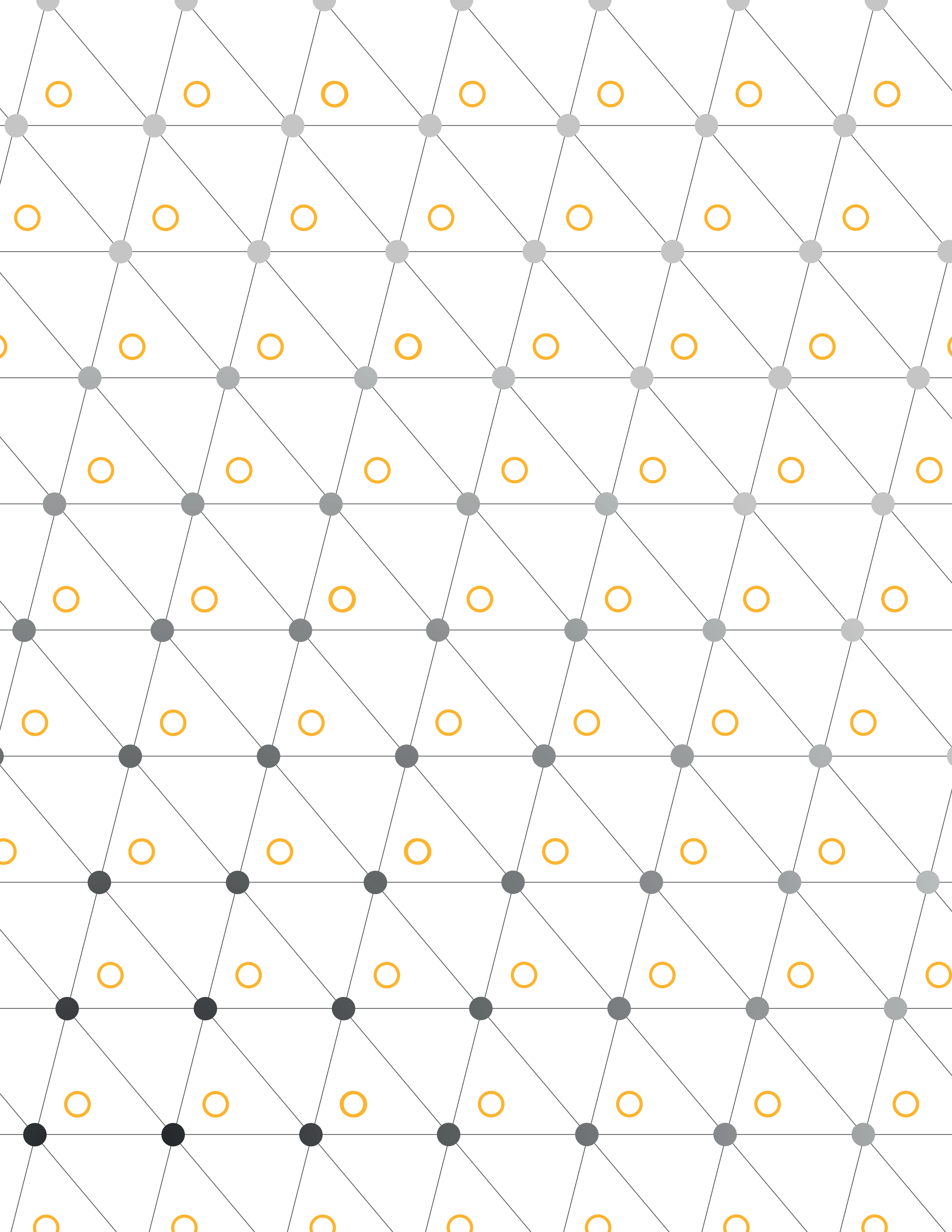
YES PLASMA NITRIDING WORKS *for* TITANIUM

Here's When and Why.

IONHEAT
Advanced Process Technologies



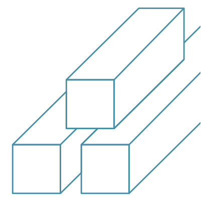
Yes, Plasma Nitriding Works for Titanium.

↘ Here's When and Why

Andrés Bernal D. | José Domingo Guerra B. | María Fernanda Cadavid T.

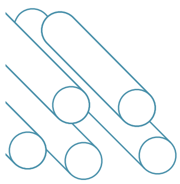
ION HEAT
Advanced Process Technologies

Named after the Titans of Greek mythology, this metal has the qualities of a true warrior:



BIOCOMPATIBLE

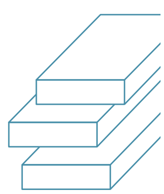
Well tolerated by the human body.



LIGHTWEIGHT

About 40% lighter than steel, yet with mechanical strength comparable to alloy steels.

CORROSION RESISTANT



Due to the spontaneous formation of a thin passive layer of titanium oxide, which protects it even in aggressive environments such as seawater or biological fluids.

Despite its exceptional properties, titanium is **not widely used as a bulk metal** because extraction and refining are costly.

Although abundant in the Earth's crust, titanium is not found in pure form but strongly bonded to oxygen. It occurs mainly as ilmenite ($FeTiO_3$), which is more common, and rutile (TiO_2), which is richer in titanium. **To be industrially useful, it must be refined, purified, and alloyed**.

Plasma nitriding for titanium

OVERVIEW

LET'S START FROM THE BEGINNING

ALLOYS

CLASSI FICATION

ALLOYS

Industrial Classification Of Titanium

ALLOY TYPE	ASTM GRADE	ALLOYING ELEMENT(S)	KEY CHARAC-TERISTICS	LIMITATIONS	TYPICAL APPLICATIONS	HEAT TREATMENT NOTES
COMMERCIALLY PURE TITANIUM (α) / CP TITANIUM (α)	GRADE 2	**Oxygen (plus traces of Fe, N, C)**	Excellent oxidation resistance. Good performance at elevated temperatures.	Lower tensile and fatigue strength compared to alloys.	Cold-formed parts or components exposed to constant heat without cyclic loading. Common in molds, housings, heat exchangers, and chemical plant structures where hardening is not required.	Not heat-treatable (does not respond to quenching or aging).
BETA (β):	GRADES 19, 20, 21, OR 38	**Vanadium, Molybdenum, Chromium, Niobium**	High hot-workability. Good response to hardening.	Lower corrosion resistance. Higher density. Limited availability and relatively higher cost.	Used where complex forming plus subsequent heat treatment is required: anchors, structural supports, or parts that need hardening	Heat-treatable (responds to quenching and aging).
ALPHA-BETA (α+β):	GRADE 5 (TI-6AL-4V) GRADE 23 (TI-6AL-4V ELI)	**Aluminum, Vanadium, or other β-stabilizers**	Balanced combination of strength, toughness, and machinability. High resistance to heavy loads and cyclic stresses. Good corrosion resistance, even in biological or marine environments.	Expensive	Versatile choice for critical components requiring machining, cyclic load resistance, and surface treatments—such as fasteners, wear parts, and nitrided components.	Suitable for surface treatments, including plasma nitriding.

GRADES 5 AND 23:
THE ESSENTIALS

The **Ti-6Al-4V** alloy (alpha-beta), classified as Grade 5, makes up more than 50% of all titanium used worldwide. It is the benchmark in aerospace, medical, and mechanical engineering.

The 6% aluminum content improves oxidation resistance while keeping the alloy lightweight, and the 4% vanadium enhances hardenability and overall strength.

Ti-6Al-4V ELI (Extra Low Interstitials) —Grade 23— is a version of Grade 5 with lower amounts of interstitial elements such as oxygen, nitrogen, and carbon. It is widely used in medicine and dentistry because of its excellent chemical stability and reliable performance in long-term contact with biological tissues.

WHY

NITRIDING TITANIUM?

BECAUSE

Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

IONHEAT
Advanced Process Technologies

IMPROVING WEAR RESISTANCE

1

Plasma nitriding is not a conventional heat treatment because it does **not alter the bulk structure of the material or depend on phase transformations**. It is a thermo-chemical surface process in which nitrogen atoms are energized in a plasma and diffuse into the titanium surface, **forming hard titanium nitrides such as TiN and Ti_2N**.

This is especially important for titanium, whose most recognized limitation is its poor surface wear resistance.

While titanium has excellent corrosion resistance and high tensile strength, its surface deteriorates rapidly in applications involving sliding contact, continuous friction, or moderate abrasion.

This premature wear can shorten component life, cause loss of dimensional accuracy, or interfere with the function of moving or precision parts.

> By producing a hard nitride layer on the surface through plasma nitriding, **wear resistance is greatly increased without affecting the core properties of the material.** The result is a more stable, longer-lasting surface that performs well under prolonged mechanical contact.

PRESERVING CORROSION RESISTANCE

2

One of titanium's most important properties is its **excellent corrosion resistance**, even in aggressive environments such as saline solutions, marine atmospheres, or biological systems. This performance comes from the spontaneous formation of an ultrathin, stable, and self-healing passive layer of titanium oxide (TiO_2).

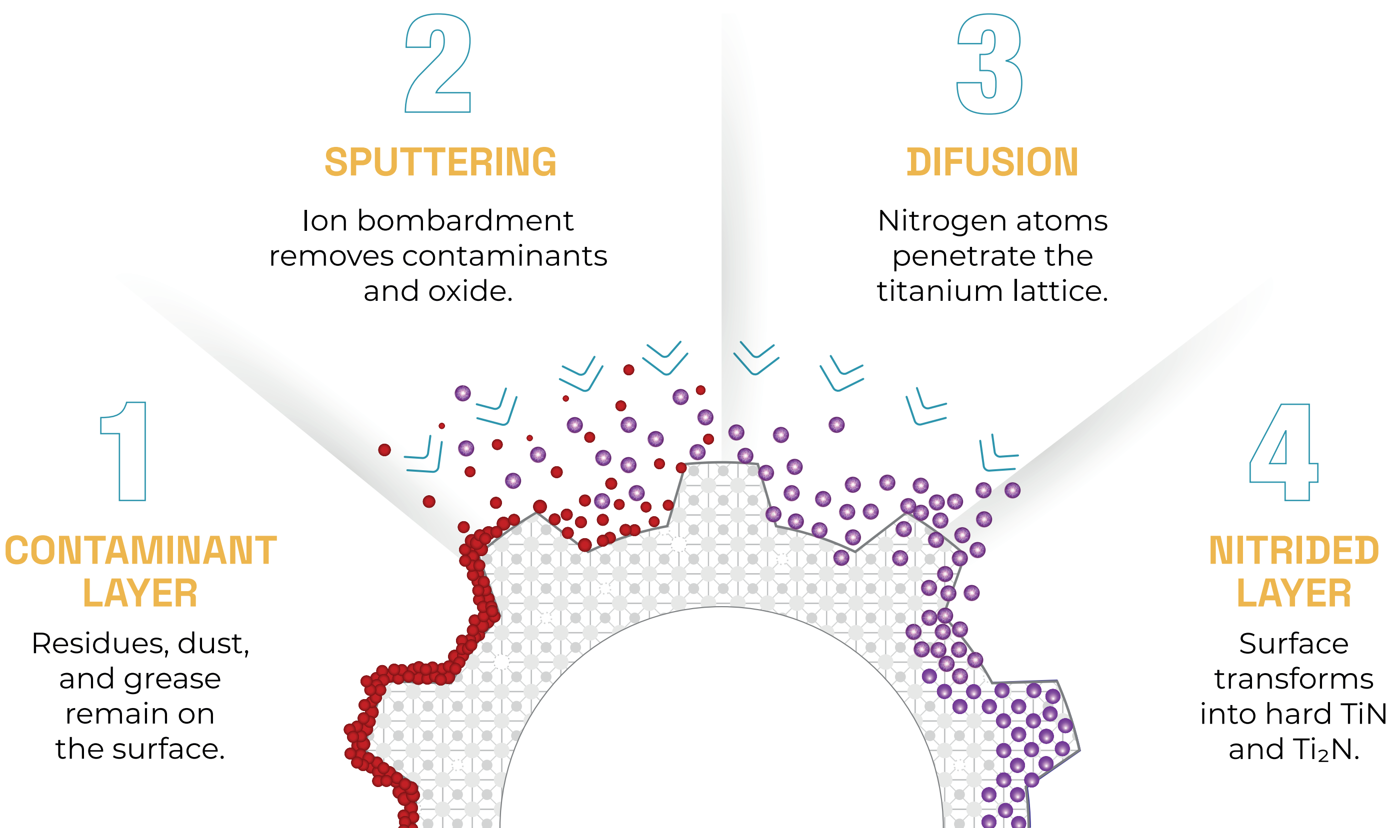
Conventional heat treatments can compromise this layer, especially when carried out:

- In atmospheres containing free oxygen.
- At high temperatures for long durations.
- Without precise control of the process gases.

Under these conditions, the oxide layer can grow excessively and become porous, brittle, or discontinuous, losing its protective function and weakening the surface's chemical resistance.
Plasma nitriding, on the other hand, is performed under vacuum in tightly controlled atmospheres, using a plasma ignition system that activates the surface through a **process known as sputtering**.

During sputtering, plasma ions bombard the surface, **removing impurities, contaminants, and the existing passive film**. Rather than being a drawback, this step is critical: it leaves the surface clean, active, and ready to form a new protective layer.

Instead of the original TiO_2 film, the surface develops titanium nitrides (TiN and Ti_2N), which are chemically stable, highly corrosion resistant, and far harder than the native oxide.



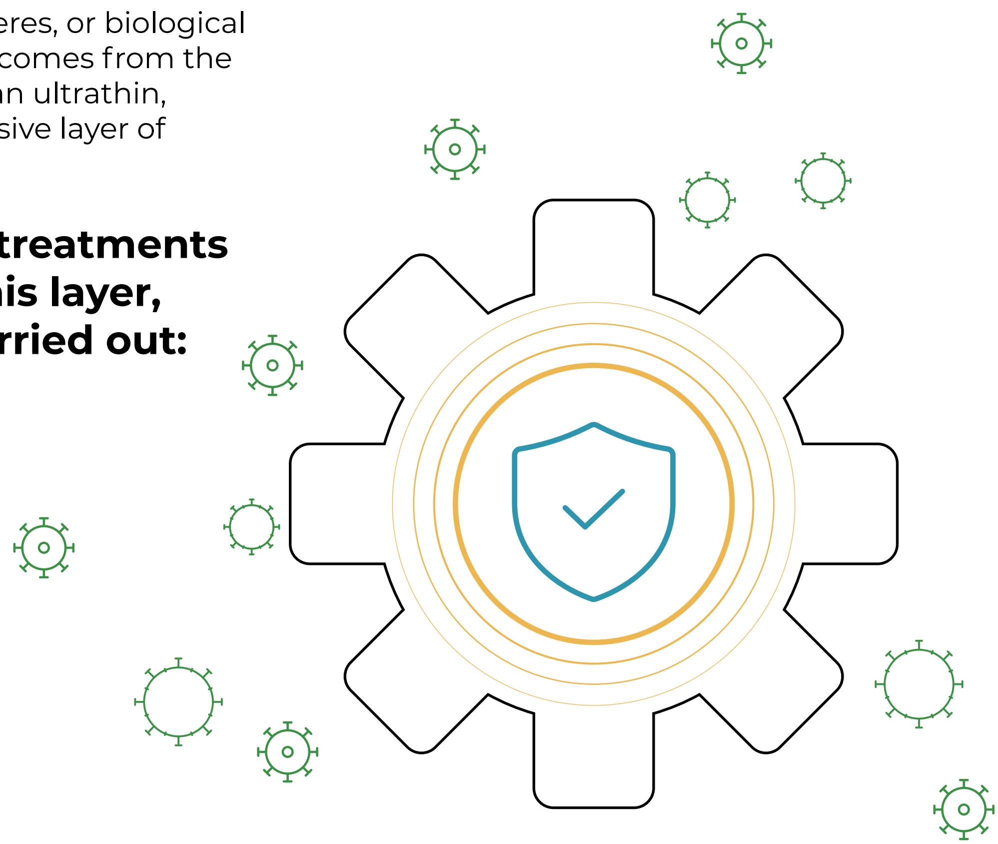
In short, plasma nitriding removes the initial passive layer but replaces it with a more effective protective barrier, preserving—and even enhancing—the chemical resistance of titanium in aggressive environments.

PRESERVING BIOCOMPATIBILITY

3

One of titanium's most important properties is its excellent corrosion resistance, even in aggressive environments such as saline solutions, marine atmospheres, or biological systems. This performance comes from the spontaneous formation of an ultrathin, stable, and self-healing passive layer of titanium oxide (TiO_2).

Conventional heat treatments can compromise this layer, especially when carried out:



CERTIFYING

CRITICAL PARTS WITHOUT MARGIN FOR ERROR

4

Industrial, surgical, aerospace—some applications leave no room for mistakes or variation. When a part must perform flawlessly for years—whether inside the human body or in flight—surface treatment cannot be experimental. It has to be repeatable, traceable, and certifiable.

That is exactly what plasma nitriding delivers.

Because it is performed in a controlled vacuum environment, free from unpredictable chemical atmospheres, plasma nitriding ensures that every cycle:

- Uses the exact same parameters (temperature, voltage, pressure, time, and gas composition).
- Produces consistent, verifiable results.
- Is digitally recorded, with integrated process reports, ideal for certified quality systems.

> This is especially critical in **aerospace,** where a single failure can be catastrophic, and in **biomedical applications,** where every screw or implantable device must be sterile, biocompatible, and completely reliable.

Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

BENE-
FITS

ADVANTAGES *of* PLASMA NITRIDING

Enhanced Properties

Plasma nitriding significantly modifies the surface of titanium, enhancing its mechanical properties while leaving the bulk structure unchanged.

SURFACES HARDNESS

Hardness values of **1,800-2,100 HV** are measured in the outer TiN layer after plasma nitriding.

In the intermediate diffusion zone (Ti_2N and a-Ti(N)), hardness ranges from **800 to 900 HV.**

For commercially pure titanium, post-treatment hardness is typically 550-890 HV.

NITRIDED LAYER THICKNESS

Outer compound layer of TiN/Ti_2N: typically 3-5 µm.

Additional diffusion zone: 20-50 µm.

COMPRESSIVE STRESSES

The nitrided layer develops **residual compressive stresses** at the surface, ranging from 1 to 5 GPa depending on the material and process parameters. These stresses are essential **for improving fatigue resistance** and delaying crack initiation.

Precise Temperature Control

At room temperature, titanium exists in the alpha (α) phase, with a hexagonal close-packed (HCP) crystal structure.

Above about 882 °C, it transforms into the beta (β) phase, which has a body-centered cubic (BCC) structure. Unlike steels—**where the austenite-to-martensite transformation directly produces hardening**—this phase change in titanium does not by itself create harder microstructures.

Instead, the α-to-β transformation is used as a tool to:

Improve the diffusivity of elements such as nitrogen.

Facilitate hot forming and forging.

Adjust the balance between α and β phases to tailor toughness, ductility, and fatigue strength.

Titanium also has low thermal conductivity, which promotes internal temperature gradients during conventional heat treatments. This can lead to localized overheating, uneven microstructures, or undesirable residual stresses.

This is where plasma nitriding in hot-wall furnaces makes a difference: **it enables slow, stable, and uniform heating cycles that minimize temperature variations within the part and preserve the integrity of its microstructure.**

Controlled Atmosphere

Above 600 °C, titanium becomes highly reactive to elements such as oxygen, nitrogen, carbon, and hydrogen, increasing the risk of forming brittle or undesirable surface layers.

One of the key advantages of plasma nitriding is that it is carried out in a controlled vacuum atmosphere, minimizing unwanted reactions.

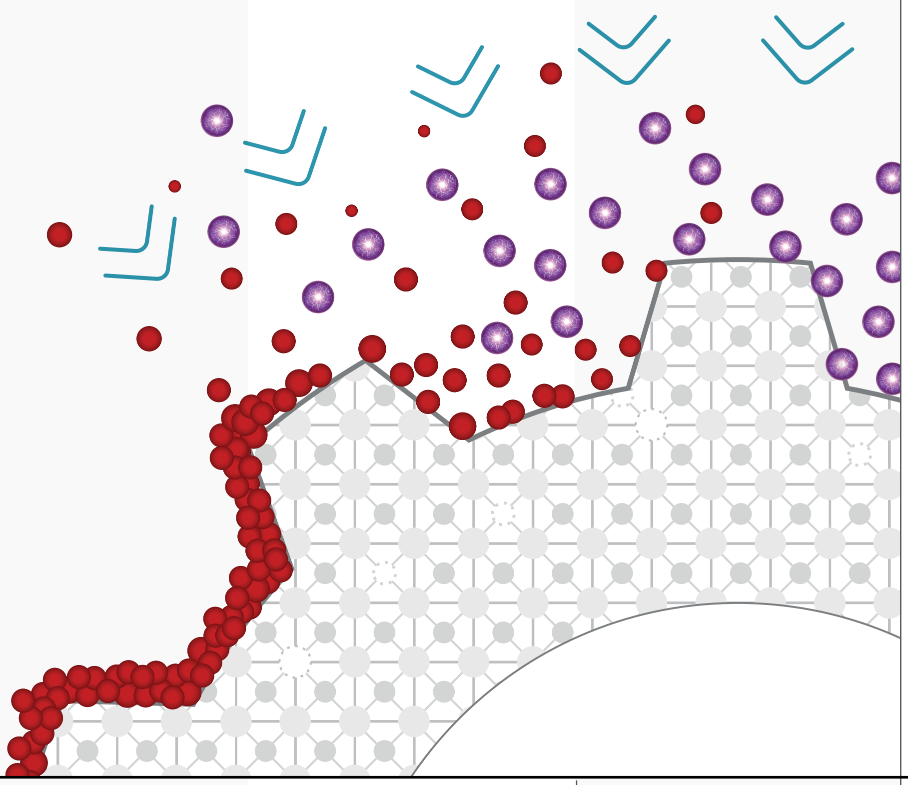
This helps avoid:

- **Oxidation, which degrades the protective passive layer.**
- **Hydrogen embrittlement, which sharply reduces toughness and can cause internal cracking.**
- **Carburization, which produces brittle carbides (TiC) that reduce surface ductility.**
- **The formation of irregular or unstable nitrides that compromise mechanical strength.**

This tightly regulated environment preserves surface integrity and ensures the foundation for a high-precision treatment.

D

Sputtering



As noted earlier, a natural part of the plasma nitriding process is the ion bombardment known as sputtering, which actively **cleans the surface of components** before nitrogen diffusion begins.

This step removes oils, greases, metallic particles, and dust—a critical factor for titanium, since any contaminant in contact with the hot metal can degrade surface quality and compromise essential properties such as **biocompatibility or adhesion** of the nitrided layer.

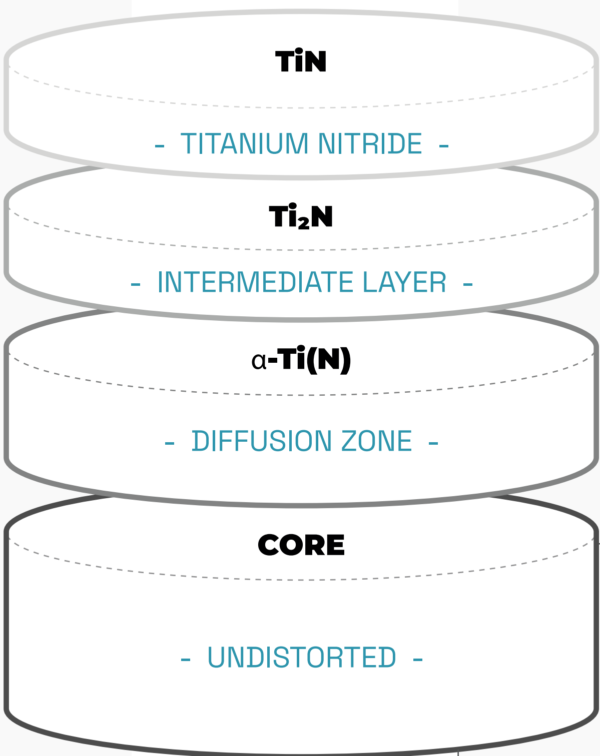
Nitrided Layer

Unlike processes such as anodizing, PVD, or other coating techniques, plasma nitriding does not deposit an external layer on the part. Instead, it alters the atomic composition of the titanium surface by diffusing nitrogen into the crystal lattice.

This distinction is crucial:

- No added coating.
- No risk of delamination.
- No dimensional issues or interference in precision fits.

The modified layer form within the base metal itself and typically consists of three well-defined zones:



- **A very hard, ceramic-like, golden surface layer.**
- **With high hardness and excellent adhesion.**
- **Nitrogen dissolved in the titanium lattice, more ductile and gradual in structure, acting as an anchor to prevent crack propagation.**

This graded architecture produces a system that is hard on the outside and tough on the inside, improving wear resistance without altering part geometry, while withstanding thermal cycling and dynamic loads without risk of flaking or spalling.

ION HEAT Advanced Process Technologies

Masking

Plasma nitriding can be applied only where it is required, thanks to the ability to mask selected areas of a component before processing.

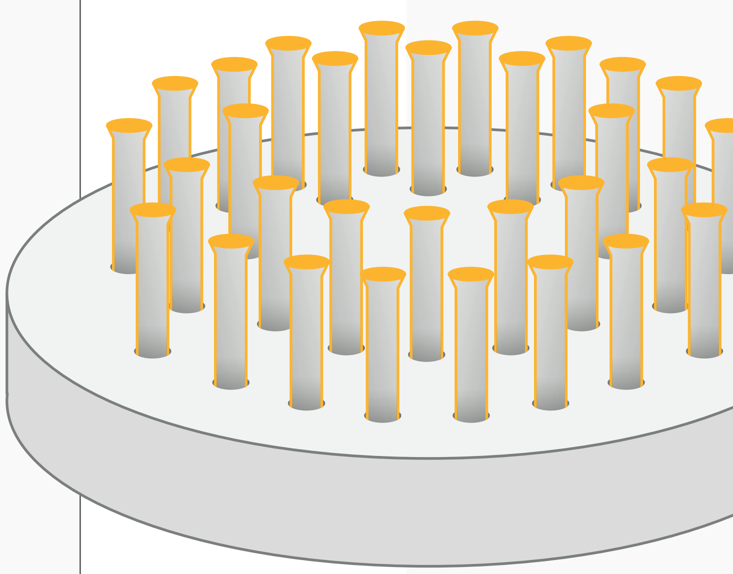
This is particularly useful for:

Holes, grooves, or narrow cavities where a hardened layer could hinder assembly, interfere with tolerances, or create unwanted stresses.

Electrical contact areas, such as threads or mating surfaces, where conductivity must be preserved.

Surfaces that require subsequent joining processes, such as welding or specialized coatings.

Masking is done using conductive or insulating materials such as stainless steel sheets, metal meshes, or temporary plasma-resistant coatings. These block plasma activation on protected areas and prevent nitrogen diffusion into those regions.



Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

LIMITS

WHEN PLASMA NITRIDING TITANIUM *is* NOT RECOMMENDED

While plasma nitriding offers significant benefits, it is not a universal solution. There are cases where it may be unnecessary—or even counterproductive:

A

WHEN THERE IS NO SIGNIFICANT FRICTION OR WEAR

If the surface of the part is not subject to sliding contact, abrasion, or surface fatigue, hardening it by plasma nitriding may not be needed. In such cases, the cost of treatment is not justified by the functional gain.

B

WHEN A SPECIALIZED COATING IS REQUIRED

In medical applications, for example, some implants are coated with hydroxyapatite to promote osseointegration. Plasma nitriding beforehand may reduce coating adhesion or alter its bioactive properties.

NOT RECOMMENDED

C

WHEN THE DESIGN CREATES SHADOWED AREAS

Plasma nitriding relies on direct ion bombardment, so geometries with deep recesses, closed cavities, or very sharp angles may prevent uniform treatment. These areas can end up only partially nitrided—or left untreated altogether.

COMPARE

ADVANTAGES OF PLASMA NITRIDING *over* GAS NITRIDING

BENEFITS

Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

IONHEAT
Advanced Process Technologies

Advantages of Plasma Nitriding Compared to Gas Nitriding:

01 PROCESS CONTROL

Plasma nitriding allows precise adjustment of variables such as voltage, pressure, temperature, atmosphere composition, and time. **This ensures consistent, repeatable, and customizable results.**

Gas nitriding, by contrast, offers less refined control and is more sensitive to environmental or load variations.

02 AVOIDANCE OF BRITTLE COMPOUNDS AND UNWANTED REACTIONS

In gas nitriding, the ammonia-rich atmosphere can form excessive or unstable compounds—particularly in titanium, where overly thick or porous TiN layers may compromise mechanical performance or layer adhesion.

Plasma nitriding, performed under vacuum, **minimizes contamination and regulates layer growth.**

03 TEMPERATURE CONTROL ADAPTED TO THE MATERIAL

In plasma nitriding, temperature is not dictated by gas decomposition but can be precisely set according to the alloy and the desired outcome.

ION HEAT furnaces, for example, can be equipped with add-ons capable of reaching up to 850 °C, making it possible to treat complex titanium alloys that require higher temperatures without losing control of the process.

Gas nitriding, on the other hand, operates within more rigid parameters, since it relies on gas decomposition, which makes it difficult to achieve precise or reproducible thermo-chemical profiles.

04 NO HARMFUL BYPRODUCTS

Gas nitriding generates chemical residues, requiring post-process treatment and controlled ventilation.

Plasma nitriding produces **no hazardous waste, uses no toxic gases such as ammonia, and does not contaminate the parts or the environment.**

05 INTEGRATED CLEANING (SPUTTERING)

Whereas gas nitriding requires separate pre-cleaning, plasma nitriding incorporates ion cleaning that automatically prepares the surface before treatment.

This improves nitrogen uptake and prevents failures due to contamination.

06 SELECTIVITY AND MASKING

Plasma nitriding can be **applied only to the required zones** by masking holes or critical surfaces.

Gas nitriding, in contrast, exposes the entire surface to nitrogen with no localized control.

07 THINNER, HARDER, AND MORE ADHERENT LAYER

Plasma nitriding forms a thinner but **denser and more uniform layer, with excellent wear resistance and metallurgical adhesion.**

Gas nitriding can produce thicker layers, but they are less controlled and show sharper transitions between the compound layer and the base metal.

IN SUMMARY

For surface treatment of titanium parts, plasma nitriding offers key advantages over gas or salt bath techniques, particularly in thermal control, process cleanliness, compatibility with critical applications, and the quality of the resulting layer.

What about SALT BATHS?

Although salt bath nitriding is used in surface treatment of metals, it is not suitable for titanium for several reasons:

Bath temperatures do not provide the same level of thermal control as plasma.

Exposure to this environment can cause unwanted reactions or alter the surface microstructure of titanium.

The process generates hazardous chemical waste, such as nitrite or molten nitrate salts, which require specialized handling and have a significant environmental impact.

CAN *all* PLASMA NITRIDING FURNACES TREAT TITANIUM?

Not necessarily. Most plasma nitriding furnaces operate between 400 and 600 °C, but certain alpha-beta titanium alloys—such as Ti-6Al-4V—may require temperatures near 850 °C to produce a deeper nitrided layer with improved tribological properties, provided the resulting microstructure is carefully controlled.

Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

IONHEAT
Advanced Process Technologies

This is not about raising temperature arbitrarily: pure or alpha alloys, for example, can be nitrided at standard ranges without issue. But when the application requires higher wear resistance or a thicker layer **without compromising biocompatibility,** the thermal increase is justified.

HIGH-TEMPERATURE ADD-ON

Nitriding titanium up to 850 °C

—without losing control —

Although salt bath nitriding is used in surface treatment of metals, it is not suitable for titanium for several reasons:

Extend the furnace's thermal range with full stability and **precision.**

Process demanding titanium alloys without **precision.**

Preserve all the advantages of plasma: cleanliness, control, selectivity, and **biocompatibility.**

This added capability is not common in standard plasma furnaces,
yet it is critical when design, load, or application requirements demand it.

IONHEAT Advanced Process Technologies

Titanium
Yes, Plasma Nitriding Works for Titanium. Here's When and Why.

IONHEAT
Advanced Process Technologies

INVESTING IN A PLASMA NITRIDING FURNACE IS A *major* DECISION

That's why our technical consultations are not about persuasion, but about guiding a careful analysis of feasibility, capabilities, and real-world applications—based on each customer's parts, materials, and industry.

If you are considering plasma nitriding for titanium components, let's talk. We back your decision with solid technical reasoning, proven experience, and reliable data.

IONHEAT
Advanced Process Technologies