and 6 show the Fourier transform Raman spectrum of as prepared nanocrystalline $SrWO_4$ (Sample code: ST2) in the range 50 to 300 cm^{-1} and 300 to 1000 cm^{-1} respectively. Sharp peaks were observed at 921, 837, 798, 372, 336, 189, 133, 101 and 75 cm^{-1}. There are 13 zone centre Raman active modes for $SrWO_4$ crystals given by the equation

$$\Gamma_{Raman} = 3A_g + 3B_g + 5E_g \quad (2)$$

The vibrational modes of scheelite structured $SrWO_4$ may be classified as low frequency lattice or external modes and high frequency internal modes. External modes of vibrations arise from lattice phonons which may be resulting from the movement of $[SrO_8]$ clusters and the rigid units. Relatively high frequency internal modes are attributed to the vibrations of the strong bonds inside the sublattice $[WO_4]$ clusters (S.P.S Porto and J.F. Scott, 1967, J.C Sczancoski et. al., 2009, J.C Sczancoski et. al., 2015). First prominent Raman peak was found at 75 cm^{-1} with a shoulder peak. Up on deconvolution it was found that there are two peaks one at 75 cm^{-1} and another at 85 cm^{-1}. The prominent Raman peak found at 75 cm^{-1} was reported as the B_g mode and is attributed to the symmetric bending vibrations O — Sr — O bonds in $[SrO_8]$ clusters. A new peak of weak intensity was found at 85 cm^{-1} which may be due to the contribution of surface atoms which will be prominent in nanostructured systems. It may be attributed to surface modes prevalent in nanosized systems. The peak found at 101 cm^{-1} is ascribed to the free motion of $[SrO_8]$ clusters and the peak at 133 cm^{-1} is due to the symmetric stretching vibrations of $[SrO_8]$ clusters. The Raman peaks 189 and 235 cm^{-1} correspond to free rotations of $[WO_4]$ tetrahedra. Asymmetrical bending vibration of $[WO_4]$ sublattice

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results in the Raman peak at 336 cm^{-1}; The peak recorded at 372 cm^{-1} is characterized with marked asymmetry and hence it was deconvoluted to get two peaks one at 371 cm^{-1} and other at 379 cm^{-1}. These peaks correspond to B_g and E_g modes and are related to the symmetric bending vibrations $[WO_4]$ sublattice. Asymmetric stretching vibrations of bonds in the $[WO_4]$ sublattice give rise to Raman peaks observed at 798 and 837 cm^{-1} which match with E_g and B_g modes of symmetry. The strong Raman band observed around 921 cm^{-1} can be assigned to the symmetric stretching vibrations of $[WO_4]$ sublattice correspond to A_g mode of symmetry. It may be noted that the reduction of grain size to nanometer do not alter the frequencies of internal modes of vibrations. The surface to volume ratio of nanoparticles is very large and the contribution of surface atoms will become significant compared to that of bulk material. These surface atoms will collectively oscillate to give new low frequency surface modes of vibration. The high surface to volume ratio can create a surface stress which may be compressive or tensile. This strain also can shift the frequency of the Raman lines.

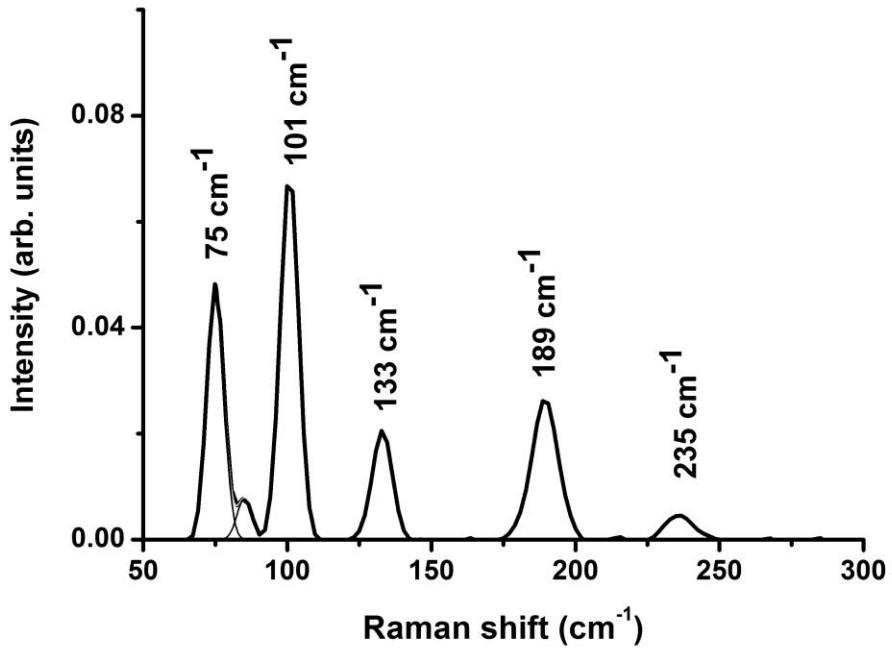

Figure 5 Raman spectrum of nanocrystalline $SrWO_4$ in the range 50-300 cm^{-1}

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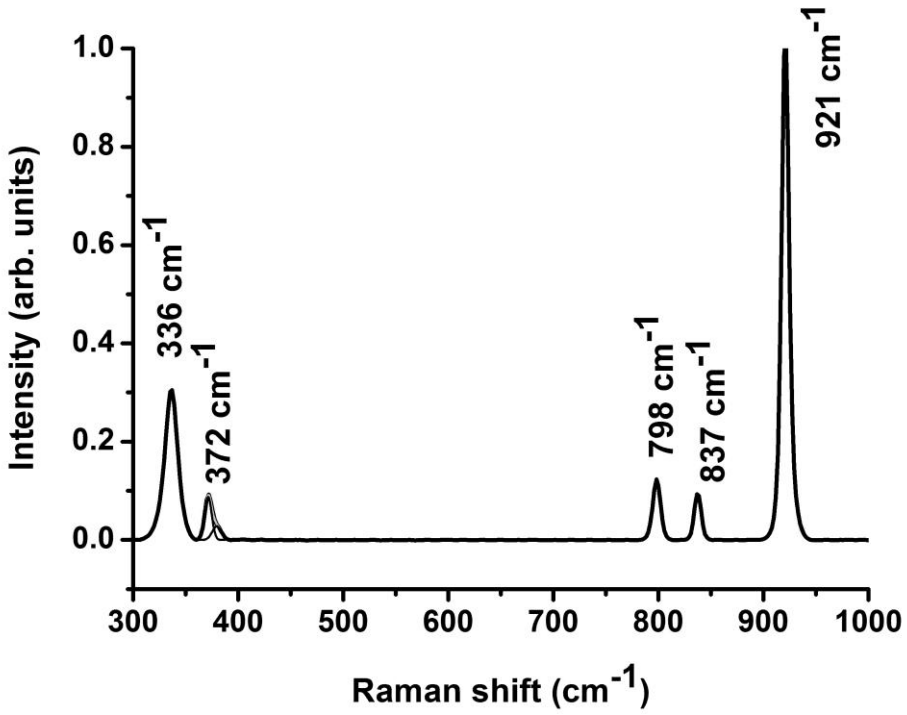

Figure 6 Raman spectra of nanocrystalline $SrWO_4$ in the range 300 to 1000cm^{-1}

Conclusion

$SrWO_4$ is an important material having excellent optical properties. They have wide spread applications in various fields, such as in photoluminescence, microwave applications, optical fibers, scintillator materials, humidity sensors, magnetic properties and catalysis. In the present study, nanocrystalline samples of $SrWO_4$ having three sizes were synthesized using controlled chemical precipitation technique. The crystal structure, phase and the average grain size were calculated by analyzing the X-ray diffraction pattern. The crystal structure is found be tetragonal with typical scheelite phase. The grain sizes were obtained to be 21, 16 and 25 nm. The FTIR spectrum recorded in the range 400 to 1200 cm^{-1} showed characteristc peaks at 410 and 820 cm-1 indicating that the synthesized samples are pure. The UV-Visible absorption spectra of the as prepared samples with grain sizes 21 and 16 nm showed a sharp absorption peak around 250 nm while the sample with average grain size 25 nm exhibited a peak around 275 nm. All the absorption peaks of the samples are blue shifted compared to the bulk crystal indicating quantum confinement and it establishes grain size dependence. The photoluminescence spectra of the samples recorded with an excitation wavelength of 240 nm showed peaks at around 420 nm for the samples with lower grain sizes and around 430 nm for sample with grain size 25 nm. The FT Raman spectra of the sample with grain size 16 nm was recorded in the range 50 to 1000 cm^{-1}. It showed characteristic peaks that can be assigned

to internal and external vibrations of $SrWO_4$. Confinement of phonons in nanosized grains results in broadening and shifting of Raman peaks.

References

1. Liang Tian and Lin Li (2018) : A review on the strengthening of nanostructured materials, International Journal Current Engineering and Technology, 8(2): 236-249p.
2. Abdalla M. Abdalla, Shahzad Hossain, Atia T. Azad, Pg Mohammad I. Petra, Feroza Begum, Sten G. Eriksson and Abdul K. Azad (2018) : Nanomaterials for solid oxide fuel cells : A review, Renewable and Sustainable Energy Reviews, 82: 353-368p.;
3. Sagar D.M, Joanna M. Atkin, Peter K.B. Palomaki, Nathan R. Neale, Jeffrey L. Blackburn, Justin C. Johnson, Arthur J. Nozik, Markus B. Raschke and Matthews C. Beard (2015): Quantum confined electron-phonon interaction in nanocrystals, Nano Letters, 15: 1511-1516p.
4. Nazek El-Atab and Ammar Nayfeh (2016) : Corrigendum:1D versus 3D quantum confinement in 1-5 nm ZnO nanoparticle agglomerations for application in charge-trapping memory devices, Nanotechnology, 27 (41): 419501p.
5. Chen Zhou, Jing Yu, Yanping Qin and Jie Zheng (2012) : Grain size effects in polycrystalline gold nanoparticles, Nanoscale, 4(14): 4228-4233p.
6. Parvez Ahmad MD, Venketeswara Rao A, Suresh Babu .K and Narsinga Rao G (2019) : Particle size effects on dielectric properties of ZnO nanoparticles, Materials Chemistry and Physics,224: 79-84p.
7. Van Loo .W, Luminescence of lead molybdate and lead tungstate I. Experimental (1975) : Physica Status Solidi (a), 27(2) : 565-574p.
8. Basiev T.T, Sobol A.A, Voronko Y.K and Zverev P.G (2000) : Spontaneous Raman Spectroscopy of tungstate and molybdate crystals for Raman lasers, Optical Materials, 15(3): 205-216p.
9. Di Chen, Guozhen Shen , Kaibin Tang, Huagui Zheng and Yitai Qian (2003) : Low temperature synthesis of metal tungstates nanocrystallites in ethylene glycol, Materials Research Bulletin, 38: 1783-1789p.
10. Maurera M.A.M.A, Souza A.G, Soledade L.E.B, Pontes F.M, Longo .E, Leite E.R and Varela J.A (2004) : Microstructural and optical characterization of $CaWO_4$ and $SrWO_4$ thin films prepared by a chemical solution method, Material Letters, 58:727-732p.
11. Guohua Jia, Chaoyang Tu, Zhenyu You, Jianfu Li, Zhaojie Zhu, Yang Wang and Baichang Wu (2004) : Czochralski technique growth of pure and rare-earth-doped $SrWO_4$ crystals, Journal of Crystal Growth, 273: 220-225p.
12. Arora S.K and Chudasama .B (2006) : Crystallization and optical properties of $CaWO_4$ and $SrWO_4$, Crystal Research Technology, 41(11): 1089-1095p.
13. Lingna Sun, Qingrong Guo, Xinglong Wu, Shengjun Luo, Wanlong Pan, Kunlin Huang, Junfeng Lu, Ling Ren, Minhua Cao and Changwen Chu (2007) : Synthesis and photoluminescent properties of strontium tungstate nanostructures, Journal Physical Chemistry C, 111:532-537p.
14. Sczancoski J.C, Avansi .W, Costa M.G.S, Li M.S, Mastelaro V.R, Santos R.S, Longo .E and Cavalcante L.S (2015) : Effect of different strontium precursors on the growth process and optical properties of $SrWO_4$ microcrystals, Journal of Material Science,50: 8089-8103p.

15. Hossainian .H, Salavati-Niasari .M and Bazarganipour .M (2016) : Photodegradation of organic dye using strontium tungstate spherical-like nanostructures ; synthesis and characterization, Journal of Molecular Solids, 220: 747-754p.
16. Potanina E.A, Orlova A.I, Mikhailov D.A, Nokhrin A.V, Chuvildeev V.N, Boldin M.S, Sakhrov N.V, Lantcev E.A, Tokarev M.G and Murashov A.A (2019) : Spark plasma sintering of fine-grained $SrWO_4$ and $NaNd(WO_4)_2$ tungstates ceramics with the scheelite structure for nuclear waste immobilization, Journal of Alloys and Compounds, 774:182-190p.
17. Gupta S.K, Sudharsan .K, Ghosh P.S, Sanyal .K, Srivastava A.P, Arya .A, Pujari P.K and Kadam .R.M (2016) : Luminescence of undoped and Eu3+ doped nanocrystalline $SrWO_4$ scheelite : time resolved fluorescence complemented by DFT and positron annihilation spectroscopic studies, RSC Advances, 6 : 3792-3805p.
18. Zhang .Y, Wang .X, Li .Y, Li .Yand Yao .X (2018) : Excellent up-conversion temperature sensing sensitivity and broad temperature range of Er –doped strontium tungstate multiphase phosphors, Optical Materials Express, 8(1): 12-23p.
19. Lou .Z and Cocivera .M (2002) : Cathodoluminescence of $CaWO_4$ and $SrWO_4$ thin films prepared by spray pyrolysis, Materials Research Bulletin, 37:1573-1582p.
20. Wang .A, Wang .C and Jia .G (2010) : Recent advances in strontium tungstate scheelite material, Frontiers of Chemistry in China, 5(1):61-70p.
21. Sczancoski J.C, Cavalcante L.S, Joya M.R, Espinosa J.W.M, Pizani P.S, Varela J.A and Longo .E (2009) : Synthesis, growth process and photoluminescence properties of SrWO4 powders, Journal of Colloidal Interface Science, 330:227-236p.
22. Lin .K, Cheng .H, Hsu .H, Lin .L and Hsieh .W (2005) : Band gap variation of size-controlled ZnO Quantum dots synthesized by sol-gel method, Chemical Physics Letters, 409:208-211p.
23. Rahman I.A, Vejayakumaran .P, Sipaut C.S, Ismail .J and Chee C.K (2009) : Size-dependent physicochemical and optical properties of silica nanoparticles, Materials Chemistry and Physics, 114: 328-332p.
24. Segets .D, Gradl .J, Taylor R.K, Vassilev .V and Peukert .W (2009) : Analysis of optical absorbance spectra for the determination of ZnO nanoparticle size distribution, solubility and surface energy, ACS Nano, 3(7):1703-1710p.
25. Xia .C, Wu .W, Yu .T, Xie .X, Oversteeg C.V, Gerritsen H.C and Donega C.M (2018) : Size-dependent band-gap and molar absorption coefficients of colloidal $CuInS_2$ quantum dots, ACS Nano, 12(8): 8350-8361p.
26. Tian .G, Sheng .N and Qiu .X (2014) : Structure and photoluminescence properties of $SrWO_4$ 3D microspheres synthesized by the surfactant-assisted hydrothermal method, Crystal Research Technology, 49(6) 360-365p.
27. Thongtem .T, Phuruangrat .A and Thongtem .S (2008) : Synthesis of $CaWO_4$, $SrWO_4$ and $BaWO_4$ with nanosized particles using cyclic microwave radiation, Journal of Ceramic Processing and Research, 9(3): 258-2661p.
28. Porto S.P.S and Scott J.F. (1967) : Raman Spectra of $CaWO_4$, $SrWO_4$, $CaMoO_4$ and $SrMoO_4$ Physical Review, 157(3): 716p.