Characterisation and Mechanical Properties of Neo Photocurable Coating of Vitamin D With Pegda on Titanium Surface

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**Abstract:** PEGDA combines with vitamin D to form a scaffold or matrix that can gradually break down and release the vitamin D that has been encapsulated over an extended period of time. Vitamin D, with the help of PEGDA (polyethylene glycol diacrylate), helps in the sustainable release of vitamin D into the body. Over a longer length of time, sustained release systems can assist in keeping the medicine or active ingredient at a consistent concentration in the body . This may prove advantageous for medications that have a limited therapeutic range or those that need constant exposure to be as effective as possible [(Doshi et al., 2023; Lampl et al., 2023; Pandiyan et al., 2023)](https://paperpile.com/c/7Spts7/JA27N+UOq6O+JOWVq)[(Pavithra et al., 2023; Shenoy et al., 2023; Thomas & Jain, 2023)](https://paperpile.com/c/7Spts7/oexD+lvfS+ehEs). Sustained release devices can frequently decrease the frequency of dose, increasing patient compliance and convenience by delivering a constant release of the medication. By minimizing drug concentration swings, sustained release devices may lessen the likelihood of peak drug level-related negative effects [(Pavithra et al., 2023; Shenoy et al., 2023; Thomas & Jain, 2023)](https://paperpile.com/c/7Spts7/oexD+lvfS+ehEs)[(Rajeshkumar & Lakshmi, 2021; Sivakumar et al., 2021)](https://paperpile.com/c/7Spts7/g5hyX+HG4eL) .Vitamin D, specifically the active form of vitamin D, 1,25-dihydroxy vitamin D, has been found to stimulate intestinal absorption of calcium and phosphate, which is essential for maintaining bone mineral homeostasis. [(Norman et al., 2020)](https://paperpile.com/c/7Spts7/lK84) It stimulates the osteoblasts, which produce new bone, and the osteoblastic cells, which break down existing bone. [(Compston & Lian, 2009)](https://paperpile.com/c/7Spts7/wMuMo)This effectively manages and prevents osteoporosis.

**keywords:** Etching of Ti Plates, Coating Preparation, Material Coating, photodetector, Microscopic techniques

# INTRODUCTION

The rate of success of any implant depends upon the osseointegration, the strength of which is improved with an increase in bone implant contact (BIC) [(Rajeshkumar & Lakshmi, 2021; Sivakumar et al., 2021)](https://paperpile.com/c/7Spts7/g5hyX+HG4eL). Implant plays a key role in gaining stability based on the quality of bone. The osseointegration of the implant might vary in various bone qualities; this can be improved by enhancing the surface characterization of the implants [(Chokkattu et al., 2023; Dharman et al., 2023; Govindaraj & Shanmugam, 2023)](https://paperpile.com/c/7Spts7/mqy7t+Tdp6Y+A7Mab). The choice of the material for implant fabrication and the surface characterization plays a key role in this. Titanium is a widely used metal in the medical system. Titanium (Ti) as an implant material has its own advantages, as it possesses increased mechanical strength within the range of 170–480 MPa of commercially pure titanium and strength of up to 160 MPa of Ti alloy and biocompatible properties [(Gandhi et al., 2021; Katyal et al., 2023; Priyadharshini et al., 2023)](https://paperpile.com/c/7Spts7/ZXhPU+ZGMLX+GQxBa). Certain titanium alloys, especially those with particular compositions and surface treatments, have been found to have improved osseointegration characteristics when compared to pure titanium. Ti-6Al-4V, which is composed of titanium, aluminum, and vanadium, is one such alloy. The strength and flexibility of aluminum and vanadium are combined with the biocompatibility of titanium in this alloy. Further surface alterations that can enhance osseointegration include micro-texturing and the use of bioactive coatings, which encourage bone formation and cell adhesion[(Rajaraman et al., 2021)](https://paperpile.com/c/7Spts7/SMQn). These developments in titanium alloy technology, by creating stronger and longer-lasting connections with the surrounding bone tissue, have the potential to improve the efficacy and longevity of medical implants, including prosthetic limbs[(Janani et al., 2021; Kachhara et al., 2021; Subramanian et al., 2023)](https://paperpile.com/c/7Spts7/WqmuH+KiULw+TEAXc). It has been reported that along with the surface modifications and the application of bioactive agents may result in enhanced osteogenic properties to the implant surface[(Piattelli, 2016)](https://paperpile.com/c/7Spts7/pb7z)[(Gandhi et al., 2021; Katyal et al., 2023; Priyadharshini et al., 2023)](https://paperpile.com/c/7Spts7/ZXhPU+ZGMLX+GQxBa). PEGDA(Polyethylene glycol diacrylate), a photopolymerizable substance that is thought to be nontoxic, cytocompatible, and simple to handle, is one of the materials that is commonly utilized for this purpose[(Ashok et al., 2024)](https://paperpile.com/c/7Spts7/cpRu)[(Chokkattu et al., 2023; Dharman et al., 2023; Govindaraj & Shanmugam, 2023)](https://paperpile.com/c/7Spts7/mqy7t+Tdp6Y+A7Mab). A cross-linkable polymer called polyethylene glycol diacrylate (PEGDA) is utilized in medication delivery systems to regulate the release of active ingredients like vitamin D into the body. PEGDA combines with vitamin D to form a scaffold or matrix that can gradually break down and release the vitamin D that has been encapsulated over an extended period of time. Vitamin D, with the help of PEGDA (polyethylene glycol diacrylate), helps in the sustainable release of vitamin D into the body. Over a longer length of time, sustained release systems can assist in keeping the medicine or active ingredient at a consistent concentration in the body . This may prove advantageous for medications that have a limited therapeutic range or those that need constant exposure to be as effective as possible [(Doshi et al., 2023; Lampl et al., 2023; Pandiyan et al., 2023)](https://paperpile.com/c/7Spts7/JA27N+UOq6O+JOWVq)[(Pavithra et al., 2023; Shenoy et al., 2023; Thomas & Jain, 2023)](https://paperpile.com/c/7Spts7/oexD+lvfS+ehEs). Sustained release devices can frequently decrease the frequency of dose, increasing patient compliance and convenience by delivering a constant release of the medication. By minimizing drug concentration swings, sustained release devices may lessen the likelihood of peak drug level-related negative effects [(Pavithra et al., 2023; Shenoy et al., 2023; Thomas & Jain, 2023)](https://paperpile.com/c/7Spts7/oexD+lvfS+ehEs)[(Rajeshkumar & Lakshmi, 2021; Sivakumar et al., 2021)](https://paperpile.com/c/7Spts7/g5hyX+HG4eL) .Vitamin D, specifically the active form of vitamin D, 1,25-dihydroxy vitamin D, has been found to stimulate intestinal absorption of calcium and phosphate, which is essential for maintaining bone mineral homeostasis. [(Norman et al., 2020)](https://paperpile.com/c/7Spts7/lK84) It stimulates the osteoblasts, which produce new bone, and the osteoblastic cells, which break down existing bone. [(Compston & Lian, 2009)](https://paperpile.com/c/7Spts7/wMuMo)This effectively manages and prevents osteoporosis. In vitro studies have demonstrated that titanium (Ti) implants coated with UV-activated 7-dehydrocholesterol, the precursor ofVitamin D3 , outperform control implants in terms of osteoblast proliferation and differentiation. While Vitamin D3 supplementation has demonstrated improved BIC, some detrimental outcomes have also been documented.[(Bikle et al., 2020)](https://paperpile.com/c/7Spts7/LszXI) For example, rats given Vitamin D3 had much greater bone volume and Ti implant osseointegration than controls. However, other research has not demonstrated a substantial impact of Vitamin D3 supplementation on elevated BIC.[(Bratengeier, 2019)](https://paperpile.com/c/7Spts7/0taJl) Direct bone-to-implant contact (BIC) and primary stability of the implant are the two essential requirements for the overall success of dental implant therapy. [(Cameron, 1994)](https://paperpile.com/c/7Spts7/J97NF)[(Doshi et al., 2023; Lampl et al., 2023; Pandiyan et al., 2023)](https://paperpile.com/c/7Spts7/JA27N+UOq6O+JOWVq) Multiple studies have confirmed that incorporating supplements such as vitamin D, hormone replacement, growth factors, and stem cells with standard implant placement techniques can significantly enhance BIC.[(Shi & Clegg, 2008)](https://paperpile.com/c/7Spts7/5ooMy) Moreover, rougher surface implants have been found to promote osteoblastic growth, collagen production, and integrin expression in the extracellular matrix, further enhancing the osseointegration process.[(Brånemark et al., 1985)](https://paperpile.com/c/7Spts7/QNdpU) These advancements in conventional implant therapy can even aid osseointegration in immunocompromised patients, previously thought to have a negative impact on osseointegration.[(Marei, 2010)](https://paperpile.com/c/7Spts7/5pBQI)15)[(Ramsundar et al., 2023; Rieshy et al., 2023; Singh et al., 2023)](https://paperpile.com/c/7Spts7/gUqX3+Tt9er+UxgBl) Research had shown that vitamin D, whether supplemented or incorporated into various forms, including coatings, can enhance bone formation and osseointegration within the body.The main objective of this study was to synthesise a photocurable coating on dental implants and analyze the bone adhesion and biocompatibility.

# MATERIALS AND METHODS

This study was conducted at the Department of Implantology,, utilizing white lab techniques from November 8, 2023, to January 15, 2024.

The present in vitro study was conducted after obtaining ethical approval from the institutional ethical committee (SRB/SDC/MSIMPLANT-2309/24/038). Considering the In-vitro nature of the study, the post-hoc power of the study was calculated using G Power software. The effect size was calculated based on the mean recorded in the parent study The Influence of 1α.25-Dihydroxyvitamin D3 Coating on Implant Osseointegration in the Rabbit Tibia for the variables tested in the study[(Hanna et al., 2023)](https://paperpile.com/c/7Spts7/bvpmx). The alpha error was kept at 0.05 for a study with two groups. Making the sample size of seven in each group. With the above input values, the power of the study was 1.

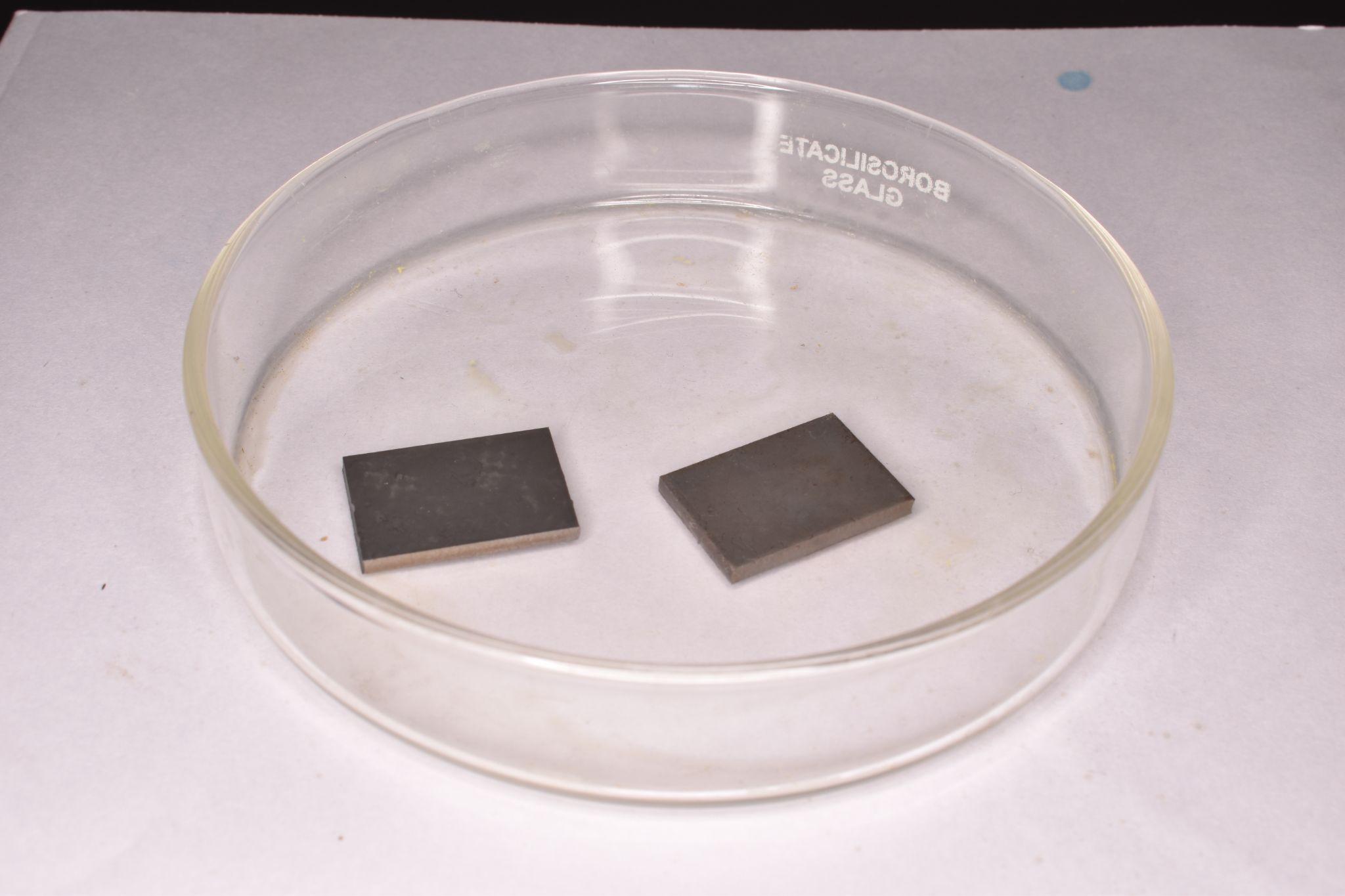
The two groups of the study are:

Group I (TEST GROUP): Vitamin D-Coated Titanium Plate

Group II (CONTROL GROUP): Non-Coated Titanium Plate

# Coating Preparation

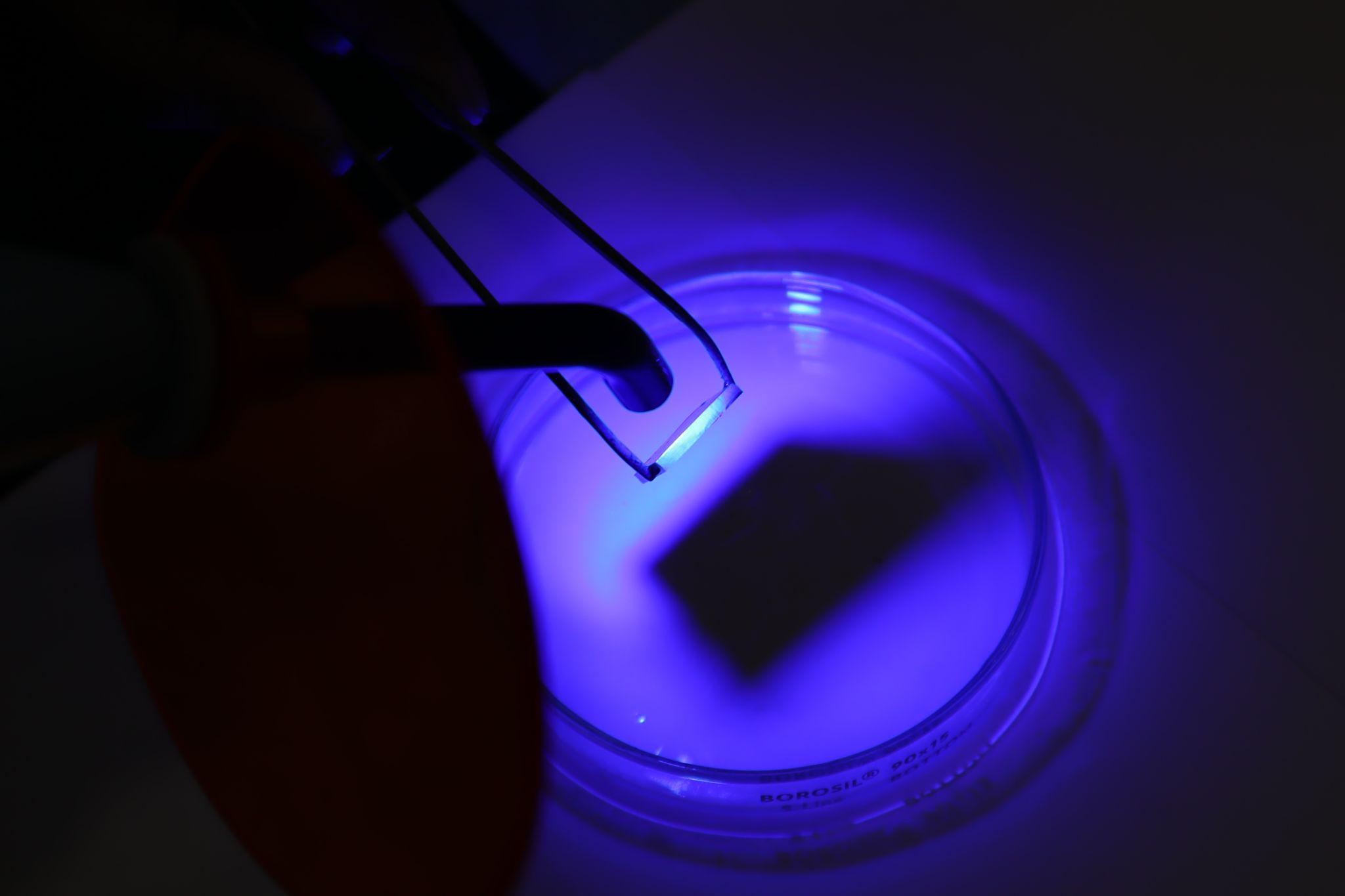
The titanium plates (3 cm x 5 cm) were dipped in 3% hydrofluoric acid (HF) for 10 minutes (Fig 1). This etches the surface, potentially improving adhesion. This step should be carefully performed in a well-ventilated fume hood with proper personal protective equipment (PPE), including gloves, goggles, and a lab coat. The etched plates were placed in a hot air oven for 4-5 hours to remove any residual moisture (Fig 2). The solution was prepared by mixing PEGDA and Vitamin D solution in a ratio of 3:2. Ethyl 4-dimethylaminobenzoate 0.2% was measured and added with camphorquinone (C10H14O2). 0.5% added with 6 ml Polyethylene Glycol Diacrylate (PEGDA) with 4 ml Vitamin D in a ratio of 3:2. All the materials were added into the beaker according to the required composition as mentioned required to cover the complete solution with the help of lab foil to prevent the solution from light exposure because the PEGDA was light sensitive; it will get cured during the exposure of light. All the materials were stirred together with the help of a magnetic device for 30 minutes until they were completely mixed with each other.



**Figure 1**:Etching of Ti Plates in 3%(HF) **Figure 2:**Dried Ti Plates

# Material Coating

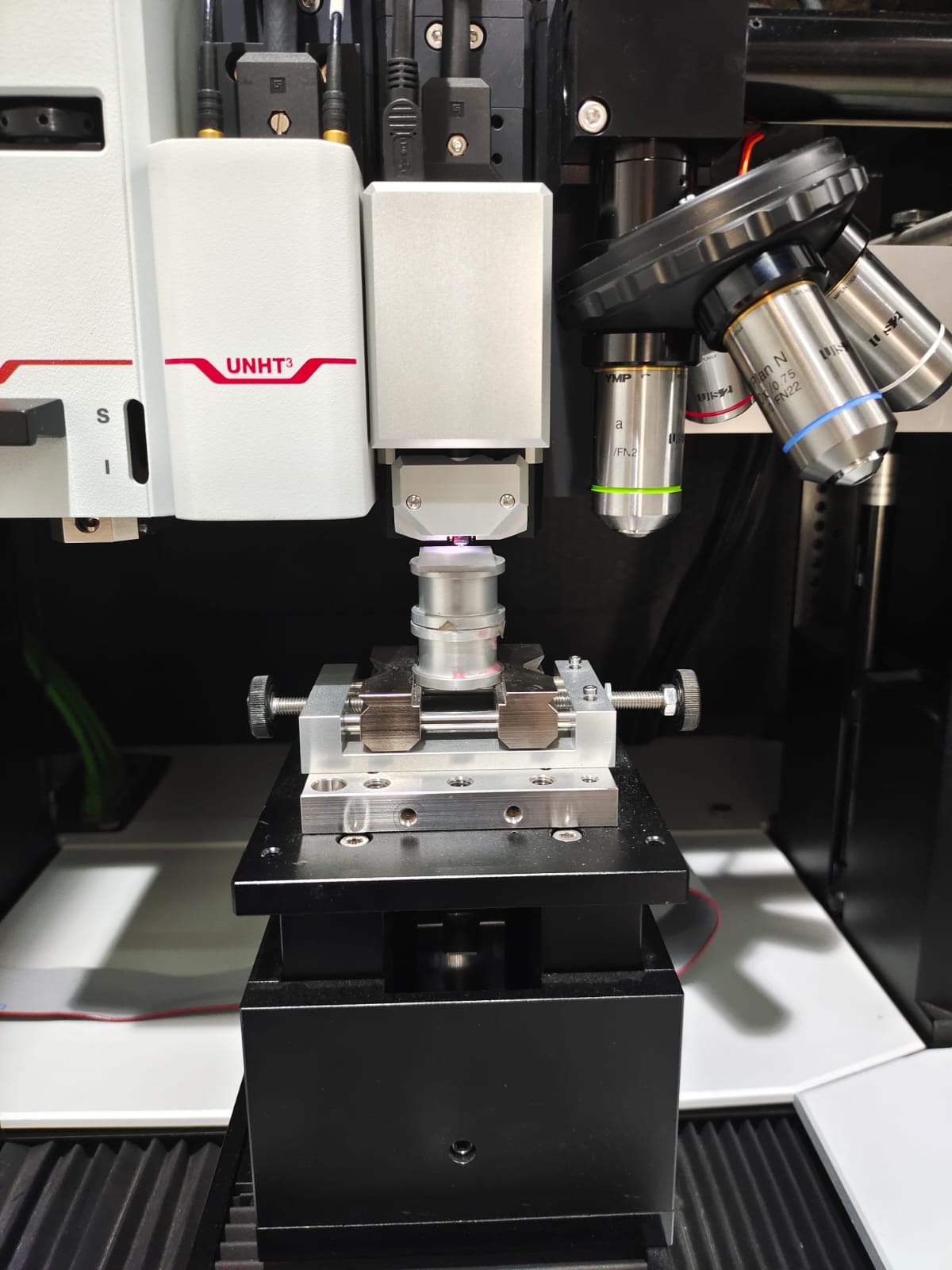
Titanium plates are dipped into the prepared solution with an appropriate ratio of 3:2 of PEGDA and vitamin D, respectively for 10 minutes to get a proper coating of the titanium plate (Fig 3).The titanium (Ti) plates were then crosslinked with concentrations of the vitamin D as well as PEGDA through the dip-coating technique. Plates were then cured with the help of a UV-curing light for 40 seconds (Fig 4). PEGDA was sensitive to light, and it gets cured with the help of UV light exposure.



**Figure 3:** Etching of Ti Plates in 3% HF **Figure 4:** UV Curing Ti Plates

## AFM

To ensure that the AFM readings were not impacted by impurities or debris, clean the sample surface. Securely attach the sample to the AFM sample holder by using was steady and level.After turning on, give the AFM instrument some time to reach its operating temperature.Install the cantg the proper glue or mounting technique (Fig 5). Ascertain if the samilever or probe that was right for the kind of measurement you want to take. [(Lung et al., 2021)](https://paperpile.com/c/7Spts7/sAmJs) Adjust all of the instrument's components, such as the photodetector, cantilever spring constant, and laser alignment[(Naito et al., 2014)](https://paperpile.com/c/7Spts7/HfRuY).Configure the parameters for the scan, including the size, rate, and quantity of data points as well as the imaging mode (contact, tapping, non-contact,etc). During scanning, select the proper feedback parameters to ensure that the interaction forces between the probe and the sample surface remain consistent.



**Figure 5:** Sample mounted on Microscope for AFM analysis

## SCRATCH TEST

The behavior of the coating under typical loading and mechanical properties are examined using variations in lateral force. The indenter tip was made of diamond material with radius 100 (μm).Rockwell type of indenters was used with serial number 0-131.When the lateral force suddenly drops, the normal force associated with it is called the critical load. This was a linear scratch test which was progressive in nature and the beginning load starts with 0.03(N) and end load with 30(N). Loading rate for the scratch test is 5.99 (N/min).A micro-scratch test was conducted to evaluate the scratch resistance of a coating. The test involved applying a progressively increasing load (0-1000 μN) to a diamond indenter tip as it moved across the coating at a constant speed of 0.13 μm/s. After penetrating the coating in 10 seconds, a horizontal force was applied for 30 seconds, creating a 4 μm long scratch. The resulting scratch and surface topography were analyzed using atomic force microscopy (AFM) to determine the critical load required to cause coating failure.

## F-TIR

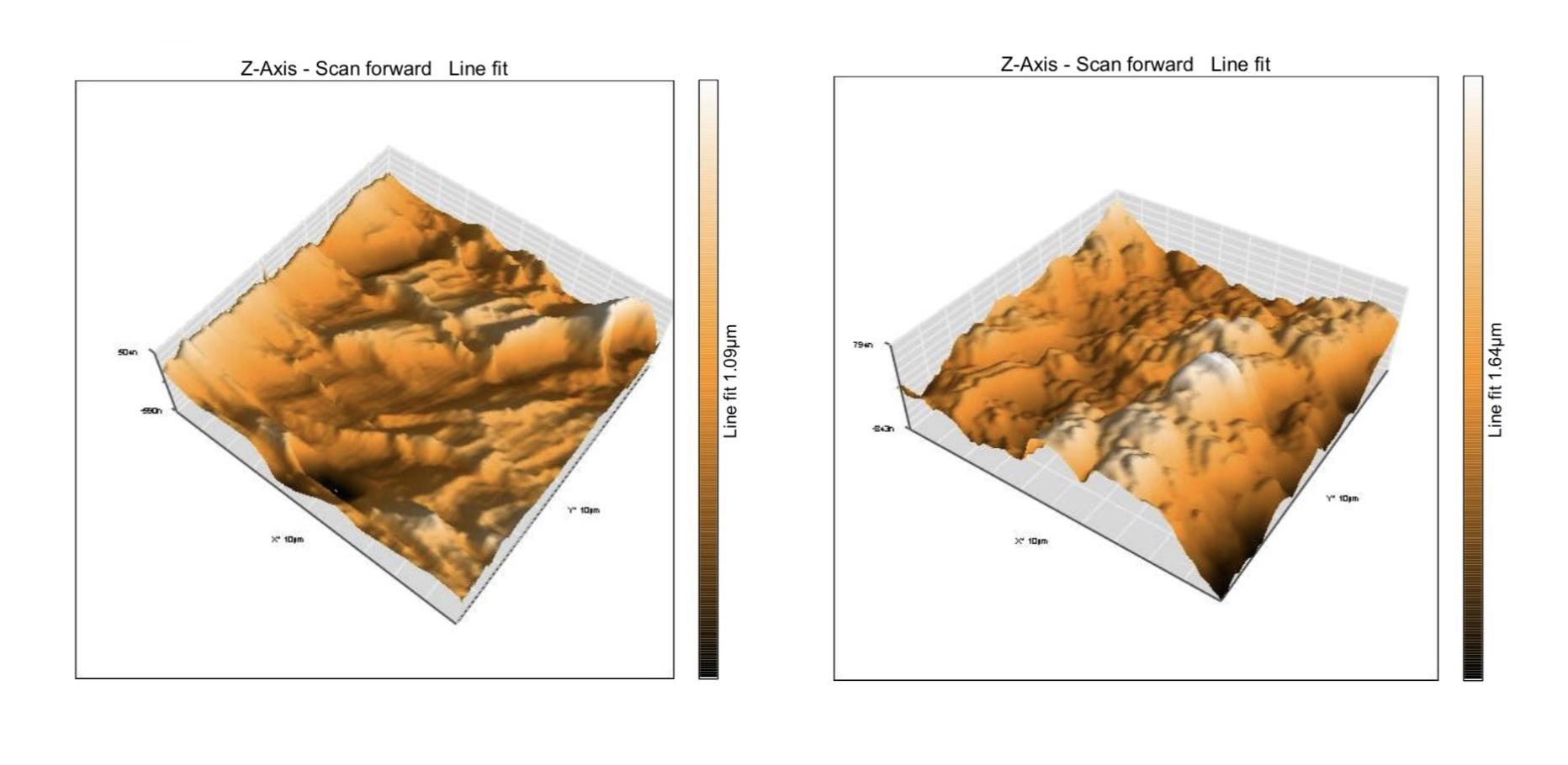
The functionality and bonding characteristics of the Vitamin D coating were analyzed using Fourier Transform Infrared Spectroscopy (FTIR). The spectra were recorded in the wavenumber range of 4000–400 cm⁻¹ using a Spectrum 2 FTIR spectrometer (PerkinElmer, Waltham, MA, USA). The analysis was performed in attenuated total reflectance (ATR) mode to minimize sample preparation and enhance spectral accuracy. Spectral data were collected with a resolution of 4 cm⁻¹, averaging 32 scans per measurement to improve signal-to-noise ratio. The obtained spectra were used to identify characteristic functional groups and confirm the chemical bonding of the Vitamin D coating.

## SCANNING ELECTRON MICROSCOPE

To provide conductivity for the purpose of capturing high-resolution images, the sample surfaces were sprayed with platinium for 30 seconds. High-resolution SEM pictures (magnification: 1.50 kV) offered a high resolution for assessing the presence of corrosion, impurities, fractures, and surface roughness.Using an in-column detector (Immersion Lens detector (InLens) and Angle Selective Backscatter detector (AsB)), scanning electron microscopy (SEM) (Ultra Plus, Carl Zeiss Meditec AG, Jena, Germany) was used to examine the properties of the titanium plates both before and after modification. An Energy-dispersive X-ray spectroscopy (EDS) microanalysis system (Bruker, Quantax 400 with an ultrafast detector with an energy resolution of 127 eV and an active surface of 30 mm) was used to map the elements. At 1000, 25,000, and 100,000 magnifications, SEM pictures were acquired.

# Results

## AFM

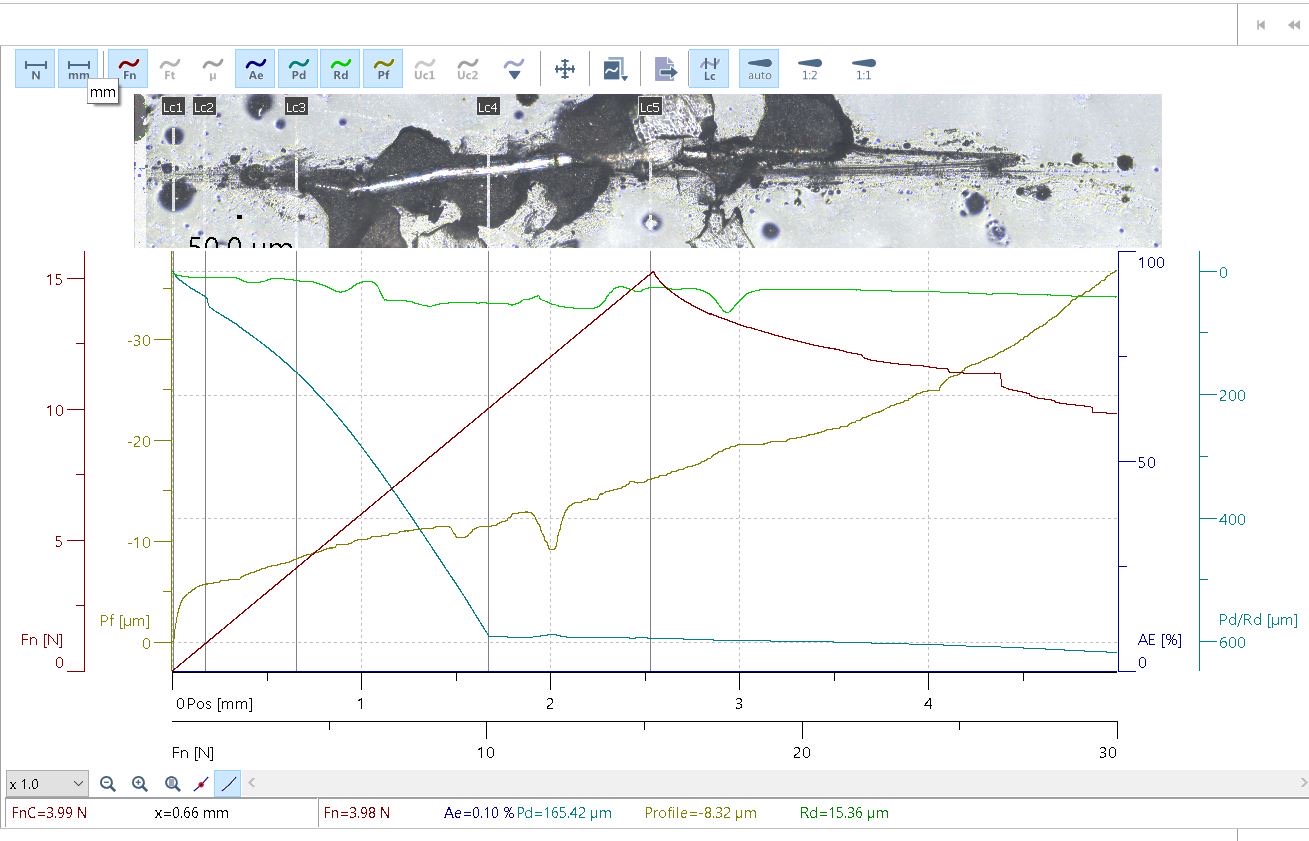


**Figure 6:**AFM Scan

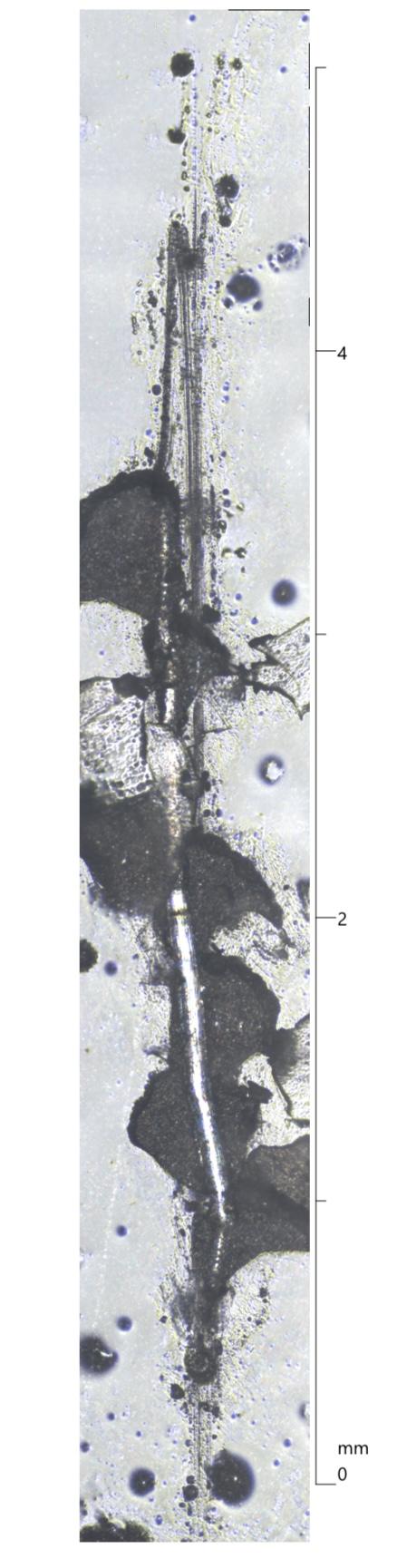
The AFM examination revealed the presence of numerous short-rounded edge protrusions with an average roughness (Sa) of 204.47nm. These values are compared with the pre-existing studies that show that there is enhanced surface roughness which will attract the osteoblasts and enhance osseointegration.(Fig 6)

## SCRATCH TEST

The tangential strain was produced by the tangential frictional force that was created when the ball indenter traveled across the sample surface, whereas the observed normal strain resulted from the normal load delivered via the ball indenter.The results of the scratch test showed that the maximum depth was reached at 10.03N and the maximum force at 15.18N.(Fig 7, Table1,2) These values are comparable with the previous studies and we can ascertain that premature delamination of the coating will not occur.The indenter tip plows the coating and moves both horizontally and vertically as the normal force increases. The surface imperfections and the tip's attempt to penetrate the coatings cause the first oscillations. However, at higher stresses, a sharp decline in the curve indicates that the coating has failed due to several causes, including cracking, component detachment, or, in the worst scenario, substrate delamination.Curves of lateral force vs normal force and Microscopic pictures of the scratch tracks are displayed here.Between each sample, the ball indenter was cleaned with ethanol and then wiped with a fresh towel to get rid of any dirt. Using a ball indenter that was fastened to a firm spring, load was imparted to the sample and lowered upon it.(Fig 8) A precise motor that produced horizontal motion to create a scratch over a sample's surface was attached to the sample stage. A sequence of known loads was applied to the load cell in order to calculate the calibration factors, which were then utilized to translate the recorded strains into forces.



**Figure 7:** SCRATCH TEST GRAPH



**Figure 8:** Linear Scratch Test(Sample plate)

**TABLE 1:**Force value Maximum depth

|  |  |  |
| --- | --- | --- |
| Groups | Mean + SD (n) | Significance |
| Coated Plates | 10.05+ 2 N(7) | 0.04\* |
| Non Coated Plates | 8.1+1.02N (7) |  |

\*Significance pvalue <0.05

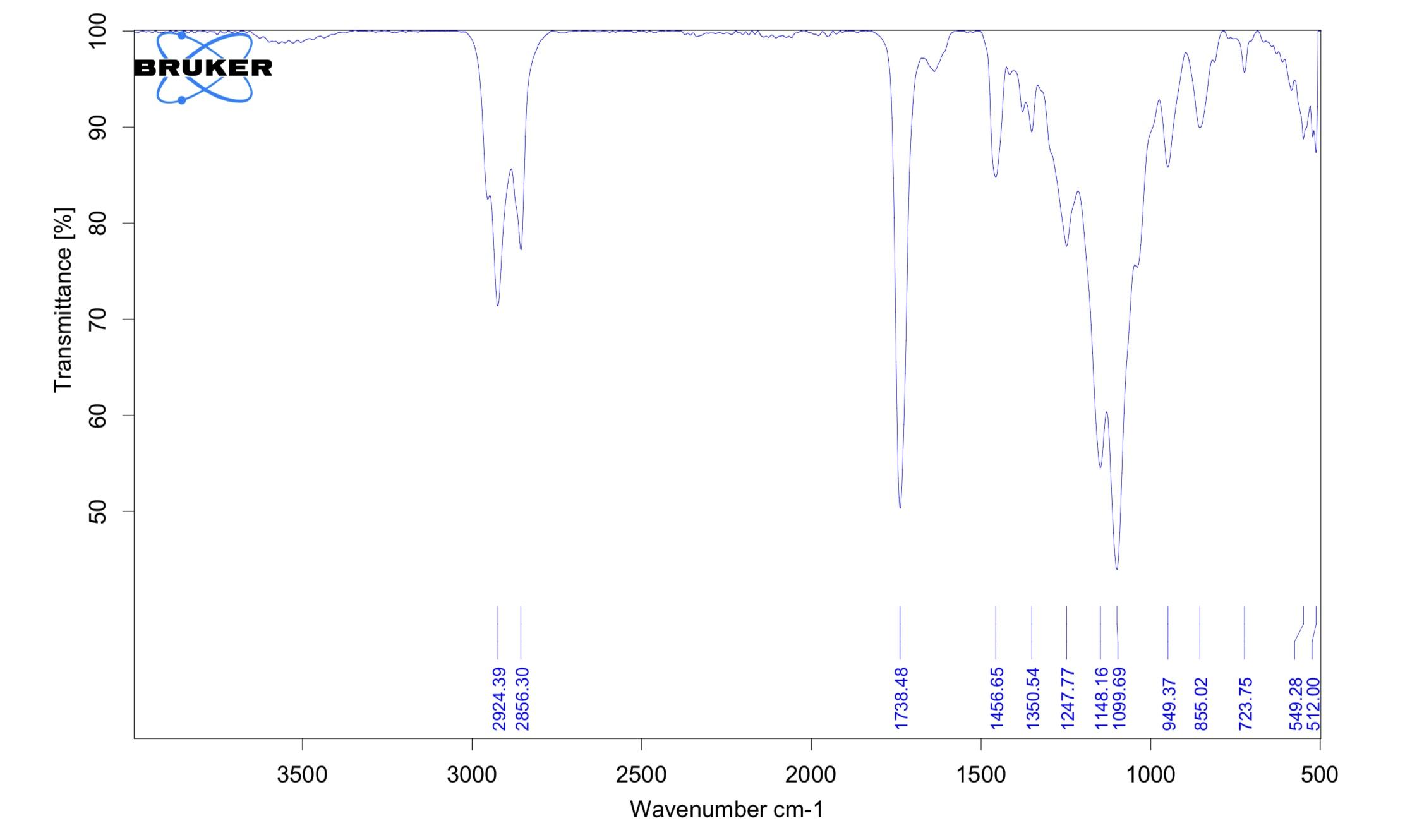
**TABLE 2:** Maximum force percentage

|  |  |  |
| --- | --- | --- |
| Groups | Mean + SD (n) | Significance |
| Coated Plates | 15.18 + 4 N(7) | 0.07\* |
| Non Coated Plates | 16 + 2N (7) |  |

\*Significance pvalue <0.05

## F-TIR

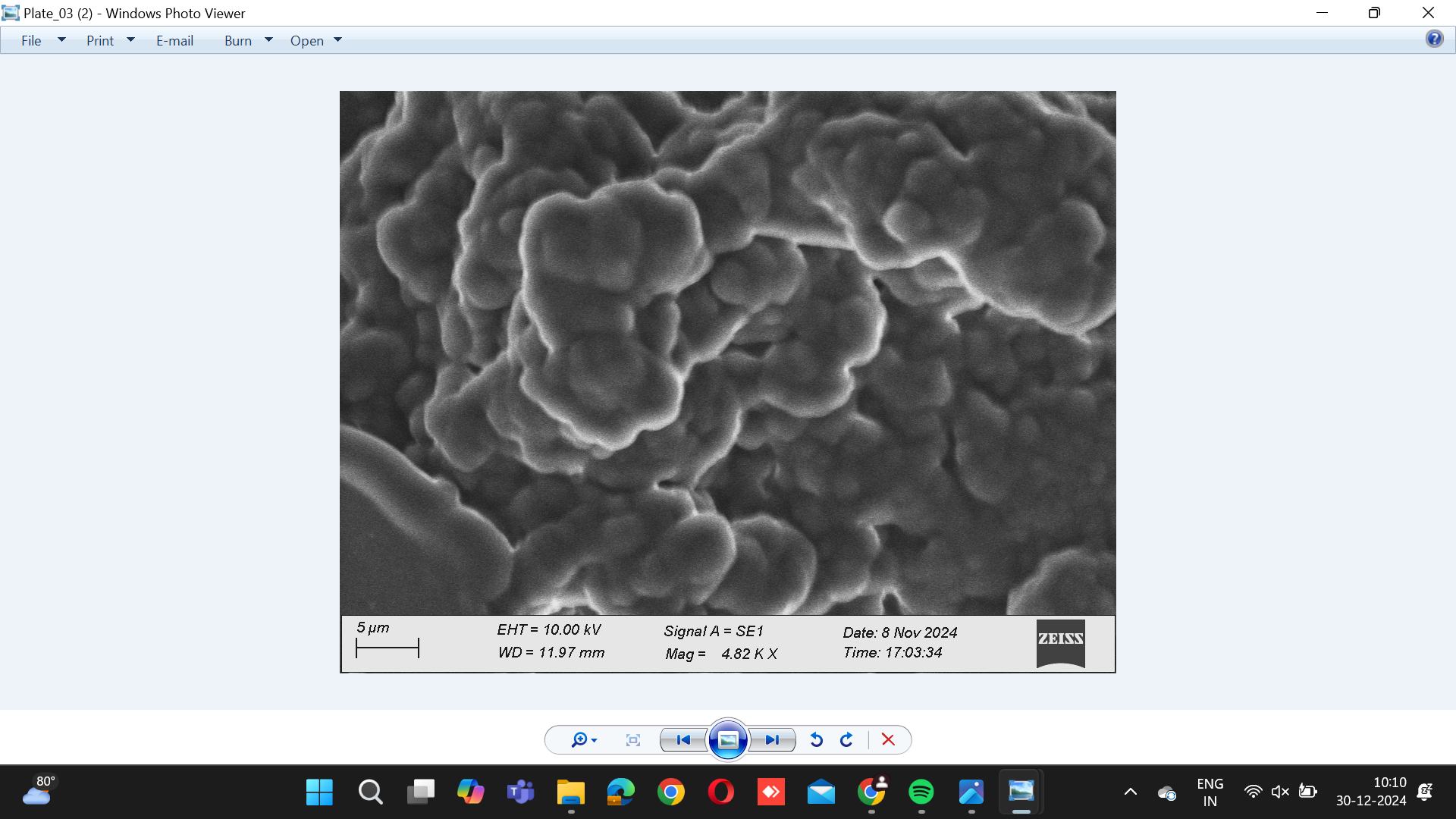
In the FTIR spectrum of Vitamin D3 coating on Ti plates , the peak consistent to the frequency range of 1650-1740 cm−1 indicates the existence of double bonds between C atoms, of which VD3, consuming the name cholecalciferol, has four. The peak position at around 855 cm−1 corresponds to the presence of aromatic rings, exclusively an alkaline ring with six C atoms with three substitutions, of which the VD3 fragment has two in its structure. Between 1000-1450 cm−1, the peaks corresponding to C-C and C-O bonds can be found, which are related to aliphatic chains and a hydroxyl group that form the chemical structure of VD3.(Fig 9) In the meantime, Vitamin D3 is considered by the asymmetric CH3 and symmetric CH2 stretching modes at 2924 cm−1 and 2856 cm−1, respectively . Two other typical peaks are formed around the positions of 1738 and 1099 cm−1, indicating the stretching vibrations of C=O and C-O-C bonds, respectively.



**Figure 9**: F-TIR analysis of Vitamin d coated Ti Plates

## SCANNING ELECTRON MICROSCOPE

An SEM image of the coated sample at a magnification of 1.50 KV reveals a porous surface with Vitamin D–Titanium agglomerates. When AFM values are present, the average surface roughness of coated titanium is lower than that of the uncoated metal surface. The titanium samples that were not coated had more surface cracks. There was no sign of surface deterioration in the specimens[(Pokrowiecki et al., 2022)](https://paperpile.com/c/7Spts7/XqZgc).The SEM pictures obtained on the film's surface demonstrate how continuous and compact layers with spherical particle agglomerations grow on top of titanium substrates. The average grain size appeared to vary slightly between samples, but it ranged between 10 and 50 nm. It also clearly decreased as the substrate temperature increased, which has been shown previously.



**Figure 10:** SEM analysis of Coated Samples

Figure depicts the Vitamin D coating's SEM shape and elemental content. With its compact, porous, and agglomerated morphology, the Vitamin D coating had a rough surface and consistent dispersion across the whole surface of the Ti metal. There were no gaps in the overall coverage of the surface. The Vitamin-D coating is formed by combining all of the elements in the coating, as well as the percentages of carbon, titanium, and oxygen with the base Metal. The elements were spread across the entire surface. The coating's elemental composition (%) may enhance bioactivity by increasing cell viability. The porosity size particles and rough surface may aid in osseointegration, cell proliferation and cell attachment.

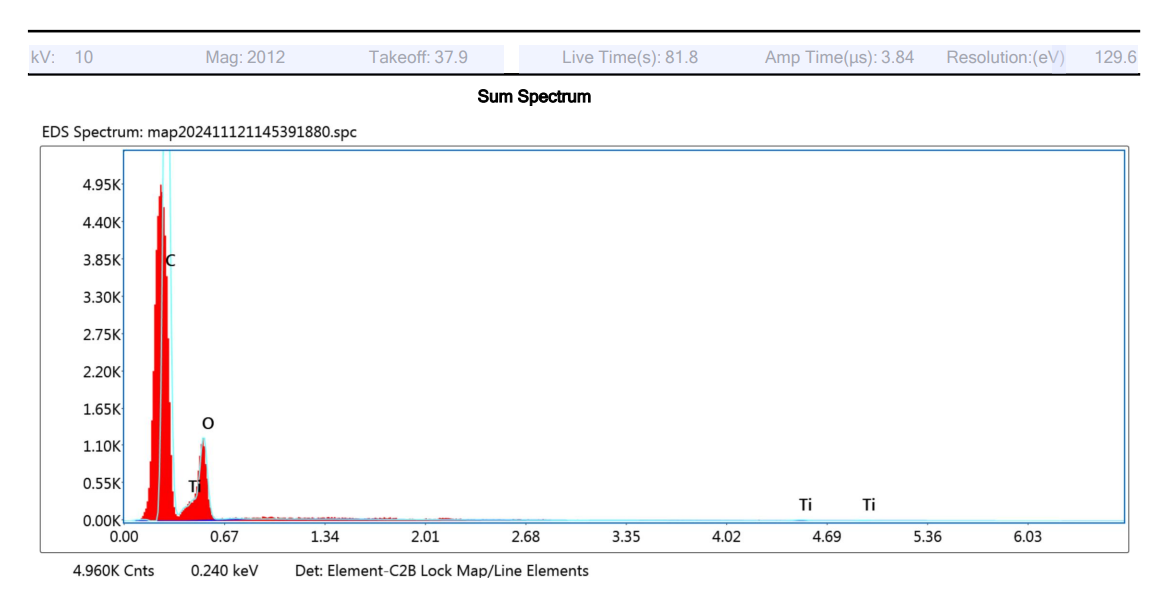


Figure 11: sum spectrum

# Surface Analysis

Surface analysis was crucial to understanding the properties and characteristics of a vitamin D coating on titanium plates. It helps evaluate the coating's composition, thickness, uniformity, and its interaction with the titanium substrate. Here are some common techniques employed for this purpose. Microscopic techniques were used like atomic force microscopy (AFM), which provides detailed topographical information about the coating surface, including roughness, thickness, and uniformity. Scanning electron microscopy (SEM) offers high-resolution imaging of the coating's morphology and can be used in conjunction with energy-dispersive X-ray spectroscopy (EDX) for elemental analysis.

# Discussion

Surface modifications involving additives have demonstrated improved osseointegration of implants. Incorporating a coating of Vitamin D alongside PEGDA has been shown to promote bone formation, which could be particularly beneficial for the Indian population, given the prevalent Vitamin D deficiency among a majority of its people. This in vitro study aimed to histologically assess the biological response to titanium surfaces coated with vitamin D. Although some research on vitamin D3 supplementation has had encouraging results, opinions on how it affects osseointegration remain divided. In animal models, especially rats, studies have demonstrated that vitamin D3 administration can result in increased bone volume and better osseointegration. Nevertheless, other research has found no discernible effect on BIC in spite of v1itamin D supplementation. This suggests that the effects of vitamin D on implant osseointegration may differ based on a number of variables, including dosage, timing, and the type of vitamin D administered (e.g., systemic supplementation or coating). To isolate the effect of the non-coating, smooth titanium surfaces were used as a control, eliminating the influence of surface roughness on bone response. While the overall surface roughness remained consistent across groups, subtle differences in surface topography were observed with increasing coating concentrations. Despite these topographic changes, no significant differences were found in nanoscale surface characteristics [(Ramsundar et al., 2023; Rieshy et al., 2023; Singh et al., 2023)](https://paperpile.com/c/7Spts7/gUqX3+Tt9er+UxgBl). Although a trend towards enhanced bone response was noted with vitamin D-coated plates, the results were statistically significant. This suggests that a method of coating application was required for the sustained release of vitamin D over time. Future studies should focus on optimizing coating techniques and evaluating the long-term release kinetics of the bioactive agent. It's interesting to note that immunocompromised individuals, who were previously believed to be at a higher risk of implant failure because of reduced immune function, may also benefit from developments in implant technology. Bioactive coatings have the potential to address some of the issues related to impaired bone health by promoting osteogenesis and improving the biological response of the surrounding tissue.

# Conclusion

The present work demonstrates that Ti plates dipped into the prepared solution by mixing PEGDA and Vitamin D solution in ratio 3:2. Ethyl 4-dimethylamino benzoate 0.2% was measured and added with Camphorquinone (C10H14O2) 0.5% added with 6 ml Polyethylene glycol Diacrylate (PEGDA) with 4 ml Vitamin D in a ratio of 3:2 promote in vitro performance and coating stability expression of bone formation markers and keep their osteopromotive potential in vitro and composition when stored up to 2 weeks at -28°C and avoiding light, oxygen and moisture. Developing a coating for dental implants with potential to improve the biological response in skeletal compromised structures and with minimum shelf-life stability and bioactivity is critically relevant for its further clinical application.

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