

A Literature Review on: Synthesis Approaches of Metal doped Titanium Dioxide

Satish A. Ahire^{1*}, Ashwini A. Bachhav², Vinayak R. Bagul³, Bajirao B. Ahire⁴, Umesh J. Tupe⁵

^{1,3}Department of Chemistry, Arts, Science and Commerce College, Surgana, Dist. Nashik, Maharashtra (India)

²Sandip Institute of Pharmaceutical Science, Mahiravani Dist. Nashik, Maharashtra (India)

⁴N.V.P Mandal's, Arts, Science and Commerce College, Lasalgaon, Dist. Nashik, Maharashtra (India)

⁵Department of Electronic Science and Research Center, L. V. H. Arts, Science and Commerce College, Nashik, Dist. Nashik, Maharashtra (India)

Abstract: Titanium dioxide (TiO₂) nanoparticles are synthesized using various approaches of synthesis. Various synthesis approaches are subsequently compared in terms of their morphology and structural properties like crystallite size, surface area, particle size and phase. Titanium dioxide nanoparticles have unique properties such as optical, electrical, mechanical, physical, chemical, photo catalytic and electronic. The paper presents the various methods of synthesis of pure titanium dioxide and with dopant like alkali metals, alkaline earth metals, transition metals, inner transition metals and codoped materials and its applications.

Keywords: Titanium dioxide, Nanoparticles, Synthesis, Transition metals.

I. Introduction:

Titanium is the world's fourth abundant metal and the ninth abundant elements. This new element was discovered by the Reverend William Gregor in 1791 in ilmenite. It was rediscovered by the German chemist Heinrich Klaproth in rutile ore. He named it as Titans means mythologically the first son of the goddess Ge i.e.earth¹. Primarily, it occurs in ilmenite, rutile, anatase, brookite and perovskite.

Titanium dioxide (TiO₂) is one of the most important compounds in the field of the nanotechnology due to its non-toxicity, low cost, photocatalytic activity and photocatalytic activity^{2,3}. TiO₂ exist in three polymorphs anatase, brookite and rutile⁴. Rutile is thermodynamically stable while the anatase and brookite are metastable, transforms to rutile by calcination⁴. Pure TiO₂ shows low utilization of solar energy because of wide band gap (as shown in figure-1) and low quantum yield since electron-hole pairs combines fast⁵. Some strategies were developed to improve the efficiency of the TiO₂. Doping with metals^{6,7,8,9,10,11}, non-metals^{12,13,14,15,16}, depositing with noble metals^{17,18} and combining with semiconductors^{19,20} improves the efficiency of TiO₂.

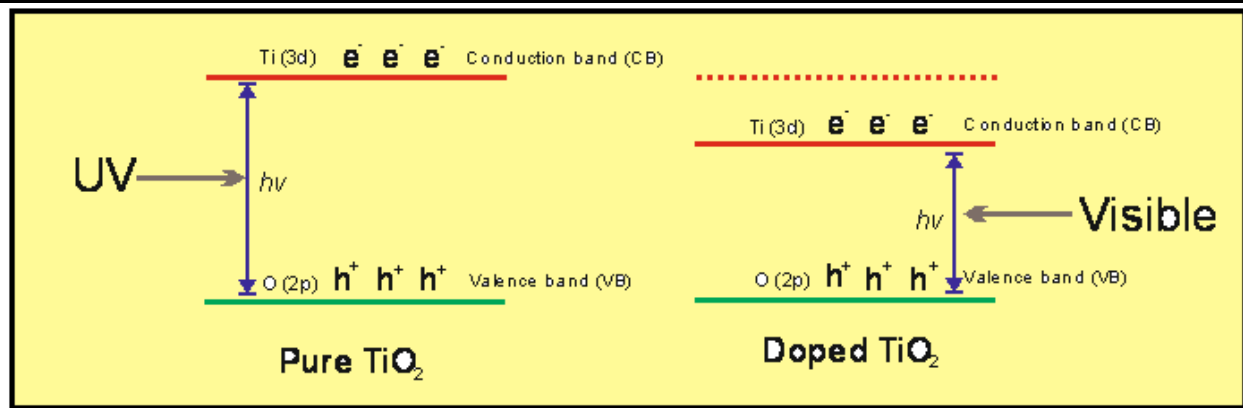


Figure-1: Comparison of band gap between the pure and doped TiO₂.

Modified TiO₂ is widely used as skin protective compound in sunscreen²¹, hydrogen production^{22,23}, water splitting²⁴, waste water treatment^{2,25}, water and air purification^{26,23}, UV protection²¹, self-cleaning surfaces²³, photo electrochemical conversion²³, sterilization²³, antibacterial agent²⁶.

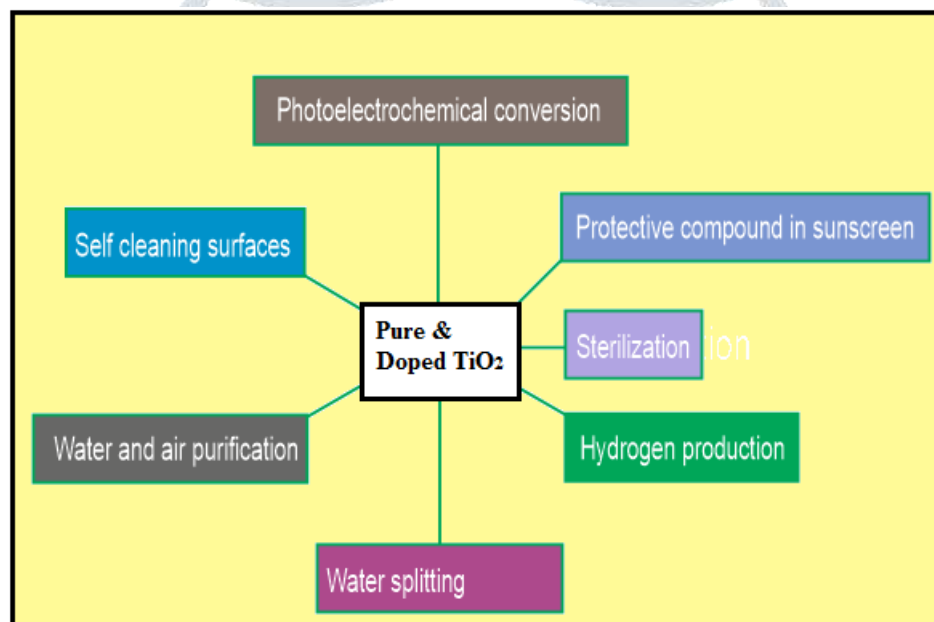


Figure-2: Applications of pure and doped TiO₂.

In this review, we focus on the research work that has been done on metal doped TiO₂. This article will be helpful for the research scholars who have keen interest in the field of TiO₂.

1. Alkali metal doped

Bessekhouad and coworkers⁶ prepared Alkali(Li, Na, K) doped TiO₂ nanoparticles by sol-gel route and impregnation technology. The study revealed that the crystallinity of the catalysts is mostly dependent on both the nature and the concentration of alkaline. The greatest crystallinity is gained for Li-doped TiO₂ and is lowermost for K-doped TiO₂. For photocatalytic study, organic pollutants such as Malachite green oxalate, 4-hydroxybenzoic acid and benzamide were used. For a given alkaline concentration, the catalysts synthesised by the impregnation method were more efficient than those by sol-gel route. From

these results, they concluded that in the small concentrations, alkaline improves TiO₂ efficiency. They found that the sodium can activate TiO₂.

Chen and coworkers²⁷ synthesized K⁺ doped TiO₂ by sol gel method from KOH and titanium isopropoxide. From the study, it was found that doped TiO₂ was more photoactive than the undoped TiO₂. K⁺ doping with TiO₂ decreases the size of the TiO₂ crystals, increases the surface area and the temperature at which anatase changes into the rutile phase. The catalyst was used for the photodegradation of Everdirect Supra Blue BRL dyes (BRL). The optimal K⁺ amount was 4.6% while the calcination temperature was 973 K for the photoactivity. The most effective pH for the BRL was 7.2. The photocatalytic reaction rate has found to be increased with the increase of the catalyst dosage to the power of 0.72 and the optimal dosage of K⁺ catalyst is around 1.5 g/l.

2. Alkaline earth metal doped:

Salim and coworkers²⁸ synthesized calcium, strontium or barium ions doped TiO₂ (anatase) photocatalyst powders by sol gel method. Greater than 15 mol% alkaline earth ions compositions resulted in largely amorphous materials. As the concentration of alkaline earth ions increases, the residual anatase showed decrease in the crystallite sizes and increase in the crystallographic cell volumes, while the BET surface areas of the materials increases at higher levels of additive. The band gaps of the materials increased with increasing of the Ca²⁺ content, due to the decreasing particle sizes. During the synthesis, except rutile (v1% w.r.t. anatase), no other crystalline phase was observed. Oxalic acid was used for the determination of the relative effects of the additives on the photocatalytic activities. From this study, it was found that the titania containing 20 mol% alkaline earth ions showed approximately double the photocatalytic activity.

3. Transition Metal doped:

Ghasemi and coworkers⁷ has synthesized nanocrystalline transition metal (TM) doped TiO₂ by using sol-gel method. They use 2-hydroxyethylammonium formate as a ionic liquid as a solvent media. They doped transition metals such as Cr, Mn, Fe, Co, Ni, Cu, and Zn with TiO₂. The findings revealed that doped nanoparticles have reduced crystalline size as well as higher surface area than pure TiO₂. They found a noteworthy absorption shift into the visible region due to dopant ions in the TiO₂ structure. The TM doped TiO₂ nanoparticles exhibited higher photocatalytic activity than pure TiO₂ for the degradation of Acid Blue-92 (AB92) in water. The increase in activity may be due to higher efficiency for the electron-hole generation and lower the electron-hole recombination rate.

Rauf and coworkers²⁹ has studied the degradation of azo dyes using transition metal (Cr, Cu, Fe, Mn, Zn, V, Ag and W) doped TiO₂ as photocatalysts in aqueous solutions. These dopants reduce the recombination of e⁻ and h⁺ and decrease the band gap or create intra-band gap states that result in more light absorption. Likewise, these dopants can alter the surface properties such as surface acidity and surface area, of the TiO₂ catalyst. Thus, by using the visible light, the photocatalysis on modified TiO₂

can be promoted. They study the effect of pH, catalyst concentration, substrate concentration and the nature of the doping substances, on the degradation of dyes. Transition metal doped TiO₂ has found to be very effective for the photodegradation of azo dyes. The photocatalytic processes became more efficient through the formation of intermediates such as aromatic amines, phenolic compounds and several organic acids result in enhanced dye degradation.

3.1 Silver (Ag)doped

Sokemon and coworkers¹⁷ synthesized silver-loaded TiO₂. This catalyst was studied for the photocatalytic degradation of organic dyes. The dyes such as methyl violet, a cationic dye; Cibacron Blue FMR, a reactive dye; and Maxilon Red GRL, a mono azo basic dye were used for the degradation study. They found that the undoped TiO₂ degraded about 63% of methyl violet within 4 min while the Ag-loaded TiO₂ catalyst degraded the same to 95% within the same time period. Finally, they concluded that the Ag-loading dramatically reduced the degradation time.

Lee and coworkers¹⁸ synthesized the Ag-TiO₂ particles by sol-gel process involving a reduction agent. The sol synthesized was transparent and stable for several months. The prepared Ag-TiO₂ particles were mostly an anatase structure, regardless of the AgNO₃ content. All the particles had a crystallite sizes in between 5 and 6 nm. They found that the addition of AgNO₃ did not affect the crystallite size of the particles. It was confirmed that the calcination improves the crystallinity of the particles. With the increase of calcination temperature, the amorphous TiO₂ changing into the anatase phase and then the anatase phase changing into the rutile phase. In addition, they conclude that the presence of Ag in TiO₂ resulted in higher photodegradation of p-nitrophenol and the photocatalytic activity of TiO₂-Ag increased with increasing AgNO₃ content.

3.2 Iron (Fe) doped

Marami and his coworkers³⁰ prepared Fe doped TiO₂ by the simple sol-gel synthesis method. The XRD patterns study revealed the coexistence of rutile and anatase phases and the structure was determined to be tetragonal for both undoped and doped TiO₂. The mixed phase ratio of the rutile-to-anatase was 29:71. The particle size of about 18 nm for 4 mol.% Fe-doped TiO₂. The the XRD results, it was found that the increase of Fe impurity decreases the crystallite size. The UV-DRS data exhibited a red shift, because of the reduction of the band gap produced by the increase of Fe content. The optimal band gap was found for 4 mol.% Fe-doped TiO₂ at about 2.6 eV. From their study, it was concluded that the Fe³⁺ ions increase the photocatalytic activity by the separating the photogenerated charges, affecting the material efficiency as a photocatalyst for solar energy conversion.

Wang³¹ and his colleagues were synthesized novel M(OH)_x/TiO₂ nanoparticles by the modified wet precipitation process at low temperature, where M(OH)_x represents ferric(Fe³⁺) or cupric(Cu²⁺) hydroxide. Methyl orange (MO) as a model of organic pollutants was used to study the photocatalytic activity. XRD, UV-vis DRS, TGA, and FT-IR characterization showed that these nanoparticles have a surface that enriched with hydroxyls and coordinated water. These composites showed a strong

photocatalytic activity in the degradation of methyl orange in aqueous solution. The photocatalytic activity of $0.05\text{-M(OH)}_x/\text{TiO}_2$ was increased by about fivefolds as compared to the undoped TiO_2 . From this study, it was revealed that the new photocatalysts has outstanding photocatalytic activity with the pH range from about 3 to 7. Simple preparation method and excellent photochemical stability were the most important features of this catalyst.. From this study, it was concluded that the improved effect of M(OH)_x deposition is due to the surface that were enriched hydroxyl groups and the interface of $\text{M(OH)}_x/\text{TiO}_2$ that promotes the charge separation.

Zhu and coworkers³² were prepared iron-doped TiO_2 photocatalysts by the combination of sol–gel process with hydrothermal treatment. This method produced a novel photocatalysts that have high surface areas, mesoporous structure, and small crystal sizes. Moreover, this catalyst also have a large amount of surface adsorbed water and hydroxyl groups that contributes to their high photocatalytic activity. From this study, it revealed that there was a decrease in the Fe^{3+} doping content from the surface to the core. This dopant distribution may be in favor of the interfacial transfer charge reactions. Fe^{3+} can assist the separation of the photogenerated electrons and holes by trapping them temporarily. Doped photocatalysts absorb and utilize the visible light for the photocatalytic degradation of the yellow XRG.

3.3 Cobalt(Co) doped

Bouras and coworkers³³ has synthesized the thin films of pure or doped nanocrystalline TiO_2 on glass slides by using a sol–gel procedure. The Triton X-100 was used as surfactant that acts as template of the nanostructure. Fe^{3+} , Cr^{3+} and Co^{2+} were used as dopants with a concentration from low to high levels. The photocatalytic efficiency of undoped or doped TiO_2 was studied for the degradation of Basic Blue-41. In this work, they found that the pure nanocrystalline TiO_2 is a better photocatalyst than doped TiO_2 .

Chekuri and colleagues³⁴ has synthesized 0.5 wt. % Co^{2+} doped TiO_2 by sol-gel method and used 1,4-Butane sultone anionic Gemini surfactant. From the results it was found that the surfactant controlled the grain morphology, the particle sizes and the specific surface area. The superior activity of the Co^{2+} - TiO_2 (with surfactant) for Acid Red dye degradation efficiency was attributed due to decrease in band gap, small particle size and then enhanced specific surface area. In addition, the catalyst showed a stronger absorption in the visible region and shift in the band gap transition was observed at 400nm- 800 nm. This shift was related to the doping of cobalt into TiO_2 . The photocatalytic degradation of Acid Red, model azo-dye pollutant has been studied in detail. From the XRD studies, all the Co^{2+} - TiO_2 (with surfactant) catalysts synthesized were reported in anatase phase. The crystallite size was obtained ranging from 8nm- 14 nm. From XPS chemical analysis it has been confirmed that the presence of cobalt was present in the catalyst as Co^{2+} . SEM micrographs have indicated change in morphology. Due to doping of cobalt into TiO_2 lattice morphological change of the TiO_2 particles has been observed with decrease in particle size for the doped catalyst in presence of catalyst. From TEM analysis of the catalyst were reported with much reduction in particle size of 8-12 nm. This was due to encapsulation of cobalt doped TiO_2 by the surfactant which restricted the further growth of particle resulting in formation of particles with much

reduction. FT-IR studies revealed that cobalt was doped substitutionally into the TiO₂ matrix. The optimum conditions for the degradation of acid red dye solution with catalyst were found at 0.5 wt. % dopant concentration with pH-4, 0.1g catalyst dosage and 5 mg L⁻¹ as initial dye concentration. The observed rate at optimum conditions for the degradation of Acid Red was found to be 13.81 mg L⁻¹min⁻¹. The synthesized catalyst was proved to be effective where degradation was completed within 30 min. Hence the catalyst Co²⁺-TiO₂ prepared in presence of gemini surfactant had exhibited the highest photocatalytic activity.

Hamadian and coworkers³⁵ synthesized undoped and Co doped TiO₂ nanoparticles by sol-gel method with sonication. From their study, it was concluded that the doping of Co in the TiO₂ decreases the grain size. This doping shows the red shift (the absorption to higher wavelength) and lowers the surface area. The photocatalytic activity of these catalyst was studied on the methyl orange under UV and visible irradiation. In their study, it was revealed that the activity of the catalyst was higher in the presence of the undoped TiO₂ than the cobalt doped TiO₂. Among the doped samples, the 1.0% Co doped TiO₂ catalyst exhibited the highest photocatalytic activity under UV irradiation while the presence of 0.5% of cobalt doped TiO₂ exhibited the highest activity under visible irradiation.

Mugundan and coworkers³⁶ synthesized undoped and 4, 8, 12 and 16 % cobalt doped TiO₂ nanoparticles by sol-gel method at room temperature. In their study it was revealed that the all doped samples show increased particle size as compared to undoped catalyst. The band gap energies values of the TiO₂ and Co doped TiO₂ was in between 3.58 and 3.93 eV. The catalyst also shows the photoluminescence emission spectra that shows the creation of new luminescent centers.

3.4 Copper (Cu) doped

Wong and coworkers³⁷ synthesized Cu-doped TiO₂ by photo-deposition and sol-gel methods. These catalysts were used to study the photocatalytic activities of the organic dye, Orange-II. From this study it was revealed that the Cu-doped TiO₂ catalysts prepared by the photo-deposition method showed enhanced photocatalytic activity than the catalysts synthesized by the sol-gel method. It was revealed that the 1% Cu doped TiO₂ showed the best performance. The catalyst has removed the color completely. By using this catalyst, about 99% of the total organic carbon (TOC) was removed after 150-min of reaction. It was found that, more than 1% amount of Cu doped with the TiO₂ by the photo-deposition method, there was a decrease in the photocatalytic activities of the catalyst.

Yoong and coworkers²² synthesized a 10% Cu-Glycerol complex TiO₂ (10CuGT) photocatalyst by the complex-precipitation method. This catalyst showed better activity than the other wet impregnation catalyst. SEM analysis predicts that there were a relatively uniform dispersion of CuO on TiO₂. This uniform dispersion of the dopant confirms the fast charge transfer from TiO₂ to CuO.

Khairy and coworkers³⁸ investigated the photocatalytic activities Cu and Zn doped TiO₂ nanoparticles for the chemical oxygen demand (COD) and degradation of methyl orange. The XRD results of these nanoparticles has confirmed the formation of the anatase phase for the TiO₂ nanoparticles. Their crystallite sizes were in the range of 9–21 nm. The growth of the TiO₂ anatase phase was due to the small crystallite size and doping ions (Cu and Zn) that inhibited any phase transformation. From the optical study, they found that the doping ions lead to an increase in the absorption edge wavelength, and a decrease in the band gap energy of TiO₂ nanoparticles. The doped TiO₂ nanoparticles in general showed higher photocatalytic activities than the pure ones. Based on measured chemical oxygen demand (COD) values, they conclude that the Cu doped TiO₂ nanoparticles showed the best photocatalytic activity. The catalytic degradation rate under both UV and visible radiation decreases according was in the order of: Cu/TiO₂ > Zn/TiO₂ > TiO₂ pure. The improved photocatalytic activity under light irradiation is due to incorporation of doping metal ions that diminished the electron-hole recombination. The kinetics of photo-degradation of methyl orange followed first order reaction. The Cu/TiO₂ showed the highest rate constant and the highest efficiency in chemical oxygen demand (COD) determination.

3.5 Nickel (Ni) doped

Ganesh and coworkers³⁹ prepared Ni (Ni = 0.1 to 10%)-doped TiO₂ nanomaterials as well as thin films by a coprecipitation and sol-gel dip coating method, respectively. The TiO₂ nanomaterial prepared from TiCl₄ by a coprecipitation method exists in the form of crystal pure rutile phase, while the Ni doped TiO₂ powders up to 6% was exist mainly in anatase phase. It was found that 0.1% Ni is enough to transform TiO₂ from rutile to anatase phase and to enhance its BET surface area. The dopant Ni reduces its bandgap energy significantly and absorb energy from a major portion of visible light. The 9 % Ni-doped TiO₂ nanomaterial show maximum absorption of the visible light at a wavelength 448 nm, while the 10 % doping shows maximum absorption at a wavelength 840 nm. Among all Ni-doped TiO₂ nanomaterials, 0.1% Ni doped TiO₂ shows the highest photocurrent and the 0.5% Ni doped TiO₂ shows the highest photocatalytic activity. The photocatalytic activities of methylene blue (MB) were studied under simulated solar light. The characterization study revealed that Ni as dopant stabilizes TiO₂ in the form of anatase phase and lowers its bandgap energy. The photocurrent ability as well as the photocatalytic activity of TiO₂ have been improved with doping of Ni in TiO₂. Langmuir-Hinshelwood first-order rate constant relationship was followed by the Ni-doped TiO₂ powders in the photocatalytic degradation reactions.

Hermawan and Worker⁴⁰ has prepared Ni(II) doped TiO₂ nanomaterial by sol-gel method. The concentration of Ni(II) plays a noteworthy role in the spectra absorption, crystal structure, particle size and band edge absorption. From their study it was concluded that the addition of 5% Ni/TiO₂ increases the absorbance and the particle size, while decreases the bandgap energy.

Manzoor and coworkers¹⁰ synthesized the undoped and Ni doped TiO₂ nanoparticles by sol-gel method. Titanium butoxide and nickel nitrate were used as precursors and methanol as a solvent. The Ni doped TiO₂ samples with doping concentration at 5, 10, 15, and 20% were prepared. The XRD study of the

undoped and doped material shows tetragonal system with anatase phase. In this research it was found that the particle size was decreased with increasing amount of Ni in TiO₂. The blue shift was found with small contents of Ni-TiO₂ while the red shift was found higher contents of Ni-TiO₂, that enhanced the bandgap with doping. Ni-doped TiO₂ is a magnetic semiconductor. Hence, it has many applications in spintronics, electron transporting layer, oxygen sensor and UV light absorber in photovoltaics.

3.6 Chromium (Cr) doped:

Inturi and coworkers⁴¹ observed that the flame spray pyrolysis (FSP) Cr-TiO₂ has superior activity when compared with the other given synthesis methods (Sol-Gel and Co-Precipitation). The photocatalytic activity of the synthesized catalysts was studied for photocatalytic degradation of 4-chlorophenol under visible light (400–800 nm) conditions. It was found that the flame spray pyrolysis Cr-TiO₂ has superior photocatalytic activity to other synthesis methods. The sol-gel and co-precipitation produce the anatase phase only of the material. In their study, it was found that the higher concentration of the Cr (IV) in the materials that is a noteworthy factor for the improving in the photocatalytic activity of the materials. They observed the development of the photocatalytic activity, with an addition of the Si, as a support. It also improves the surface area and structural stability.

Zhu and co-workers⁴² has synthesized the Cr³⁺-doped titanium dioxide (anatase) photocatalysts by combine methods of sol-gel process with hydrothermal treatment. The photocatalytic activity study of the Cr doped TiO₂ was performed on an aqueous solution of the azoic dye XRG. This study has done both under UV and visible light irradiation. In their study they found that the Cr-TiO₂ shows a good ability for absorbing the visible light for the degradation of the XRG. Chromium ions doping improves the photocatalytic activity of the catalyst under both UV light irradiation and visible light.

4. Inner Transition doped

Lanthanide (La³⁺) doped:

EI-Bahy and his colleagues⁴³ were synthesized Lanthanide ions doped TiO₂ nanoparticles by sol-gel method. They used La³⁺, Nd³⁺, Sm³⁺, Eu³⁺, Gd³⁺ and Yb³⁺ as the dopants. Direct Blue dye (DB53) was used to study the photocatalytic activity. The XRD data showed a characteristic anatase phase but the lanthanide phase was not detected on Lanthanide ions/TiO₂. The results analysis of this research shown that the Gd³⁺/TiO₂ has lowest particle size, bandgap, highest surface area and pore volume (V_p) too. Lanthanide ions improve the photocatalytic activity to some extent as compared with undoped TiO₂. It was found that, Gd³⁺/TiO₂ was the most active photocatalyst among all the doped TiO₂. The photocatalytic degradation occur at the optimum conditions. The illumination time was 40min, pH~4, photocatalyst loading-0.3 g/L and 100ppm DB53. This photocatalyst has 100% dye removal efficiency.

Liang and colleagues⁴⁴ prepared Undoped TiO₂ and erbium ion-doped TiO₂ (Er³⁺-TiO₂) photocatalysts by the sol-gel method. From the XRD data it was found that the doping of the erbium ion could increase the thermal stability of TiO₂ and inhibit the growth of the crystallite size. DRS results

shown that the optical absorption slightly shifted to red direction due to erbium ion. In aqueous suspension of undoped TiO₂ or Er³⁺ doped TiO₂ catalysts; the adsorption isotherm, oxidation and mineralization of orange I were studied. Er³⁺-TiO₂ photocatalyst had advanced adsorption equilibrium constants and improved adsorption capacity than undoped TiO₂. The Er³⁺-TiO₂ catalyst adsorption equilibrium constants (K_a) were approximately double those of pure TiO₂. The Er³⁺ doped TiO₂ catalyst's overall adsorption efficiency (Q_{max}) was greater than that of pure TiO₂. The 2.0 percent Er³⁺-doped TiO₂ catalyst gained the highest Q_{max} and K_a values among the catalysts Er³⁺-TiO₂. The results indicated that the degradation and mineralisation of orange I with the Er³⁺-TiO₂ catalyst was more effective than with pure TiO₂ under both UV and visible light. The highest degradation rate was achieved by optimal dosage of erbium ion at 1.5 per cent. The transitions of 4f electrons of Er³⁺ and the red shift of the optical absorption edge of TiO₂ by Er³⁺ doping were useful to enhance photocatalytic activity under visible light.

5. Codoped

Devi and coworkers⁴⁵ synthesized anatase TiO₂ doped with divalent transition metal ions like Mn²⁺, Ni²⁺ and Zn²⁺. Photocatalytic activity of these catalyst has been studied in the degradation of Aniline Blue under UV/solar light. In their study, they found that the dopant Ni²⁺ and Zn²⁺ metal ions stabilize the anatase phase while Mn²⁺ promotes phase transformation to rutile as a result of formation of surface oxygen vacancies. In this study, they found the enhanced activity of Mn²⁺(0.06 at.%)–TiO₂ both under UV/solar light because of: (I) anatase and rutile in their bi-crystalline framework shows synergistic effect; (II) smaller crystallite size that enable the effective interparticle electron transfer; (III) half-filled electronic structure of Mn²⁺, that assists as shallow trap for the charge carriers.

Kiriakidis and coworkers⁴⁶ synthesized Mn, Co and Mn-Co doped TiO₂ ternary and quaternary semiconducting materials by the co-precipitation method, with particle sizes in the range between 35-40 nm. These catalysts were used in the degradation of methylene blue under visible light irradiation. In their study, it was found that these materials show a red shift. Depending on the type of the dopant and concentration, these materials show absorption in the visible region. These materials found to be more effective photocatalysts in visible light. In the case of Co and Mn/Co dopants, they found an extra sub-band gap. Under visible light, the photocatalytic efficiencies of doped catalyst were found to be significantly higher. They concluded that these doped catalysts were useful for the degradation of organic pollutants and industrial wastewater treatment than the conventional undoped TiO₂.

Kudo and coworkers⁴⁷ has studied the effects of doping of metal cations into wide band gap semiconductor photocatalysts. They study the effect of doping effect on the morphology, visible light response, and photocatalytic performance of the catalysts. Doping of lanthanide and alkaline earth ions has improved the activity of a NaTaO₃ photocatalyst for water splitting. Lanthanum was found to be the most effective dopant. However, metal cation doping in ZnS, TiO₂, and SrTiO₃ provided visible light responses for hydrogen(H₂) or oxygen(O₂) evolution from aqueous solutions containing of sacrificial

reagents. Co-doping was effective to compensate charge unbalance brought by doping of transition metal cations, resulting in the improvement of visible light response for photocatalytic reactions.

Future Scope:

This literature review will be beneficial for research scholars those who are interested in the field of synthesis pure and metal doped titanium dioxide.

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