# SYNTHESIS OF $TiO_2$ NANOTUBES FOR DRUG RELEASE STUDY

A Dissertation for

PHY-651 Dissertation

Credits: 16

Submitted in partial fulfillment of Masters Degree

M.Sc in Physics (Solid State Physics)

Goa University

in the subject of Physics

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April 2024

Examined by:

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## DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation / Internship report entitled, "SYNTHESIS OF $TiO_2$ NANOTUBES FOR DRUG RELEASE STUDY" is based on the results of investigations carried out by me in the Physics Discipline at the School of Physical and Applied Sciences, Goa University under the Supervision of Dr.RAJESHKUMAR SHANKAR HYAM and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will be not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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# COMPLETION CERTIFICATE

This is to certify that the dissertation report "SYNTHESIS OF $TiO_2$ NANOTUBES FOR DRUG RELEASE STUDY" is a bonafide work carried out by Mr. Hrutvij Nishakant Gaunekar under my supervision in partial fulfilment of the requirements for the award of the degree of M.Sc in Physics at the School of Physical and Applied Sciences, Goa University.

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# ACKNOWLEDGEMENT

I would like thank my guide Mr.RajeshKumar Shankar Hyam as well as Goa University for providing me this golden opportunity to work on this wonderful project on the topic "Synthesis of $TiO_2$ nanotubes for drug release study" which also helped me in doing my research for my project work.

Secondly I would like to thank Miss.Neha Phadte for helping throughout the project and in operating the instruments.I would also like to thank Mrs.Supriya RajeshKumar Hyam for providing us with chemicals and guidance for drug release studies.

Lastly I would like to thank my family and friends for their constant love and support.

# ABSTRACT

In this project we have synthesised nanotubes of titanium dioxide by anodization technique.The time parameter was varied for different samples and few were heat treated to obtain crystalline phase.Characterization was done to study phases and band gap of materials.Finally drug release analysis was done using this samples by studying the absorption of the medium using UV-Vis spectroscopy.

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# Chapter 1

# Introduction

Conventional drug delivery methods has been failing lately for few drugs due to poor targeting or drug degradation before reaching the target tissue or body part.To deal with this issue there has been a need for a newer mechanism for drug release in body.There are many new methods being investigated.One of them is drug release using $TiO_2$ nanotubes.This mechanism can be used to target specific tissues, organs or cancer cells.There are many methods for formation of nanotubes of $TiO_2$.In this project we have focused on $TiO_2$ nanotubes synthesis using anodization technique and its use for drug release.[18]

### 1.0.1 Drug Release studies

Drug release analysis is studying the release of drug from the substrate over a specific period. This provides valuable information about release of drug from the substrate. In this analysis a drug is loaded on to the surface of materials through different techniques like vacuum assisted Physisorpition. The loaded drug is measured and drug release is studied by using PBS or Hanks solution. The drug releases is studied by observing the change in absorbance of medium using UV-Vis spectroscopy. [17] There are many characterization for studying the substrate with loaded drug. The drug release using nanotubes can be controlled in many ways.[11] a) Structural modification The nanotubes diameter and length can be varied by varying different parameters during formation of nanotubes. These changes affects the drug released from nanotubes. b) Surface modifications Heat treating the sample will change surface properties of materials. It might be change in hydrophobicity, hydrophilicity etc. This will change the interaction with drug and release of it. c) Polymer coating There are many biodegradable polymer coatings such as chitosan

which can be coated on surface of nanotubes to control the drug release. d) Tuning nanotubes opening By techniques like plasma polymerisation pore opening of nanotubes can be adjusted. e) Silver loading on surface Silver exhibit photo-thermal properties, basically it absorbs light and generate heat which triggers the drug release from sample.[18]

### 1.0.2 Titanium Dioxide for drug release study

The materials which are used for implanting in body and drug release should be chosen carefully as there are many problems faced by metals implanted in body. Bones and tissues have different elastic modulus(measurement of materials stiffness or rigidity). Sometimes metals have high modulus compared to that of natural bone or hard tissue which causes stress shielding. If implanted material has higher modulus then the load taken by it will increase compared to load taken by natural bone. Since the load taken by implant is high the surrounding bone will experience less load which will result in reduced stress and mechanical movement. Due to this the bone will experience reduction in bone density and potential bone resorption. The outcome of this will be loosening of implants leading to failure and complication.Bone tissue sometimes dies due to lack of blood supply known as bone necrosis. In bones wear debris induced bone necrosis takes place. Overtime due to movement and friction between joints and implants might lead to wearing of implants releasing debris into surrounding bones and tissues. When the debris comes in contact with natural bone it triggers inflammatory reactions. Immune system considers this as foreign particles causing activation of inflammatory cells to fight this debris. This might affect surrounding bones and can lead to formation of osteoclasts, cells which are responsible for breakdown of bone. Finally this leads to death of bone cells and tissues leading to infections and gangrene like diseases. We use titanium metal to deal with all this problems as titanium widely used and most researched material. Titanium material has higher Biocompatbility, good mechanical strength and good wear resistance.[4] Titanium when comes in contact with surrounding environment it forms oxide layer. This oxide layer formation can be controlled by different methods like anodization. Using this methods we can also get different types of nanostructures on the surface of the oxide layer which helps in improving biocompatibility by enhancing surface contact area with cells.[14] This nanostructures can simultaneously be used for drug release. This drug release can be controlled by different coatings and varying parameters of nanostructures which increases

chances of metals being accepted by body.$TiO_2$ nanotubes has very good stability, which is very important for drug delivery system and ensuring controlled drug release.$TiO_2$ exhibit good photo-catalytic activity under UV light irradiation.This property is used for photo-dynamic therapy in which light activated compounds are used to generate reactive oxygen species for killing cancer cells.[18]

### 1.0.3 Methods for synthesis of nanotubes

There are many methods which can be used for formation of nanotubes of titanium metals.Methods like Hydrothermal method, sol-gel method and anodization is used for formation of titanium nanotubes.

Hydrothermal method:-

This method is used to produce crystals or nanoparticles.In this method metal in powder formed is mixed with water or any preferred solvent and kept in autoclave.This autoclave is kept in furnace.Autoclave is a container which can withstand high temperature and pressure.The high temperature and pressure increases the solubility of material in solvent also known as supersaturation.At critical temperature the molecules come together and forms nuclei.The crystal growth starts around this nucleus.As crystal grows they attain specific crystallographic structures.After that crystals are allowed to cool.Like this we get desired crystals or nanoparticles.[5]

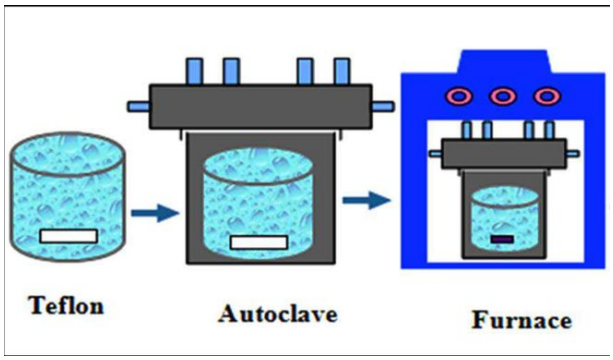


Figure 1.1: Hydrothermal technique

Sol-Gel method:-

It is a chemical process. It consists of two parts sol which is colloidal derived by dispersing the particles in desired solvent to obtain colloidal solution.A gel is formed when the solvent from sol begin to evaporate and the particles or ions left behind begins to join together in a continuous network.The gel is then dried using oven.This dried gel is then

grinded and powder is obtained.

Anodization method:-

Anodization was first discovered in 1923. Anodization or anodic oxidation is a well-established surface modification technique. In this method thick layer of oxide is grown on the surface of metal. This is an electrolytic process that is used to enhance the sur-


Figure 1.2: Anodization setup

face properties of materials. The anodization setup consists of a power supply, anode, cathode, and electrolyte solution. A power source is used to provide the electrical current necessary for an electrochemical process to occur. A power source is a very essential component of anodization as it allows for vary parameters like voltage and current density which changes the thickness and quality of the oxide layer formed on the surface of the metal. The power supply ensures that electrical current is distributed evenly which helps to form an oxide layer of uniform thickness. A cathode is a terminal where a reduction reaction occurs which is gain of electrons. The materials mostly used as cathode are materials like Platinum. Platinum is highly inert, and stable, and has a higher corrosion resistance, ensuring reduction reaction occurs smoothly without any interference. An anode is a terminal where an oxidation reaction occurs which is the loss of electrons. The materials which need to be oxidized are used as anode. The common metals which are used are Aluminum and Titanium and electrolyte solution should be chosen in such a way that it has good conductivity because this decides the flow of ions and complete

the cycle. In anodization the metal is immersed in an electrolytic solution and external supply is given. The metal acts like an anode and other electrodes act as cathode. There will be a flow of electrons from the anode to the cathode. At the anode, an Oxidation reaction occurs leading to the formation of an oxide layer on the surface of metal. As oxidation progresses, layer of oxide is formed gradually, similarly at cathode there will be Reduction reaction as this process is completed the flow of electrons will be complete.[8]

### 1.0.4 Phosphate buffer saline and solvent

Phosphate buffer saline (PBS) is cost effective and very useful solution used for drug release analysis. The phosphate buffer saline consists of Sodium Chloride(NaCl), Sodium Phosphate(Na2HPO4), Potassium Chloride(KCl) and Potassium dihydrogen Phosphate (KH2PO4). This materials are mixed together with distill water and the pH is maintained in solution. The concentration of ions in solution can be varied as per the requirement. Phosphate buffer saline is very biocompatible. It is also non-toxic making it a good contender for drug release and biocompatibility studies. The ionic strength is similar to that of body fluids and hence it can be used to simulate body conditions. The salts in solution also balance the osmotic pressure. The pH of solution is approx. 7.4 similar to that of body. Since it contains phosphate salts , it acts as a buffer. This means they resist the change in pH during the drug release study and maintains the pH throughout the experiment giving better idea of drug release without any interference. Phosphate buffer saline doesn't react with drug mostly since it is non reactive in nature. The solution also depends on the choice of solvent used to mix with phosphate buffer saline. Ethanol and methanol are the mostly used solvents. Main reason being that the drugs which are not soluble in phosphate buffer saline or which are hydrophobic can dissolve easily in phosphate buffer saline and solvent mixture. Hence it increases the solubility of solution. Ethanol and methanol also helps in drug release studies and the mixture of this solutions can be easily studied using UV spectroscopy for studying the absorbance. [12]

### 1.0.5 Curcumin

Curcumin is a naturally occurring compound. It is derived from rhizomes of turmeric plant. It has very vibrant yellow color and has been used in ayurvedic and general medicine for more then 100 years. Curcumin has been found to be having antibacterial, anti-inflammatory, anticancer, antioxidant properties. This properties has made this drug which is used in mostly all household to be interest of research. The problem with using curcumin is that it has poor aqueous solubility and low bioavailibity. Curcumin doesn't dissolve completely in water which leads to poor absorption and reduces its effectiveness when its taken from oral dosage. Further when the curcumin comes in contact with enzymes and microbial degradation in gastrointestinal tract its concentration gets reduced in the bloodstream and the required tissue where it needs to activate. To overcome this problems we can use nanotubes to deliver the drugs directly to the required parts of the body. There are many methods which can be used to slow down or increase the drug release in the body as per the required conditions. The slow release is used to maintain the drug at particular levels in body. The fast release is used to deal with inflammatory conditions. Hence curcumin was used as the preferred drug for studying drug release using nanotubes.[6]

# Chapter 2

# Sample preparation

## 2.1 Formation of $TiO_2$ Nanostructures using anodization

### 2.1.1 Electrolyte preparation

For preparation of electrolyte glycerol, ammonium fluoride and water was used.Glycerol concentration of 49.5 wt% was taken.Ammonium fluoride (0.25 wt%) and distilled water (0.5 wt%) was sonicated together for 15 minutes.Glycerol and the sonicated solution was mixed together.This solution was sonicated together for half hour.

### 2.1.2 Ti foil Preparation

Titanium foil of 0.5mm thickness and ( cm * cm) dimension was used for the experiments.The Titanium foil was first washed with water and soap followed by sonication in Ethanol and Acetone for 15 minutes in each solution.

The foils were then chemically etched in acid solution.A solution of 1 part Hydrofluoric acid , 4 parts Nitric acid and 5 parts distilled water was prepared for etching.The foil was kept for etching in solution for 1 minute until the surface became shiny.The samples were then washed with distill Water and used for anodization.

### 2.1.3 ANODIZATION

The electrolyte solution was transferred to the 100ml beaker.The two electrode setup was used for the anodization.Platinum was used as cathode.The platinum was washed with water and soap and was sonicated in distilled water for 5 minutes.At anode the cleaned titanium foil was used.A DC supply was used for the experiment.Multimeter was connected in series to DC supply and two electrode system.The electrodes were dipped in electrolyte solution covering approximately $1cm^2$ area.A fixed amount of voltage was given for all the samples and the time parameter was varied.Current was measured on multimeter throughout the experiment and was noted down at different interval of time.The distance between the electrodes was also measured.

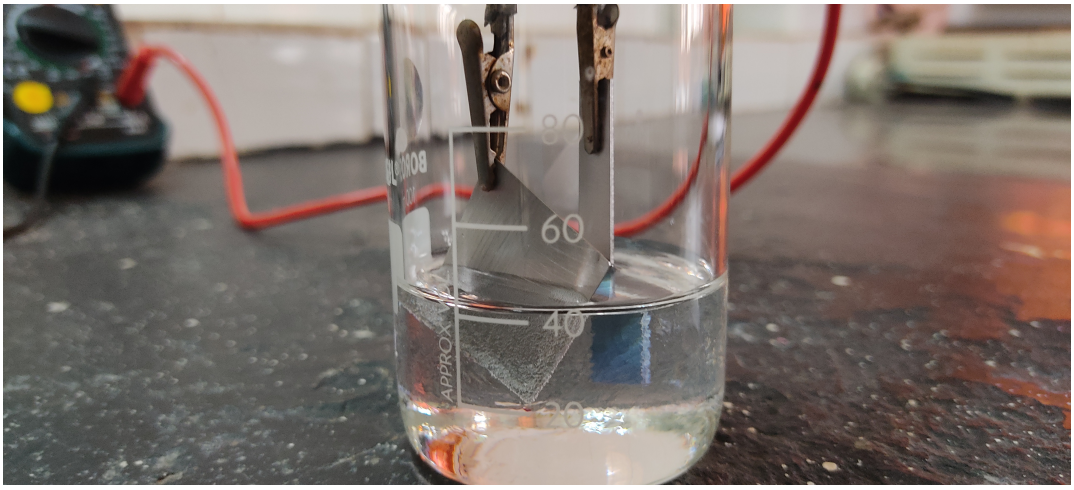


Figure 2.1: Anodization

**Sample Preparations for Drug release analysis and Biocompatibility studies:-**

4 anodized samples and 3 anodized samples were prepared for the Drug release studies and Biocompatibility studies respectively.Voltage of 60V and electrode distance of 2cm was kept fixed for all the samples.

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**For drug release analysis**

| SAMPLE | TIME | VOLTAGE | AREA ANODIZED |
|---|---|---|---|
| 1 | 4 Hours | 60V | 1.20 $cm^2$ |
| 2 | 4 Hours | 60V | 1.08 $cm^2$ |
| 3 | 8 Hours | 60V | 0.84 $cm^2$ |
| 4 | 8 Hours | 60V | 1.19 $cm^2$ |

Table 2.1: Conditions for anodization

Sample 2 and 4 were annealed.

**For biocompatibility studies**

| SAMPLE | TIME | VOLTAGE | AREA ANODIZED |
|---|---|---|---|
| 1 | 1 Hour | 60V | 1.60 $cm^2$ |
| 2 | 2 Hours | 60V | 1.47 $cm^2$ |
| 3 | 4 Hours | 60V | 1.56 $cm^2$ |

Table 2.2: Conditions for anodization

All the samples were annealed.

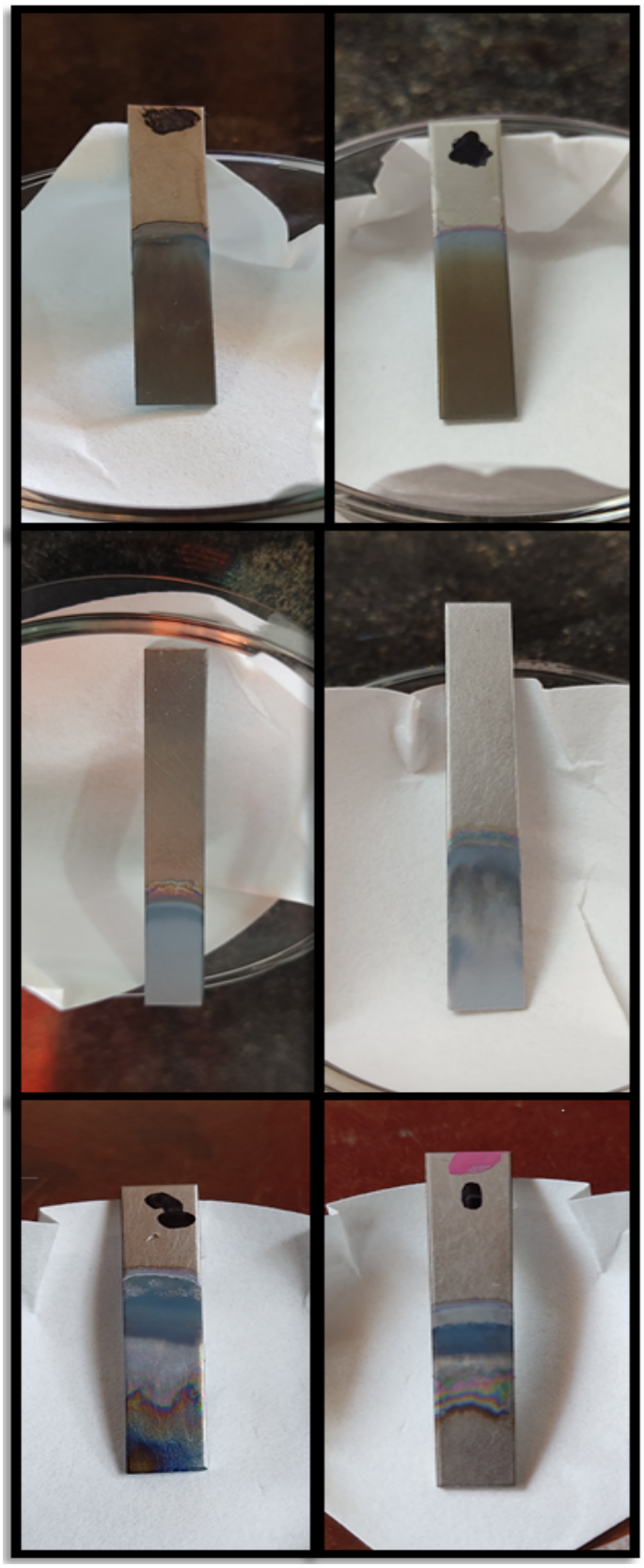

Figure 2.2: Anodized samples

**Annealing of sample:-**

Samples were annealed to obtain crystalline sample(Anatase phase).Carbolite furnace was used.Samples were kept in furnace for 1 hour at $450^0$C temperature with $2^0$ C per minute rise.Sample were allowed to cool at room temperature and were used for the characterization and applicative studies.


Figure 2.3: Furnace for annealing sample

## 2.2 Drug release studies

### 2.2.1 Drug loading on to the sample

Curcumin was used as the drug for loading.26mg of curcumin was mixed with 4ml of ethanol.The solution was then sonicated for 15 minutes.The sample was kept in petridish and 2ml of solution was dropcasted on the anodized surface only.The sample was then transferred to dessicator.It was kept in vacuum condition for half hour with vacuum being broken every 10 minutes.The same procedure was repeated again to maximize the loading on the sample.The sample was then washed with ethanol and water mixture (50-50 v%) to remove any excess curcumin from the surface.The sample were kept in vacuum for drying for 1 hour.

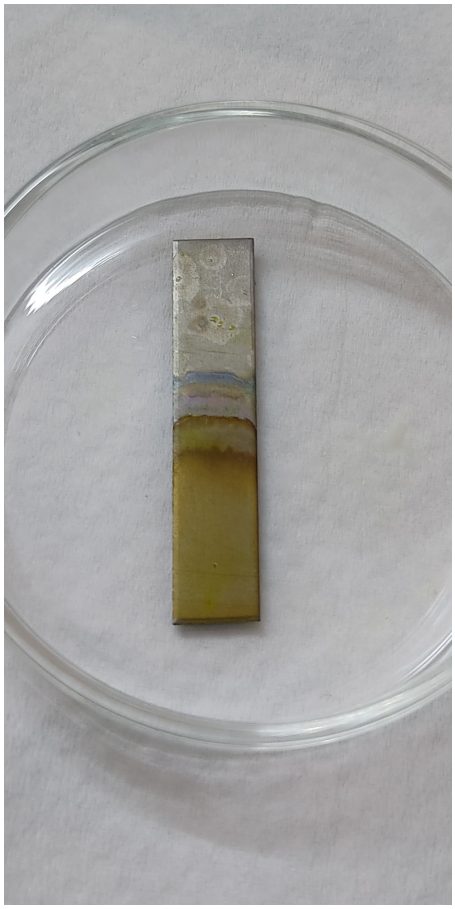

Figure 2.4: Drug loaded sample

### 2.2.2 Preparation of mixture of Phosphate buffer saline and methanol solution

For the drug release study Phosphate buffer saline was used.for preparation of solution 96.4% of PBS solution 1 and 3.6% of PBS solution was mixed together.Total 50ml of solution was prepared which consisted of 50% methanol and 50% PBS solution.Methanol was added to the PBS solution very slowly drop wise with proper care.Care was taken that no precipitate was formed.This solution was used to keep samples.

### 2.2.3 Experimental setup

The Phosphate buffer saline and methanol mixture was transferred to 100 ml beaker.The beaker was kept on constant stirring at 650 rpm and constant temperature of $37^0$C.The only area of sample which was drug loaded was kept dipped in the solution.The drug release was studied by studying the absorbance of solution through UV spectroscopy.Before experiment was started baseline of Phosphate buffer saline and methanol was taken.After the dipping of sample the initial (0 min) reading was taken followed by taking reading at every 30 minutes.The experiment was carried out for 4 hours and drug release was observed using UV spectroscopy.

Figure 2.5: Drug release study setup

# Chapter 3

# Characterization Technique

## 3.1 UV-Vis spectroscopy

Ultraviolet and visible spectroscopy is spectroscopy of dealing with recording of absorption of radiations in ultraviolet and visible regions of electromagnetic spectrum The ultraviolet region is from 10 to 400 nm.[3] This can be further classified as ultraviolet (quartz) region (200 to 400 nm) and far vacuum ultraviolet region (10-200 nm) The visible region is from 400 to 800 nm.

The absorption of electromagnetic radiations of UV-Vis regions includes excitation of an electron from a lower to higher molecular orbital level. The source of UV-visible absorption spectra is a molecule's electronic transitions. Electronic transitions occur when valence electrons are promoted from the ground state to the excited state, which has a higher energy level. excitation's, which result from radiation energy absorbed in the electromagnetic spectrum's UV visible areas. Due to the quantization of different molecular energy levels, an electronic excitation can only happen when a certain wavelength of radiation is absorbed, matching the necessary energy.

Molecular orbital theory states that a molecule is excited when it absorbs light in the UV-visible range because its electrons are promoted from a bonding (n) orbital to an anti bonding orbital.

A UV visible spectrophotometer records Spectrum as plot of wavelength versus intensity of absorption in terms of absorbance.

In the UV-vis spectroscopy the intensity of transmitted radiation is compared with incident UV Visible radiation. The instrument consists of radiation source, monochromator,

detector, amplifier.

a) Radiation source

For UV hydrogen discharge lamp is the most commonly used source of radiation. For visible region a tungsten filament lamp is used.

b) Monochromator

It disperses the radiation obtained from source in different wavelengths.This are divided by beam divider into two beams of equal intensity.

c) Detectors

These are used to detect the change in absorbance of incident and absorbed radiation.

## 3.2 Raman Spectroscopy

When monochromatic light is made incident on the surface of materials the radiations get scattered.It will have 3 type of frequency,a)Rayleigh scattering:-The scattered light will have same frequency as that of original frequency.b)Raman scattering:-The scattered light will have two different frequency.It was first discovered by DR.C.V.Raman in 1928.[1]

a)Stokes Raman scattering :- Frequency of scattered photon is less then the frequency of incident photon.This happens when the electron absorbs the energy.

b)Anti-stokes Raman scattering:-When the frequency of scattered photon is greater then incident photon due to released energy of electron.

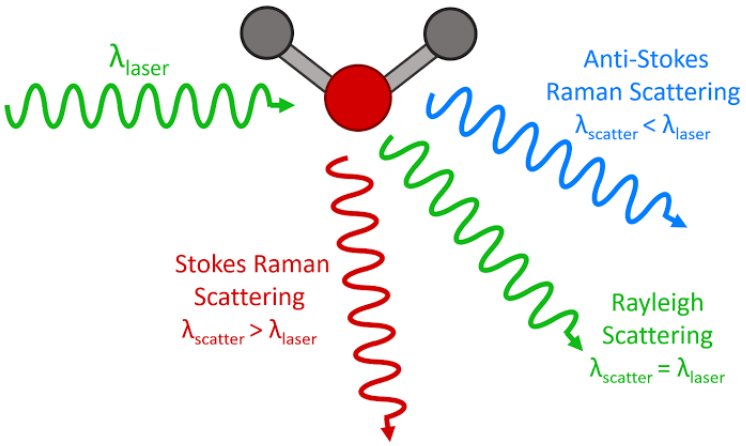


Figure 3.1: Scattering of incident rays

Raman spectroscopy is technique used to study vibrational, rotational and low fre-

quency modes in system. When material is irradiated with monochromatic light such as laser (neodymium doped yttrium aluminium garnet laser, krypton ion laser, helium ion laser, diode lasers, argon ion lasers).Some of incident photons are scattered in-elastically or elastically. In inelastic scattering a photon is first absorbed and then scattered. The energy difference between the incident and scattered photons corresponds to the energy of molecular vibrations in materials. Basically Raman scattering occurs when incident photons interact with the materials vibrational modes resulting in energy shifts in scattered photons. Raman spectra provide information about molecular vibrations, chemical compositions, crystal structures and phase transitions in material. The difference in energy between incident and scattered photons is known as Raman shift measured in wavenumber. Peaks in a Raman spectrum corresponds to specific vibrational modes in material.

a) Molecular vibrations

Raman spectra display peaks corresponding to the vibrational modes of molecules in material. Each peak represents a specific vibrational motion such as stretching, bending or twisting of chemical bonds. The positions of Raman peaks are characteristics of the types of chemical bonds present in material allowing for identification of functional groups and molecular structures.

b) Crystal structures

Raman spectra can be used to determine crystal symmetry of material. Different crystal structures exhibit distinct raman spectra due to unique vibrational modes. By analysing the Raman peaks and their intensities we can determine the crystal phase of materials such as Anatase or Rutile based on characteristic vibration of each phase. c) Chemical compositions

Raman spectra provide information about the types of chemical bonds present in a material. The presence of specific functional groups or elements can be identified based on the vibrational modes observed in the spectrum. Analysis of chemical compositions can be done by relating peak intensities with the concentration of specific components in a sample.

d) Phase transitions

Raman spectroscopy is very sensitive to phase transition and changes in crystal structures of materials. Shift in peak positions, change in peak intensity or few peaks appearance or disappearance can indicate phase transition. [13]

# Chapter 4

# Results and analysis

## 4.1 Anodization and formation of nanotubes

### 4.1.1 Formation of nanotubes

When the voltage is applied between the Titanium(anode) and Platinum plate(cathode) in electrolyte solution it will help to initiate the electrochemical process which leads to formation of nanotubes of titanium oxide.The applied voltage creates an electric field which facilitate the flow of ions in the electrolyte solution.

Applying high voltage can lead to faster oxidation of titanium.Also it increases the flow of ions in electrolyte solution which results in rapid growth of Titanium dioxide nanotubes. There are many reactions that take place during anodization process.

Stage 1:-Field assisted oxidation of Titanium.

In first stage compact oxide layer will be formed due to applied voltage.when the voltage is applied through the system the water molecules present in the electrolyte solution will decompose near metals. this produces $O^{2-}$ ions and $H^{+}$ ions. The $O^{2-}$ ions travel through the electrolyte solution due to applied voltage. This will react with Titanium to form oxide layer on the surface of Titanium.

The reactions are as follows:-

$$H_2O \rightarrow 2H^{+} + O^{2-}$$

$$Ti + 2O^{2-} \rightarrow TiO_2 + 4e^{-}$$

Stage 2:-Field assisted dissolution of oxide layer.

when voltage is applied an electric field is generated. The titanium and oxygen bond

experiences polarization under influence of electric field. This will weaken the titanium and oxygen bond leading to dissolution of oxide layer.

Stage 3:-Chemical dissolution of oxide layer

Since the bonds are weak the fluoride ions present in the electrolyte solution will react with titanium dioxide to form soluble Hexaflourotitanium complexes ($TiF_6^2-$) that dissolves into the electrolyte solution.

$$TiO_2 + 6F^- + 4H^+ \rightarrow TiF_6^{2-} + H_2O$$

while the free oxygen anions will move towards the oxide metal interface. This oxygen molecules will react with the titanium to form oxide layer again.As thus process continues formation of oxide and dissolution of oxide layer deepens the pores and nanopores will transfer into nanotubes of oxide layer.[9] [16]

From this theory we can confirm that through anodization technique we have obtained nanotubes of titanium dioxide. In our case we had kept fixed voltage of 60 V and electrode

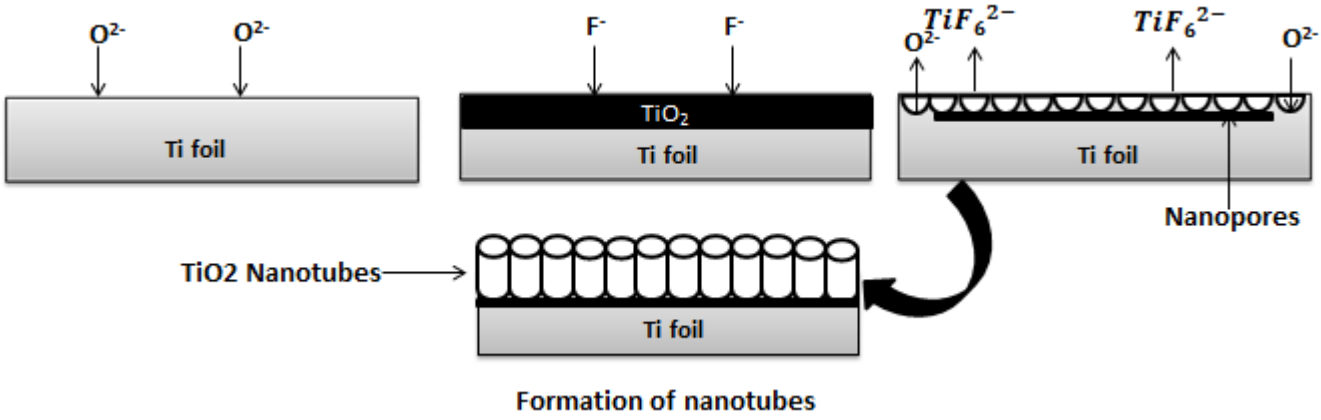


Figure 4.1: Nanotubes on surface of Titanium
[16]

distance of 2 cm.The time of anodization was varied to obtain different morphology of nanotubes.

### 4.1.2 Growth mechanism

The current was measured with respect to time and area anodized was measured.Current density was calculated and graph of current density on y-axis and Time on x-axis was plotted. Above graph shows steady drop and rise and then constant current density w.r.t time.

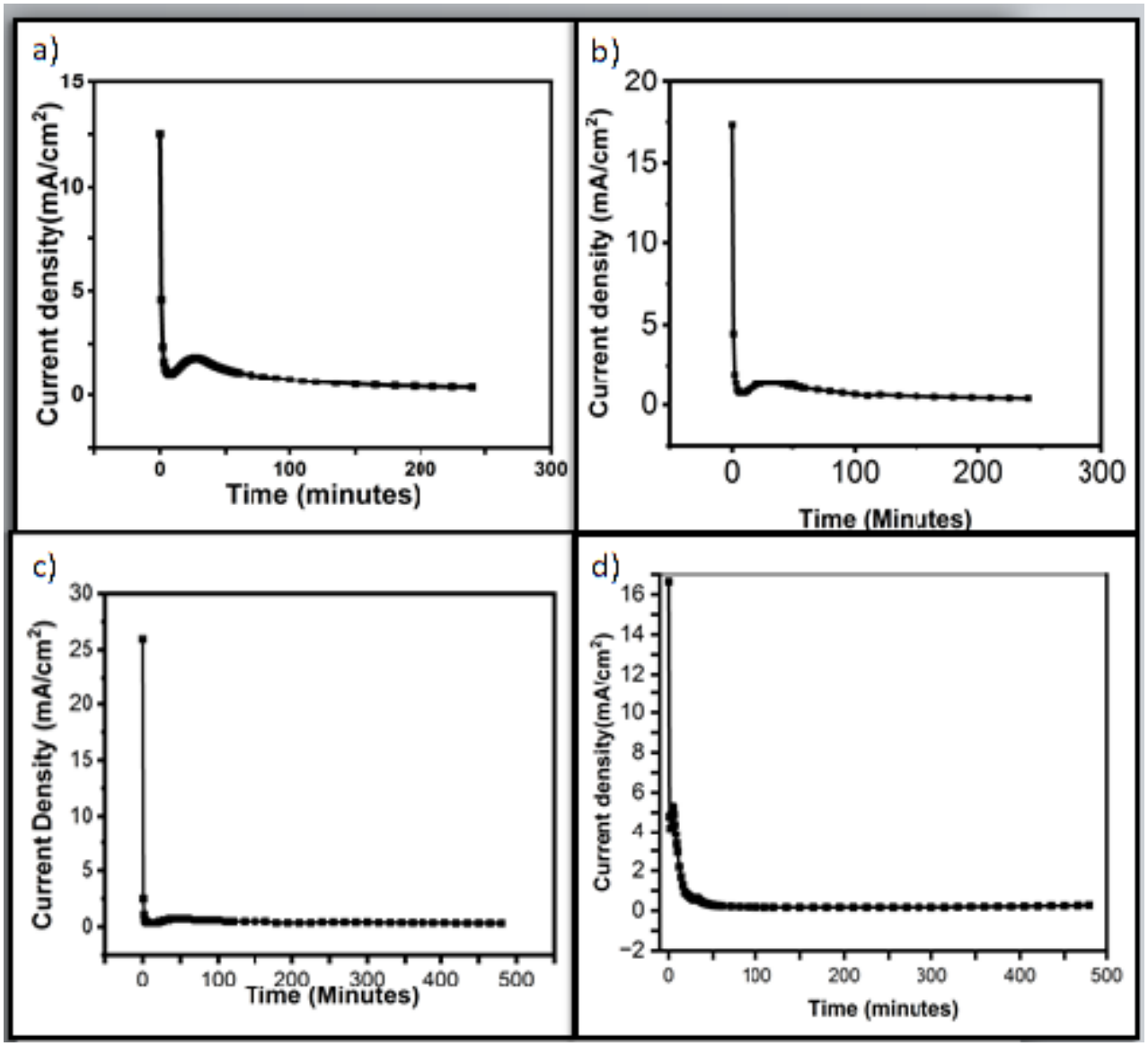


Figure 4.2: Graph of current density vs time a)sample 1 b)sample 2 c)sample 3 d)sample 4

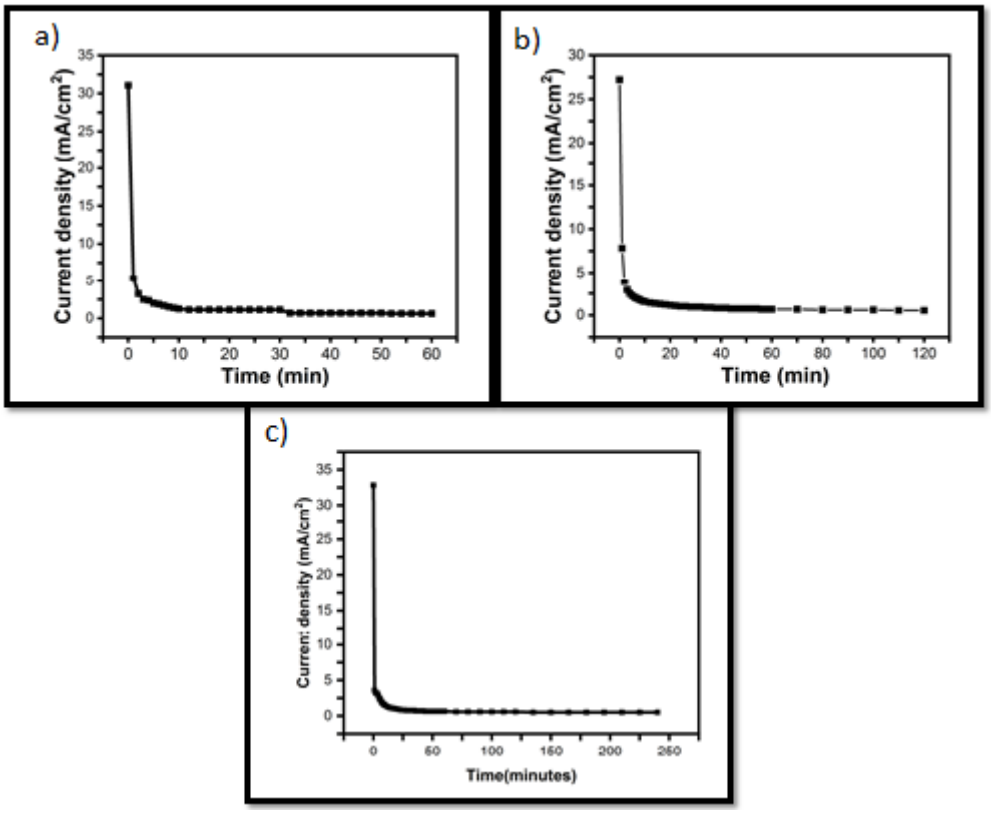


Figure 4.3: Graph of current density vs time a)sample 5 b)sample 6 c)sample 7

Graph analysis

The graphs can be divided into three regions Region 1:-

In this region initially the current density is very high. This is due to the clean titanium surface. There will be no oxide layer on the surface. The flow of current is this time period is very high. As soon as oxygen reacts with the metal oxide layer will be formed this will obstruct the flow of electrons and the current will start to drop down and hence we see steady drop in current density. Region 2:-

In this region we again see rise in current density after steady drop. The reason behind this is because of dissolution of oxide layer as metal oxide starts reacting with fluoride ions present in electrolyte solution. As the oxide layer dissolution takes place the current density increases. Region 3:-

In this region we see current density becomes steady and constant. This is the the point at which it attains equilibrium is achieved. The dissolution of and formation of oxide layer occurs at same rate. Hence the flow of current gets constant. [7]

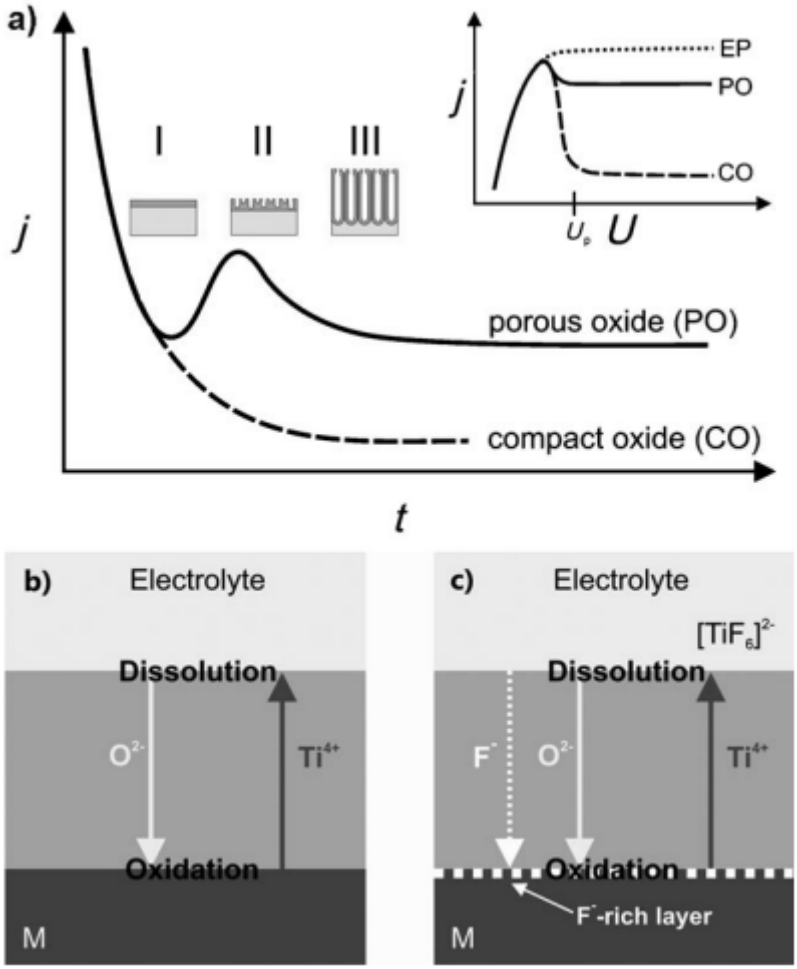


Figure 4.4: a)graph showing different regions of current density vs time plot b) and c) shows the dissolution mechanism

[7]

## 4.2 Annealing of sample

Annealing is done to obtain anatase phase crystalline Titanium dioxide.Amorphous titanium dioxide lacks long range order in its atomic structure.Atoms will be arranged randomly.Titanium and oxygen bond length can be different.In anatase phase it will have tetragonal crystal structure.It will have long range order atomic structure.The titanium and oxygen bond length and angles are well defined.

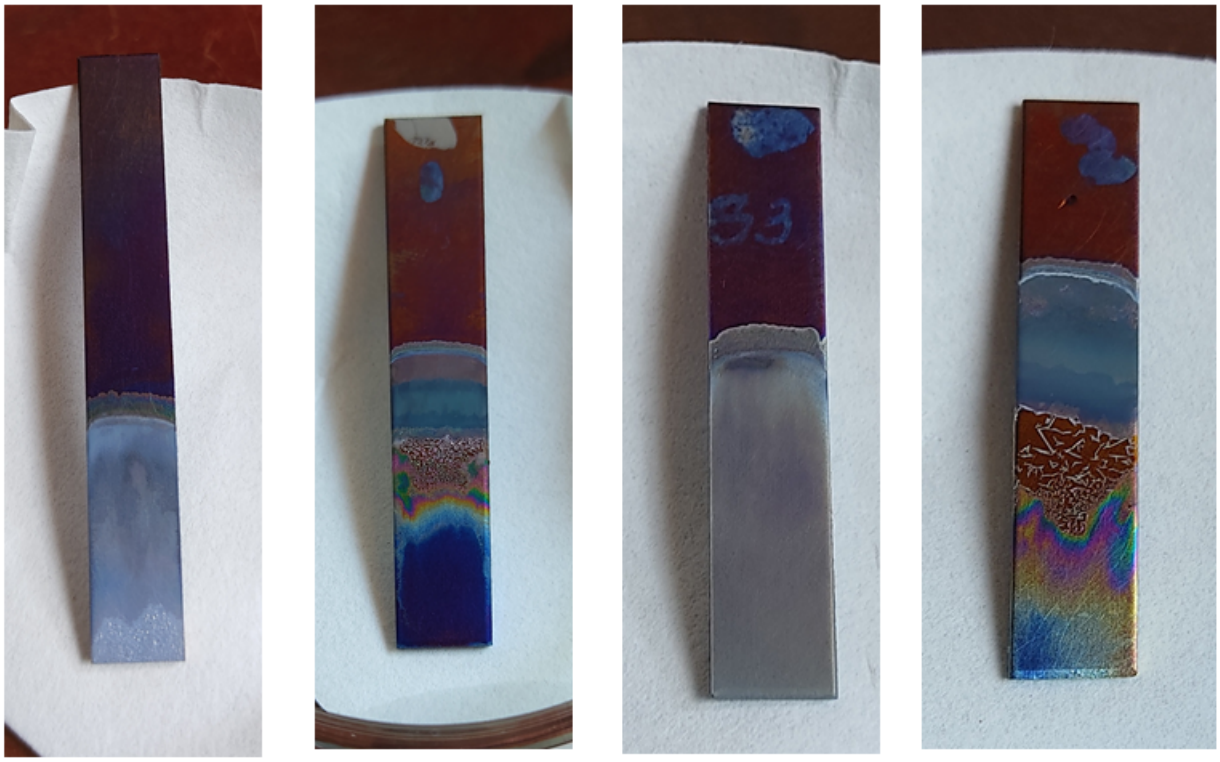


Figure 4.5: Annealed sample

### 4.2.1 Surface color of Titanium dioxide

There are wide variety of color of titanium dioxide.It can be bronze, yellow, purple, blue etc. Titanium dioxide ($TiO_2$) exhibits different colors due to a phenomenon known as interference colors. When $TiO_2$is anodized, a transparent oxide film is formed on the metal surface. This oxide film has the ability to reflect, refract, and absorb light. When white light falls on the oxide film, it is partly reflected and partly transmitted. The transmitted light reaching the metal surface is partly absorbed and largely reflected back to the oxide film, undergoing multiple reflections and phase shifts. The thickness of the oxide film determines the degree of absorption and multiple reflection, leading to the

interference of light waves and the production of colored light. The relationship between the thickness of the oxide film and its resistance to the passage of current also plays a role in controlling the colors produced, as different thicknesses of the oxide film will interact with light in unique ways at different voltages. When Anodization takes place the ions will flow in electrolyte solution. This ions are responsible for oxide formation. On anode sometimes there is release of oxygen gas and this bubbles might stick to the surface of titanium plate obstructing the reactions taking place. This leads to formation of oxide layer of different thickness and length on different regions of titanium substrate. This might result in different color formation of oxide layer.[2]

## 4.3 UV-Vis absorption study to determining band gap

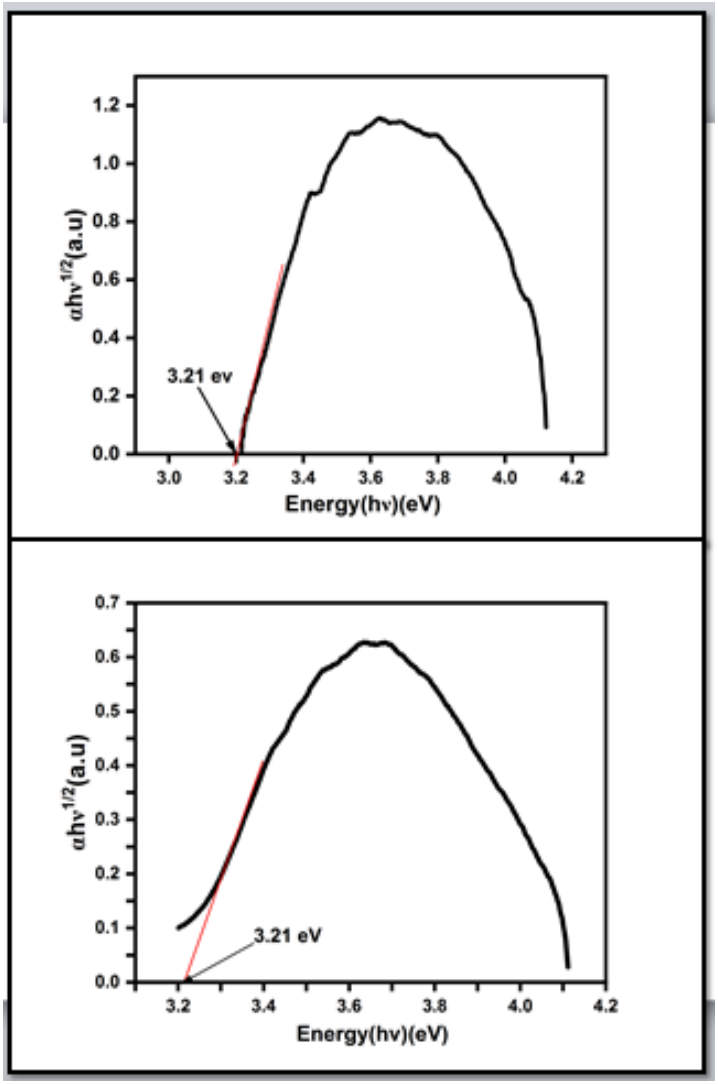


Figure 4.6: Energy vs absorbance coefficient plot

Tauc and Davis Mott relation is given as

$$(\alpha hv)^n = K(hv - Eg)$$

$\alpha$=Absorption coefficient

h=Planks constant

v=Frequency of incident light

K=Energy independent constant

Eg=Energy band gap

This equation is used to determine the optical band gap energy of materials using UV-Vis spectroscopy.In this equation (n) represents the nature of transition.

For direct band gap,n=2

For indirect band gap,n=0.5

Direct band gap:-At the same momentum values maximum of valence band and minimum of conduction occurs. For electron to have transition from valence band to conduction band it doesn't need to go any change in momentum.

Indirect band gap:-In this maximum of conduction band and minimum of valence band occurs at different momentum values. For electron to have transition from. valence band to conduction band it first requires energy for the change in momentum in addition to energy band gap.Then only it can have transition

In tauc plot method, energy is plotted on x-axis and $\alpha hv$ on y-axis. A tangent is drawn on curve where ($\alpha = 0$). The point where it touches x-axis is optical band gap energy of materials.

In our data we had wavelength and absorbance.

a) To convert wavelength to energy Max plank equation is used to calculate energy from wavelength.

$Eg = hv$

where, h= Planks constant

$v$= Frequency of incident photon

$v = \frac{c}{\lambda}$ c=speed of light

$\lambda$=wavelength

We get,

$Eg = \frac{hc}{\lambda}$

$Eg = \frac{6.62*10^{-34}Js*2.999*10^{8}ms^{-1}}{\lambda}$

$Eg = \frac{19.85*10^{26}Jm}{\lambda}$

Converting joules to electron volt

$1eV = 1.602 * 10^{-19}J$

we get,

$Eg = \frac{19.85*10^{26}eVm}{1.602*10^{-19}*\lambda}$

$Eg = \frac{1240*10^{-9}eVm}{\lambda}$

$Eg = \frac{1240eVnm}{\lambda}$

b)Absorption coefficient

we have, $\alpha hv$ Using Beer Lambert law

$I = I_0 e^{-\alpha L}$

I=Intensity of transmitted light

$I_0$=Intensity of incident light

$\frac{I}{I_0} = e^{-\alpha L}$

Taking log on both sides we get,

$log\frac{I}{I_0} = loge^{-\alpha L}$

$log\frac{I_0}{I} = \alpha L log(e)$

$A = \alpha L log(e)$

,A= absorption

$\alpha = \frac{A}{log(e)L}$ $\alpha = \frac{A}{0.4343*L}$

For standard cuvette,L=1cm

we get, $\alpha = 2.303 * Absorbance$

$\alpha hv = (2.303 * Absorbance * Energy)^n$

After plotting,linear portion of graph is determined which represents absorption behavior near band gap. By extrapolating the linear portion of graph, photon energy at which absorption coefficient becomes zero can be determined. The linear portion is where absorption coefficient increases sharply with increasing energy indicating onset of transitions across the band gap. In our case Titanium dioxide has indirect band gap. Hence using the above formula we were able to calculate the energy band gap through UV-Vis spectroscopy. Energy band gap was almost determined at 3.2 eV for crystalline samples.[15]

## 4.4 Raman Spectroscopy

Raman spectroscopy was done in order to determine the phases of anodized sample with annealed and not annealed.

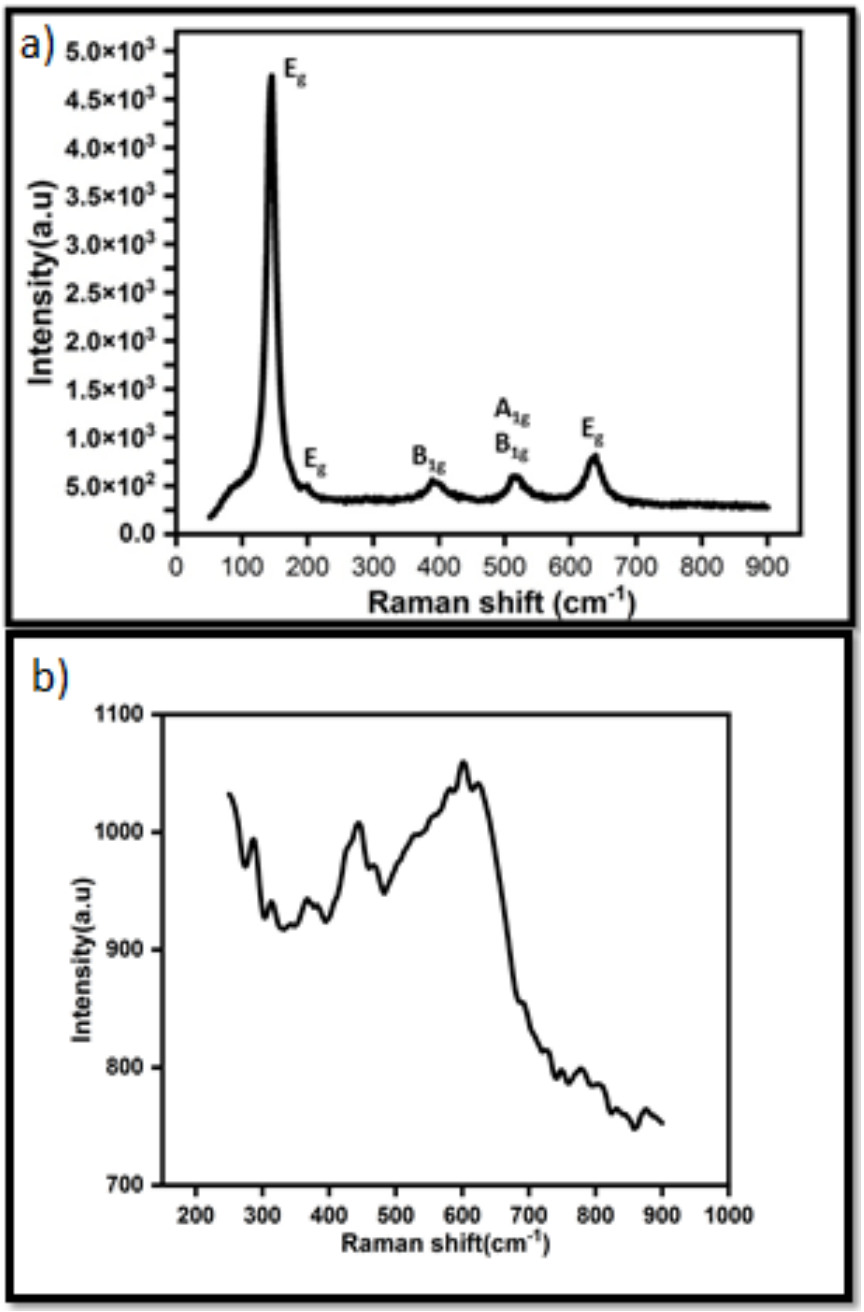


Figure 4.7: a)Raman spectra for crystalline sample, b)Raman spectra for amorphous sample

1)Crystalline sample

For crystalline sample as we can see we found the peaks at 144,199,394,515,635$cm^{-1}$.

a)at 144$cm^{-1} \rightarrow E_g$

This peak is related to symmetric stretching mode of O-Ti-O bond.

b)at 197 $cm^{-1} \rightarrow E_g$

This peak is related to symmetric stretching mode of O-Ti-O bond.

c)at 399$cm^{-1} \rightarrow B_{1g}$

This peak is related to symmetric O-Ti-O bond bending mode.

d)at 515$cm^{-1} \rightarrow A_{1g}$

This peak is related to anti-symmetric bending of Ti-O-Ti bond.

e)at 519$cm^{-1} \rightarrow B_{1g}$

This peak is related to symmetric O-Ti-O bond bending mode.

a)at 639$cm^{-1} \rightarrow E_g$

This peak is related to symmetric stretching mode of O-Ti-O bond.

From this we can say that after annealing we have obtained crystalline anatase phase.This was confirmed from reference paper.

[13] 2)Amorphous sample

From the spectra of amorphous sample we can say that we get random peaks at different positions confirming that what we had was amorphous sample.The two specific peaks were observed at around 460$cm^{-1}$ and 620$cm^{-1}$.This data was confirmed from reference paper.

## 4.5 Drug release analysis

### 4.5.1 Drug loading analysis

The amount of drug loaded was measured. Amorphous materials lacks long range order

| Samples | Weight of sample before loading (mg) | Weight of sample after loading (mg) | Amount of drug loaded (mg) | Area ($cm^2$) |
|---|---|---|---|---|
| 1 | 965.7 | 970.2 | 4.5 | 1.2 |
| 2 | 967.8 | 968.9 | 1.1 | 1.1 |
| 3 | 1129.8 | 1131.8 | 2 | 0.85 |
| 4 | 1291.5 | 1293.1 | 1.6 | 1.2 |

Figure 4.8: Amount of drug loaded on sample

which provides more free volume for drug molecules to diffuse.Amorphous phase exhibit higher surface areas and porosity increasing drug loading.Crystalline samples show lower drug loading as compared to the amorphous samples as they have ordered nature of crystal lattice.From our observation we can say that drug loading on amorphous samples is higher as compared to crystalline samples.

### 4.5.2 Drug release study

Drug release study was done for 4 hours by studying the absorbance of the medium.
Sample 1) and Sample 2) (4 hr Amorphous and Crystalline sample)
For sample 1 we see sudden rise in absorption after 30 minutes reading due to experimental error.0 and 30 minutes reading were taken by taking Methanol as baseline. For all other readings PBS and Methanol solution was used as baseline. We can conclude from the graph that for sample there is rise in absorption with respect to time suggesting that the drug was released from nanotubes. The absorption at 150 minutes is lower compared to 120 minutes. This might be due to evaporation taking place during the experiment. For sample 2 which is Crystalline sample we can see very high values of absorption Thus concludes that there was higher drug release from Crystalline sample as compared to Amorphous sample.From graph a) and c) we have conclusive evidence that drug release

is faster in Sample 2(crystalline sample) as compared to sample 1(Amorphous sample). Sample 3) and sample 4) (8 hr Amorphous and annealed sample)

For sample 3 there was very less drug release.The absorption was increasing with time but the release of drug was very slow. For sample 4 the drug released was the highest as it showed the highest absorption. The baseline for both experiments were PBS and methanol solution. Comparing both the graphs c) and d) we can say that Crystalline sample has the highest drug release compared to Amorphous sample.

From this graph we can conclude that crystalline samples has shown faster drug release as compared to amorphous samples. This property is very useful as they show different release rate. The curcumin absorption peak for all experiments were observed at 431 nm.

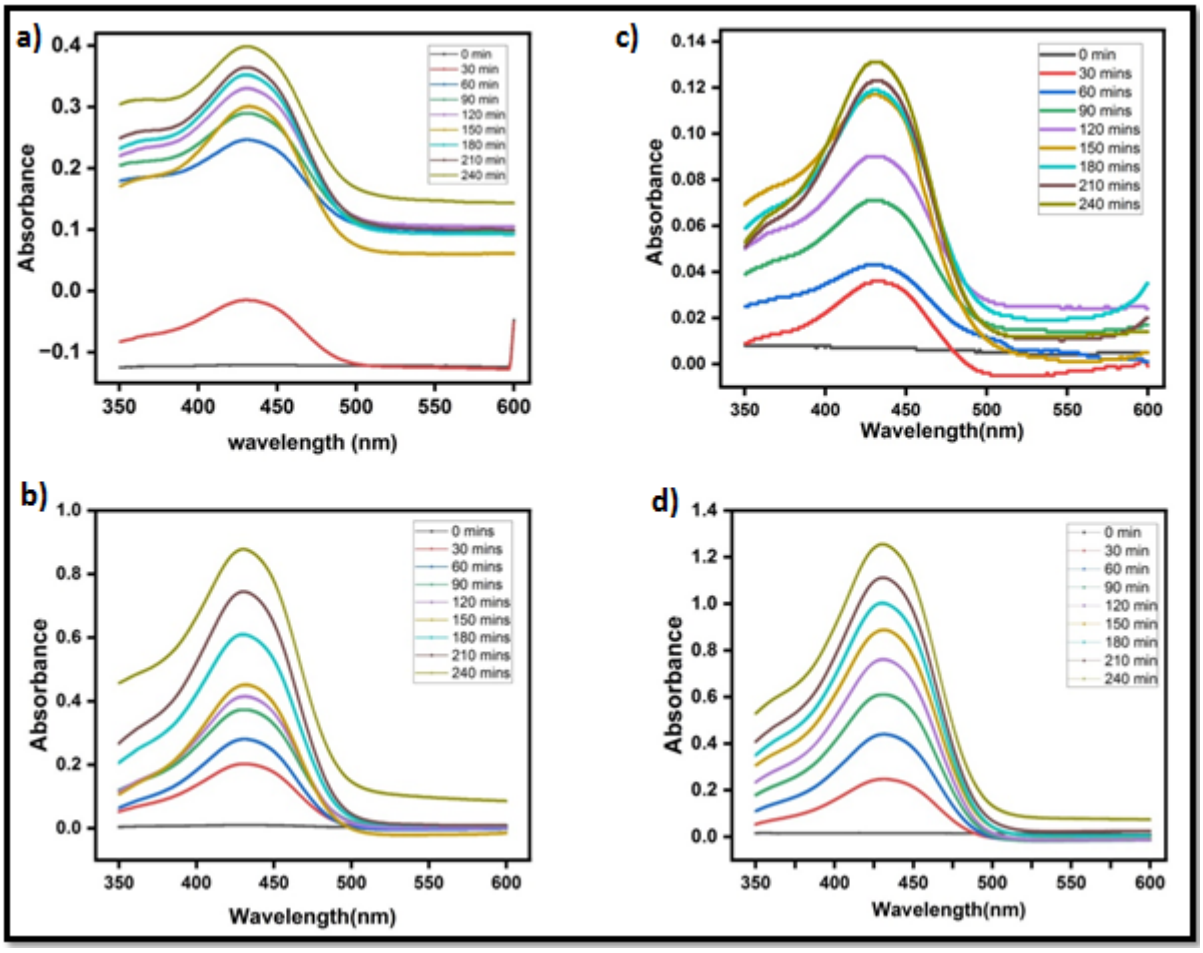


Figure 4.9: Graph of absorbance versus wavelength,a)sample 1 b)sample 2 c)sample 3 d) sample 4

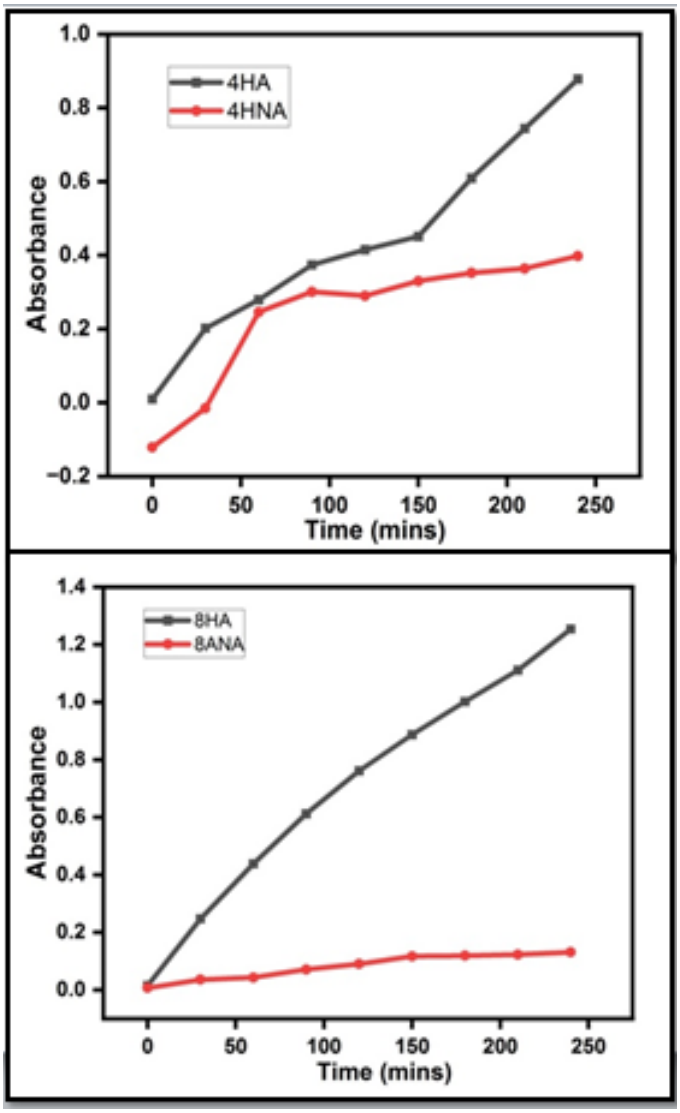


Figure 4.10: Comparison of absorbance w.r.t time for 4 hr amorphous and crystalline and 8 hr amorphous and crystalline sample

In the above graph we can notice that the drug release is higher in the crystalline samples compared to amorphous samples. This can be proved through Absorbance vs Time graph. This results are related to heat treatment of the samples. When samples are heat treated at certain temperature it increases the surface roughness. The roughness of surface increases the Hydrophilicity of surface.[10] The contact angle increases as the surface roughness decreases. Since the annealing process decreases the contact angle it increases the ability of solvent to penetrate Titanium Dioxide nanotubes.

## 4.6 Conclusion

From the results and analysis we can say that anodizationn technique can be used successfully to form nanotubes of Titanium dioxide.This samples were annealed to obtain different phases.Different phase formation was confirmed using different characterization technique.For different samples we were able to notice different amount of drug loading in nanotubes,hence this tells us that length and morphology of nanotubes and phases of materials affects the amount of drug getting loading in the samples.From drug release study of this samples we can conclude that amorphous samples and crystalline samples show different release rate of drugs.Depending upon this properties samples can be used for different applications in biomedical field.

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