A

Project Report on

“Growth of TiO_2 Nano-Coating for Futuristic Dentistry Applications”

Submitted to

DEPARTMENT OF ELECTRONICS
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'A' Grade
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DEPARTMENT OF ELECTRONICS

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CERTIFICATE

This is to certify that the project entitled "Growth of TiO_2 Nano-Coating for Futuristic Dentistry Applications" which is being submitted is the result of the work completed by **Miss. SWATI RAMAKANT LADHE,** student of Department of Electronics, Kavayatri Bahinabai Chaudhari North Maharashtra University, Jalgaon for the partial fulfillment of M.Sc. degree under the supervision and guidance of faculty and staff.

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Miss. SWATI RAMAKANT LADHE

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Dedicated

To

My

Parents, Teachers

Abstract

This abstract presents a study on the growth and application of TiO_2 nano-coating for futuristic dentistry. Titanium dioxide (TiO_2) nanoparticles exhibit exceptional biocompatibility, high mechanical strength, and antimicrobial properties, making them an ideal candidate for dental applications. The aim of this research is to develop a novel method for growing TiO_2 nano-coatings on dental surfaces to enhance their durability, aesthetics, and overall performance. The growth of TiO_2 nano-coating will be achieved using a combination of chemical vapor deposition (CVD) and atomic layer deposition (ALD) techniques.

CVD will enable the controlled deposition of a thin TiO_2 film on dental substrates, while ALD will provide precise control over the thickness and composition of the coating. Various deposition parameters, including temperature, precursor concentration, and deposition time, will be optimized to achieve the desired coating properties. The potential benefits of TiO_2 nano-coating in dentistry are significant. The enhanced durability of dental restorations and implants can improve their longevity, reducing the need for frequent replacements.

The antimicrobial properties of TiO_2 nano-coatings can inhibit the growth of oral bacteria, minimizing the risk of dental infections. Additionally, the aesthetic appeal of dental prosthetics can be improved by achieving a natural tooth-like appearance with the TiO_2 nano-coating. In conclusion, the growth of TiO_2 nano-coating holds great promise for futuristic dentistry. This research aims to develop a reliable and efficient method for depositing TiO_2 coatings on dental surfaces, exploring their potential in improving durability, aesthetics, and antimicrobial properties. The findings of this study will contribute to the advancement of dental materials and technologies, paving the way for innovative and improved dental treatments in the future.

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1.Introduction

1.1] Introduction:-

In recent years, nanotechnology has emerged as a promising field with numerous applications in various industries, including dentistry. Among the various nano materials, titanium dioxide (TiO_2) nano-coating has gained significant attention due to its exceptional properties and potential applications in futuristic dentistry. TiO_2 is a versatile compound that exhibits excellent biocompatibility, antimicrobial activity, and unique optical properties, making it an ideal candidate for dental applications.

Traditionally, dental materials have been limited to metals, ceramics, and polymers. However, these materials often lack the desired properties for optimal dental care, such as resistance to bacterial growth, durability, and esthetics. The advent of TiO_2 nano-coating has opened new possibilities in the field of dentistry by providing enhanced properties and performance.

One of the primary advantages of TiO_2 nano-coating is its antimicrobial activity. TiO_2 nanoparticles possess photo catalytic properties, which means they can generate reactive oxygen species (ROS) upon exposure to ultraviolet (UV) light. These ROS can effectively kill bacteria, viruses, and fungi, reducing the risk of infections and improving oral health. Moreover, TiO_2 nano-coating can inhibit the formation of plaque, preventing dental caries and gum diseases.

Furthermore, TiO_2 nano-coating exhibits excellent biocompatibility with oral tissues. When applied as a thin layer on dental implants or prostheses, it promotes osseo integration, the process by which bone fuses with the implant surface, ensuring long-term stability and success of the dental restoration. The biocompatibility of TiO_2 nano-coating also reduces the risk of allergic reactions or adverse tissue responses, making it a safe choice for patients.

In addition to its antimicrobial and biocompatible properties, TiO_2 nano-coating offers aesthetic benefits. Its unique optical properties allow for the fabrication of dental restorations with natural translucency and color matching to the patient's teeth. This makes TiO_2 nano-coating an excellent choice for dental crowns, bridges, and veneers, providing patients with aesthetically pleasing and durable solutions.

1.2] What is TiO_2?

TiO_2 is the chemical formula for titanium dioxide, a naturally occurring mineral that is commonly used as a white pigment in paints, coatings, plastics, and other industrial applications. It is also used as a food additive, in sunscreen, and in various other consumer products. TiO_2 is known for its high refractive index, opacity, and UV resistance.

1.2.1] Applications of TiO_2 in dentistry:

Titanium dioxide (TiO_2) has several applications in dentistry. Here are some common uses of TiO_2 in the field:

a) **Dental Implants:** Titanium dioxide is often used as a coating material for dental implants. The TiO_2 coating helps improve the biocompatibility of the implant surface, promoting better integration with the surrounding bone tissue (osseo integration). This enhances the stability and longevity of dental implants.

b) **Dental Restorations:** TiO_2 is used in dental restorative materials, such as composite resin or dental cements. It is added to these materials to enhance their mechanical properties, such as strength and wear resistance. TiO_2 particles can also provide a white color to dental restorations, improving aesthetics.

c) **Dental Whitening Products**: Titanium dioxide nanoparticles are sometimes used in tooth whitening products. They can act as a catalyst when activated by light, helping to accelerate the breakdown of tooth stains and discolorations. TiO_2 nanoparticles may be incorporated into whitening gels, toothpaste, or other dental products.

d) **Denture Base Materials:** TiO_2 can be incorporated into denture base materials, such as acrylic resins. It provides a white color and opacity, improving the esthetics of dentures. Additionally, TiO_2 can enhance the strength and durability of denture base materials.

e) **Dental Adhesives:** Some dental adhesives contain TiO_2 as a filler material. The addition of TiO_2 particles can improve the mechanical properties of the adhesive, such as bond strength and wear resistance. This helps in achieving better adhesion between dental restorations and tooth structure.

1.2.2] Reasons of TiO_2 use in dentistry:

a) **Biocompatibility:** TiO_2 is highly biocompatible, meaning it is well-tolerated by the body and does not cause adverse reactions or toxicity. This makes it suitable for use in various dental applications, including implants and restorative materials.

b) **Aesthetics:** TiO_2 provides a white color and opacity, making it useful for improving the aesthetics of dental restorations. It is commonly used as a filler or pigment in dental materials, such as composites and cements, to match the natural color of teeth and enhance their appearance.

c) **Strength and Durability:** TiO_2 can improve the mechanical properties of dental materials. When added as a filler, it enhances the strength, hardness, and wear resistance of restorative materials, making them more durable and long-lasting.

d) **Osseo integration:** TiO_2 coatings on dental implants enhance their ability to integrate with the surrounding bone, a process known as osseo integration. The TiO_2 coating improves the biocompatibility of the implant surface, promoting successful integration and long-term stability of dental implants.

e) **Whitening Effect:** Titanium dioxide nanoparticles can act as photo catalysts when activated by light. This property is utilized in tooth whitening products, where TiO_2 nanoparticles accelerate the breakdown of tooth stains and discolorations, leading to a whitening effect.

f) **Frictional Force:** TiO_2-coated archwires are used in orthodontics to provide increased friction between the wire and brackets. This enhanced frictional force facilitates tooth movement during orthodontic treatment.

1.2.3] properties of TiO_2:

Titanium dioxide (TiO_2) possesses several properties that make it a valuable material in various applications. Here are some key properties of TiO_2:

a) **White Color and Opacity:** is a white, opaque material. It has a high refractive index, meaning it efficiently reflects and scatters light, resulting in its characteristic whiteness and opacity. This property makes TiO_2 desirable for applications where a bright white appearance is desired, such as in paints, coatings, and dental materials.

b) **Photo-catalytic Activity:** TiO_2 exhibits photo-catalytic activity when exposed to ultraviolet (UV) light. This property allows TiO_2 to facilitate chemical reactions by absorbing UV radiation and generating reactive oxygen species. It finds applications in areas such as self-cleaning surfaces, air and water purification, and photo-catalytic degradation of organic compounds.

c) **High Chemical Stability:** TiO_2 is chemically stable and resistant to corrosion. It does not react with water, acids, or most organic solvents, making it suitable for use in various environments. This stability contributes to its longevity and durability in applications such as coatings, pigments, and dental materials.

d) **High Melting Point:** TiO_2 has a high melting point of around 1,843 degrees Celsius (3,349 degrees Fahrenheit). This high melting point enables the use of TiO_2 in high-temperature applications, such as ceramics, refractories, and certain manufacturing processes.

e) **Photo stability:** TiO_2 is photo stable, meaning it does not undergo significant degradation or color changes when exposed to light. This property allows it to maintain its whiteness and stability over time, making it suitable for long-lasting applications such as architectural coatings and dental restorations.

f) **Electrical Insulator:** TiO_2 is an electrical insulator, meaning it does not conduct electricity. This property is beneficial in applications where electrical conductivity needs to be minimized, such as in electronic components and insulating coatings.

These properties contribute to the versatility and usefulness of TiO_2 in various industries, including paints, coatings, plastics, ceramics, cosmetics, and dentistry. It is important to note that the specific properties of TiO_2 can be further modified through various methods, such as particle size control, surface modifications, and doping, to suit specific application requirements.

1.3] What is dental implant?

A dental implant is a prosthetic device used to replace a missing tooth or multiple missing teeth. It is a surgical fixture that is placed in the jawbone, serving as an artificial tooth root. The dental implant provides a stable foundation for attaching dental restorations, such as crowns, bridges, or dentures, to restore the appearance, function, and stability of the missing teeth.

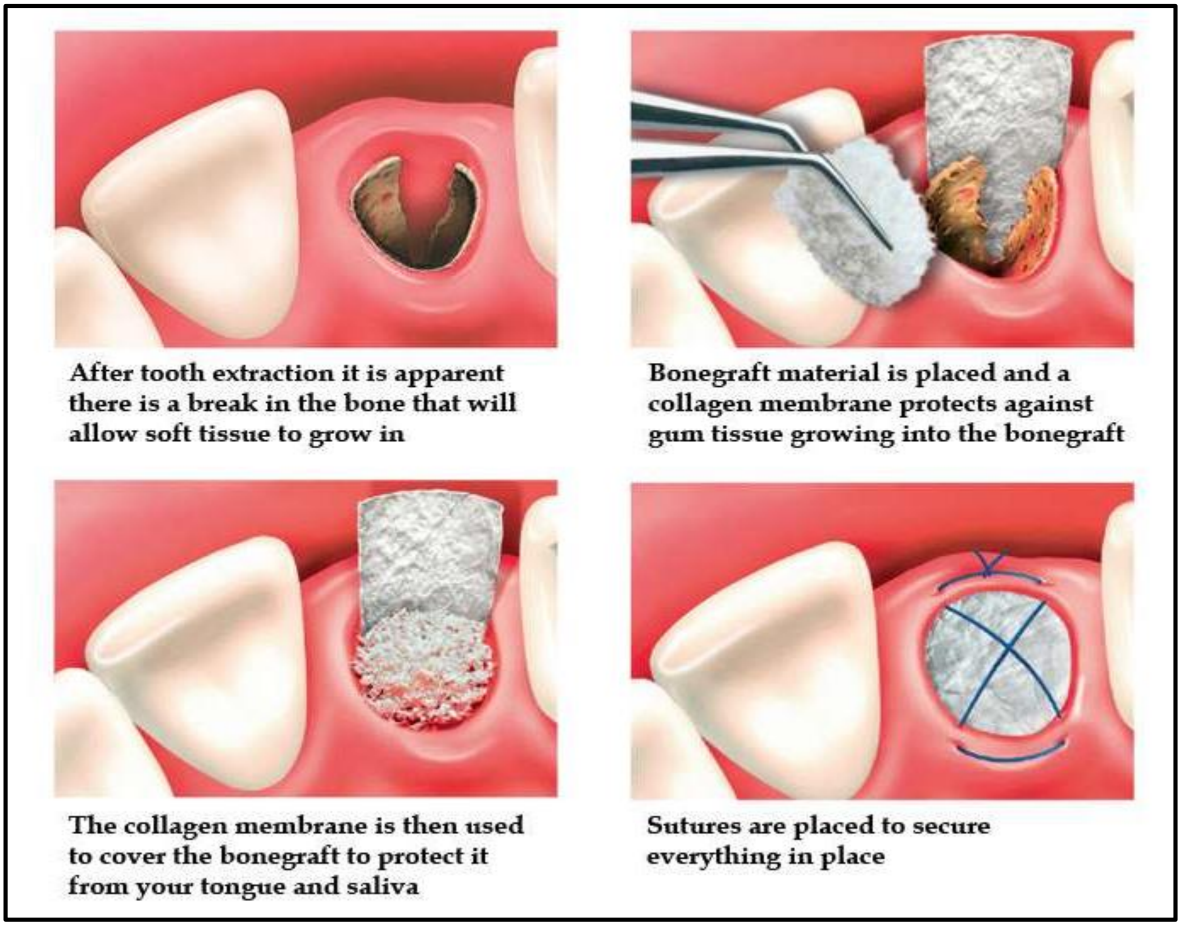

Fig.1 Dental implant of Collagen membrane

1.3.1] Components of a Dental Implant:

1] Implant Fixture: This is placed into the jawbone and integrates with the surrounding bone over time through a process called osseo integration.

2] Abutment: The abutment is a connector that attaches to the implant fixture, protruding above the gum line. It serves as a base for securing the dental restoration.

3] Dental Restoration: This refers to the artificial tooth or teeth that are attached to the implant. It can be a crown for a single missing tooth, a bridge for multiple missing teeth, or a denture for a full arch restoration.

1.3.2] The Dental Implant Process:

1] Evaluation and Planning: A thorough examination, including dental imaging and sometimes a cone-beam computed tomography (CBCT) scan, is conducted to assess the patient's oral health, bone structure, and suitability for implant placement. A treatment plan is then created based on the individual's needs.

2] Implant Placement: The implant fixture is surgically placed into the jawbone, typically under local anesthesia. In some cases, sedation or general anesthesia may be used for patient comfort. The gum tissue is then sutured over the implant, and a healing period of several months is allowed for osseo integration to occur.

3] Abutment Placement: Once osseo integration has taken place, a minor surgical procedure is performed to expose the implant and attach an abutment to it. The gum tissue is allowed to heal around the abutment for a short period.

4] Dental Restoration Placement: After the gum tissue has healed, impressions are taken, and a custom-made dental restoration (crown, bridge, or denture) is created to fit onto the abutment. The restoration is then attached to the abutment, completing the dental implant process.

2. Method of Synthesis

2.1] What is Synthesis Methods?

The synthesis of a solution refers to the process of preparing a solution by dissolving solute in a solvent to create a homogeneous mixture. It involves combining the solute and solvent in specific proportions to achieve a desired concentration or composition.

2.2] Types of Synthesis:

A) **Sol-Gel Method:** The sol-gel method is a versatile technique for synthesizing TiO_2 nanostructures. It involves the hydrolysis and condensation of titanium alkoxides, typically titanium isopropoxide or titanium tetrabutoxide, in the presence of a solvent and a catalyst. The reaction proceeds through the formation of a sol, followed by gelation and drying to obtain the desired TiO_2 nanostructures.

B) **Hydrothermal/Solvothermal Method:** In the hydrothermal/solvothermal method, TiO2 nanostructures are synthesized by heating a precursor solution under high-pressure conditions. The reaction is typically carried out in an autoclave at temperatures above 100°C. The choice of solvent and reaction conditions can influence the size, shape, and crystallinity of the TiO_2 nanostructures.

C) **Solvothermal Conversion of Precursors:** This method involves the conversion of preformed titanium precursors, such as titanium hydroxides or titanium salts, into TiO2 nanostructures under solvothermal conditions. The precursors are typically dissolved in a suitable solvent, and the reaction is carried out at elevated temperatures. This method allows for the synthesis of a wide range of TiO_2 nanostructures.

D) **Spray Pyrolysis:** Spray pyrolysis is a technique in which a precursor solution is atomized and sprayed onto a heated substrate. The precursor droplets undergo pyrolysis, resulting in the formation of TiO_2 nanostructures on the substrate. The size and morphology of the nanostructures can be controlled by adjusting the precursor concentration, spray parameters, and substrate temperature.

E) **Electrochemical Deposition:** Electrochemical deposition involves the electro deposition of TiO_2 nanostructures from an electrolyte solution containing titanium ions. The deposition process is controlled by applying a voltage between the electrode and the substrate. By adjusting the deposition parameters, such as voltage, temperature, and electrolyte composition, various TiO_2 nanostructures can be obtained.

A] What is sol-gel?

The sol-gel process is a more chemical method (wet chemical method) for the synthesis of various nanostructures, especially metal oxide nanoparticles. Solis a liquid state of colloidal solution whereas, gel is a solid or Semisolid state of colloidal solution.

- **Types of Sol-gel:**

  There are two generic variations of the sol-gel technique. One is called the colloidal method, the other is called the polymeric (or alkoxide) route. The differences between the two stem from the types of starting materials (precursors) that are used. Both routes involve suspending or dissolving the precursor(s) in a suitable liquid, usually water for the colloidal route and alcohol for the polymeric route. The precursor is then activated by the addition of an acid (such as hydrochloric acid) or a base (such as potassium hydroxide). The activated precursors then react together to form a network. The network grows and ages with time and temperature until it is the size of the container. At this point the viscosity of the liquid increases at an exponential rate until gelation occurs, that is, no more flow is observed.

- **Applications of Sol-gel:**

  The materials obtained from the sol-gel method are used in following fields:

  1. Optical
  2. Electronic
  3. Energy

4. surface engineering
5. biosensors
6. pharmaceutical
7. Separation technologies (such as chromatography).

2.3] Preparation of Sol-gel:

Experimental Procedure for synthesis of TiO_2:

At first, 15 mL of the aqueous solutions of titanium tetraisopropoxide (Ti[OCH(CH3)2]4 98+% purity, Fisher Scientific, USA) was slowly added to 30 mL of acetic acid (HCOOH 99.9% purity, Fisher Scientific, USA) in a three-neckflask, and the mixture was stirred for 5 minutes to avoid agglomeration. The mixture of deionized water (4 mL) and isopropanol (CH3CH(OH)CH3 99.9%, solution BDH Ltd Poole, England) (15 mL) was added dropwise to the solution, and then stirred vigorously for another 10 minutes. After complete mixing of the solution, 4 mL of nitric acid (HNO3) as added to the solution as stabilizer and the mixture further subjected to vigorous stirring for 20 minutes. TiO_2colloid in the nanometer range was formed from the hydrolysis and condensation reac-tions of titanium alkoxide precursors. In the presence of water, titanium alkox-ide hydrolyzed and subsequently polymerized to form a 3-dimensional TiO_2 network which was dispersed on the thoroughly cleaned borosilicate glass substrates, and spin at 4000 rpm for 30 seconds at room temperature. After the spin-coating step, the films were subjected to post thermal treatment at 300℃, 400℃ and 500℃ in air for 1 hour, and then cooled at room temperature naturally.

Sol-gel Making Process:

Fig.2 sol^n A+ sol^n B

Fig.3 Sol^n A+ sol^n B + Nitric acid

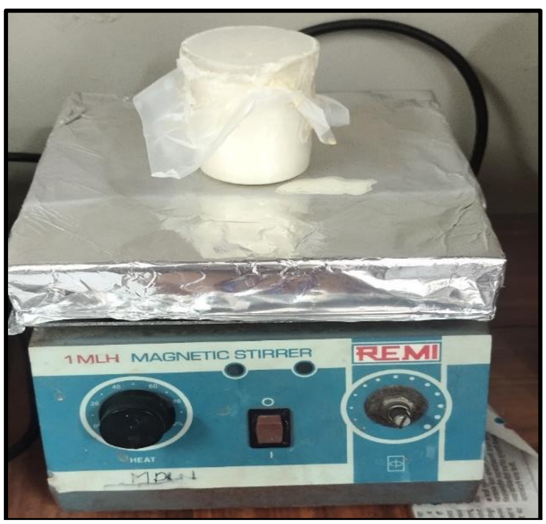

Fig.4 Stirrer for 3 hours

Fig.5 Rest for 48 hours

3. Deposition Techniques

3.1] Deposition Methods:

Deposition refers to the process of depositing or laying down material onto a surface or substrate. There are various methods of deposition used in different industries and applications. Here are some commonly used methods:

3.2] Different Types of deposition techniques:

a) **Spin Coating:** Spin coating is commonly used for applying thin films onto substrates. A liquid solution or suspension is dispensed onto the center of a rotating substrate. Centrifugal force spreads the liquid into a thin and uniform layer as it rotates.

b) **Physical Vapor Deposition (PVD):** PVD involves the vaporization of a solid material in a vacuum chamber. The vaporized material condenses on the substrate, forming a thin film. PVD techniques include evaporation and sputtering.

c) **Thermal Evaporation:** In this method, the material is heated in a vacuum chamber, and the resulting vapor condenses on the substrate.

d) **Sputtering**: In sputtering, ions are accelerated towards a target material, causing atoms to be ejected from the target and deposited onto the substrate.

e) **Chemical Vapor Deposition (CVD):** CVD involves the reaction of gaseous precursor compounds that decompose on the substrate to form a solid film. CVD can be categorized into several subtypes:

f) **Thermal CVD:** Precursor gases are heated to high temperatures, causing thermal decomposition and deposition.

g) **Plasma-Enhanced CVD(PECVD):** The precursor gases are subjected to plasma, which provides energy for the chemical reactions to occur.

h) **Low-Pressure CVD (LPCVD):** The precursor gases are introduced at low pressures, typically in the range of a few mili bar.

i) **Spray Coating:** In spray coating, a liquid solution or suspension containing the desired material is sprayed onto the substrate surface using techniques like air spraying, airless spraying, or electrostatic spraying. The solvent evaporates, leaving behind a deposited layer.

j) **Inkjet Printing:** Inkjet printing is a digital printing technique that can be used for deposition. It involves ejecting small droplets of material onto the substrate using an inkjet printed. The droplets can be deposited with precision, allowing for the creation of patterns or detailed designs.

Hardware:

Spin Coating:

Fig.6 Spin Coating Unit

Spin coating is a common technique used in various fields, such as semiconductor fabrication, thin film deposition, and materials research. It involves the application of a liquid or a solution onto a substrate by spinning it at high speeds. The centrifugal force generated by the spinning motion spreads the liquid across the substrate's surface, creating a thin, uniform film.

The spin coating process typically involves the following steps:

To deposit TiO_2 on a substrate using spin coating, the steps are as follows:

a) **Substrate Preparation:** The substrate, which can be a wafer, glass slide, or any other flat surface, is cleaned and prepared to ensure it is free of contaminants and particles.

b) **Solution Preparation:** A liquid solution or a dispersion of the desired material is prepared. This solution usually contains the material to be deposited dissolved or dispersed in a solvent.

c) **Dispensing:** A small amount of the solution is dispensed onto the center of the substrate. The volume of the solution depends on factors such as the desired film thickness and the size of the substrate.

d) **Spinning:** The substrate is placed on a spin coater chuck, which is typically a rotating platform. The chuck holds the substrate in place while rotating at high speeds, typically ranging from a few hundred to several thousand revolutions per minute (RPM).

e) **Spin Speed and Duration:** The spin speed and duration depend on various factors, including the solution viscosity, desired film thickness, and the characteristics of the material being coated. The spinning process spreads the solution radially outward due to centrifugal force, forming a thin film that covers the entire substrate surface.

3.3] Annealing:

Annealing is a heat treatment process used to modify the microstructure of a metal, Oxide layer, Semiconductor to improve its ductility while reducing internal stress and overall hardness. This allows the material to be more easily shaped without cracking. This process is particularly useful for metals, oxides, which can be too hard or brittle for forming processes.

- **Pre-deposition annealing:** This process involve heating substrate before deposition of oxide layer and deposition of metal layer.
- **Post-deposition annealing:** This process involve heating substrate after deposition of oxide layer and deposition of metal layer. To reduce reducing internal stress, modify the microstructure, increase electrical properties, etc.

In the process of annealing there are various types of annealing process like Rapid Thermal Processing System (RTPS), Furness annealing, etc.

We use Furness annealing for post-deposition annealing.

Fig.7 Furness Unit

Fig.8 Deposited Sample

4. Results

This Process uses Silicon Substrate for deposition of TiO_2. Sol-gel method spin coating technique is adopted to prepare nanoparticles titanium dioxide (TiO2) thin films. The prepared TiO2 sol was synthesized using titanium but oxide act as a precursor and subjected to deposited on the p-type silicon oxide (p-SiO2) and glass slide substrates under room temperature.

4.1] Process Parameters of Spin coating:

Process	Stages	Spinning Speed(rpm)	Spinning Duration(Sec)
K1	1^{st}	2000	44
	2^{nd}	4000	230
K2	1^{st}	2000	10
	2^{nd}	4000	30
K3	1^{st}	2000	10
	2^{nd}	4000	30

Table.1 Process parameters of Spin coating

Fig.9 Deposition of TiO_2 on Si Substrate

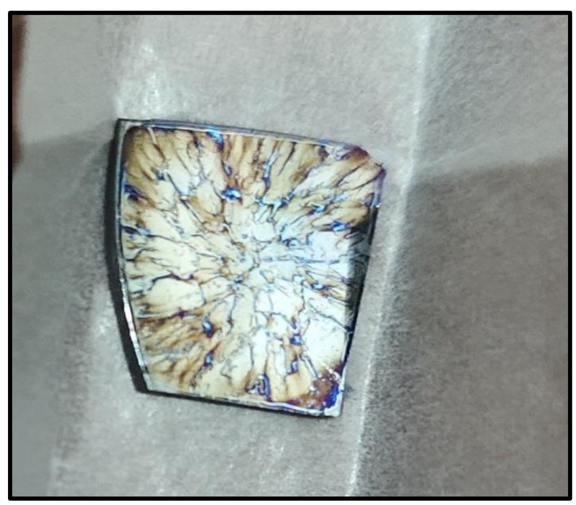

Fig.10 TiO_2 Deposited Substrate

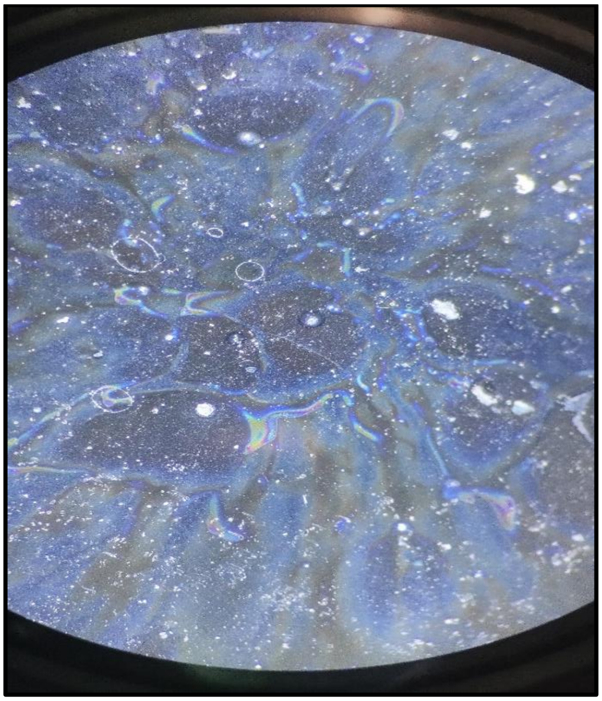

Fig.11 before annealing (microscopic View)

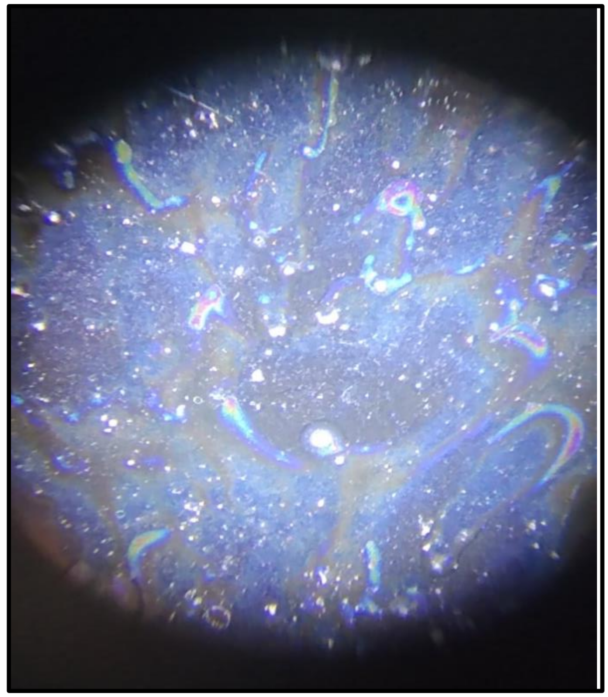

Fig.12 after annealing (microscopic View)

5. Conclusion

This Project conclude that TiO_2 has good application in various medical fields, spatially in dental field contains many more uses of TiO_2.This project contain various different techniques which can be used to deposited TiO_2 on different substrates. In this study we included that deposition of TiO_2 by spin coating on to p-type Si substrate whose thickness is 0.5 mm characterization of this deposited sample is under study. This project also conclude that there will be thick deposition of TiO_2 on Collagen membrane and its characteristics will be studied.

6. Future Work

6.1] Collagen membrane:

Collagen membrane is a thin sheet made from purified collagen, a protein that is naturally found in the body's connective tissues. It is used in various medical and dental procedures to promote tissue regeneration and healing. In dental implant procedures, collagen membrane is placed over the implant site to protect the implant and promote bone and tissue growth around it. Over time, the membrane is naturally absorbed by the body, leaving behind a strong and stable dental implant.

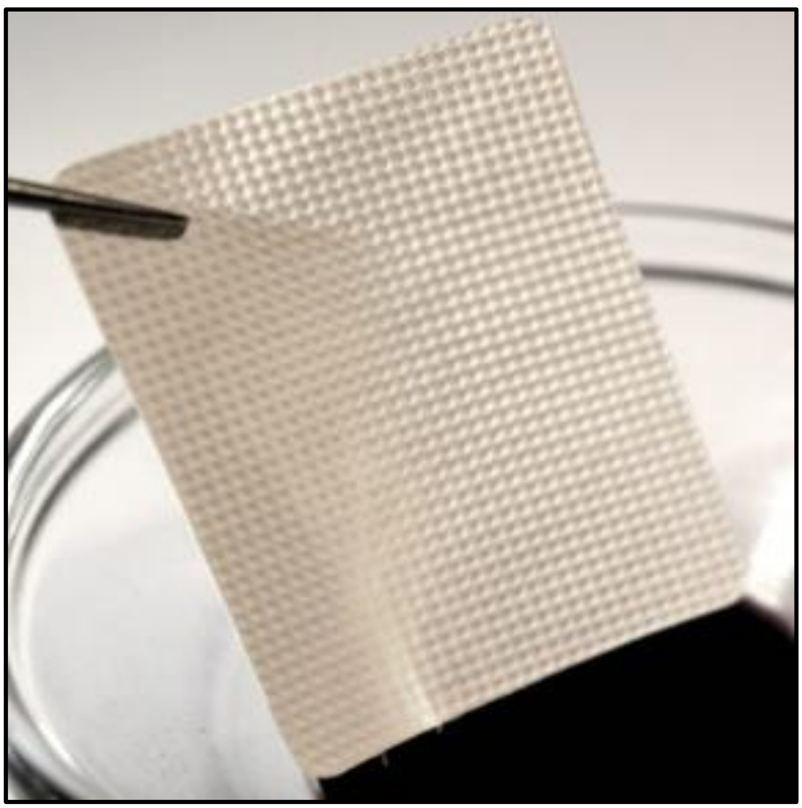

Fig.13 Collagen membrane

6.1.2] Why collagen membrane use for dentistry?

Collagen membranes are commonly used in dentistry for guided tissue regeneration (GTR) procedures. GTR is a technique used to regenerate lost or damaged periodontal tissue, such as bone and gums, around teeth. Collagen membranes act as a barrier to prevent unwanted cells from interfering with the regeneration process, while allowing beneficial cells to migrate and regenerate the lost tissue. Collagen membranes are biocompatible, meaning they are not harmful or toxic to the body, and they are easily absorbed by the body once the regeneration process is complete. They also have a low risk of infection and inflammation, making them a safe and effective option for dental procedures. In addition to GTR procedures, collagen membranes can also be used for socket preservation after tooth extraction, ridge augmentation, and sinus lift procedures. Overall, collagen membranes play an important role in promoting successful and predictable outcomes in dental procedures that involve tissue regeneration.

6.1.3] Usage of collagen membrane in dental implant?

Collagen membrane is used in dental implant procedures to promote bone regeneration and tissue healing around the implant site. Here are the steps involved in using collagen membrane in dental implant procedures:

a) The dentist or oral surgeon will place the implant into the jawbone.

b) The collagen membrane is then placed over the implant, covering the exposed area.

c) The membrane acts as a barrier to protect the implant from bacteria and other contaminants while also promoting the growth of new bone and tissue around the implant.

d) Over time, the collagen membrane will naturally dissolve and be absorbed by the body, leaving behind a strong and stable dental implant that can support a prosthetic tooth or teeth.

It is important to note that the use of collagen membrane in dental implant procedures may not be suitable for everyone. Patients should consult with their dentist or oral surgeon to determine if this treatment option is appropriate for their individual needs and circumstances.

6.1.4] Roll of collagen membrane in dentistry?

Collagen membrane is a widely used biomaterial in dentistry, primarily in periodontal and implant surgeries. It is a biocompatible and bio-restorable material that is derived from natural sources such as bovine or porcine skin. The role of collagen membrane in dentistry includes:

1. **Guided Tissue Regeneration (GTR):** Collagen membrane is used in GTR procedures to promote the regeneration of lost periodontal tissues. It acts as a barrier between the gingival tissue and the bone defect, preventing the migration of epithelial cells and allowing the growth of periodontal ligament cells and bone-forming cells.

2. **Socket Preservation:** After tooth extraction, collagen membrane is placed in the socket to prevent the collapse of the surrounding bone and soft tissue. This helps to maintain the natural contour of the ridge, making it easier for future implant placement.

3. **Sinus Lift:** In sinus lift procedures, collagen membrane is used to support the graft material and prevent it from migrating into the sinus cavity. It also promotes the growth of new bone in the sinus floor.

4. **Soft Tissue Augmentation:** Collagen membrane can be used to augment soft tissue in areas where there is insufficient keratinized tissue or recession. It provides a scaffold for new tissue growth and helps to stabilize the flap.

6.2] Deposition of TiO_2 By ALD on Collagen Substrate:

Atomic layer deposition (ALD) is well known for its unique capabilities within chemical vapor deposition processes. It offers excellent composition tunability, and precise thickness control and uniformity in deposited very thin metal oxides films. It can also facilitate conformal deposition across three dimensional substrates. ALD of an oxide is a gas phase cyclic process, and one cycle of ALD process typically consists of four main steps: precursor pulse, precursor purge, oxidizer pulse, and oxidizer purge. Pulsing time, purging time, and reaction temperature are important parameters for optimal growth during ALD processes. Different oxidizers and precursors play important roles in the thin film growth of a given metal oxide. For a typical ALD process, the oxide film thickness generally increases linearly with increasing number of ALD cycles. The substrate also plays a significant role in the growth rate and oxide film quality.

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