DEFENSE & AEROSPACE DESIGN GUIDE

PRECISION MANUFACTURING FOR DEFENSE & AEROSPACE INDUSTRY

A comprehensive guide to materials, processes, tolerances, and manufacturing partnerships for critical defense and aerospace applications.

PHOTOFABRICATION ENGINEERING INC.
PHOTOFABRICATION.COM

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CHAPTER ONE

TODAY'S DEFENSE & AEROSPACE INDUSTRY

There has never been a more consequential moment to be part of the defense and aerospace industry. Driven by geopolitical uncertainty, accelerating technological competition, and a historic wave of government investment, the sector is expanding at a pace that is reshaping American manufacturing from the ground up — and creating enormous demand for the precision components that enable modern defense and aerospace systems.

A SECTOR ON THE RISE

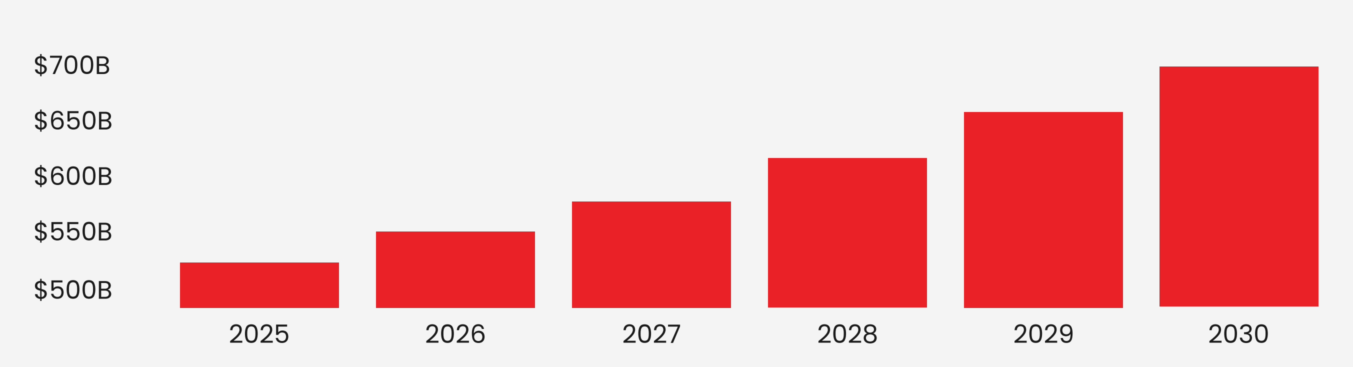
The numbers tell a compelling story. According to the Aerospace Industries Association, the U.S. aerospace and defense industry generated nearly $1 trillion in total business activity in 2024 — accounting for 1.5% of the nation's GDP and supporting more than $257 billion in wages across 2.2 million workers.

~$1T
TOTAL BUSINESS ACTIVITY (2024)

$257B
WAGES SUPPORTED

2.2M
WORKERS EMPLOYED

And the trajectory only points upward.



The defense programs that were on the drawing board just a few years ago are now in production, driving the need for precision parts and components built to tolerances that would have seemed extraordinary just a decade ago.

The aerospace industry is experiencing its own surge as manufacturers ramp up commercial airplane production, satellite demand surges, the space economy continues to draw both public and private investment at record levels, and UAVs are used in dozens of applications.

THE DEMAND FOR PRECISION PARTNERS IS HIGHER THAN EVER

Behind these headline figures lies a more granular reality that directly affects how defense and aerospace systems are designed and built. Fighter jets, commercial airplanes, unmanned aerial vehicles, missile guidance systems, and satellites are defined by their components. And those components are getting smaller, lighter, more complex, and held to tighter tolerances than ever before.

Thin metal parts sit at the heart of this challenge. The requirements for shielding, filters, meshes, contacts, apertures, flexures, and heat-management components are extraordinary in volume across all platforms. As systems are miniaturized and performance demands intensify, the ability to produce these parts with micron-level precision — repeatably and at scale — has become a genuine competitive differentiator.

The materials story adds further complexity. Titanium is among the fastest-growing materials in aerospace manufacturing, driven by its strength-to-weight ratio and its importance in applications where reducing mass is critical to performance. Stainless steel, nickel alloys, and Beryllium copper each bring their own manufacturing challenges.

> *For fabricators, the ability to work across a broad range of materials without sacrificing dimensional accuracy or surface quality is no longer a luxury — it is a baseline expectation.*

Even as 2024 delivered record revenue across aerospace and defense, demand has persistently outpaced supply, and capacity has remained constrained. Supply chain disruptions — from rawmaterial shortages to skilled labor gaps — have exposed vulnerabilities that prime contractors and OEMs are working urgently to address.

An average U.S. commercial aerospace OEM has more than 200 tier 1 suppliers and upward of 12,000 tier 2 and tier 3 suppliers, says Deloitte Insights. When any link in that chain is unreliable, the entire program feels the impact. As a result, procurement teams are scrutinizing their supplier relationships with a rigor that didn't exist even five years ago. Certifications, quality systems, ontime delivery records, and engineering capability are all under the microscope.

This environment has elevated the importance of the manufacturing partner relationship. It is no longer enough to quote a competitive price. The partners who are winning and keeping long-term contracts are the ones who bring engineering knowledge to the table, maintain consistent quality, and can flex with program demands from prototype to production.

WHY THIS MOMENT MATTERS

The defense and aerospace industry is booming. Investment in next-generation platforms, the reshoring of critical manufacturing, and the expansion of the commercial space economy are all reinforcing a multi-year demand cycle. For companies that rely on precision thin metal components, the critical question is not whether demand will be there; it's who will be able to meet it.

Uncovering new solution providers with expertise in engineering, prototyping, flexible manufacturing processes, and quality assurance can be daunting. But there are partners available with the highest certifications and reputations for excellence.

The “Precision Manufacturing for Defense & Aerospace Industry Design Guide” covers these topics to help you get the information to make the right decision. We all know that in this industry, getting it right isn’t an option; it’s mandatory.

CHAPTER TWO

THE IMPORTANCE OF DESIGN FOR MANUFACTURING & ENGINEERING EXPERTISE

As designers and engineers strive to push the boundaries of manufacturing, they must focus on creating parts and components efficiently and cost-effectively. This process, known as Design for Manufacturability (DFM), delivers quality and quantity.

When R&D departments and manufacturing engineers align their goals, improved communication and collaboration lead to more innovative and feasible designs.

THE BENEFITS OF DFM

- Minimizing production costs by simplifying manufacturing processes and reducing the quantity of complex or custom-made components
- Decreases material waste by maximizing material usage during manufacturing for peak efficiency
- Reduces the need for manual adjustments and fine-tuning during production
- Streamlines production process, leading to shorter lead times

Plus, DFM enhances the quality, reliability, and performance of parts and components while reducing manufacturing defects during production runs.

> *Hand-in-hand with DFM, defense and aerospace manufacturing companies benefit when their solutions providers have in-house engineers to vet the part's design, offer guidance on manufacturing processes, and troubleshoot application issues before the fabrication begins.*

Combining the DFM philosophy with expert engineers speeds design revisions and updates without major disruptions to production runs. The quality assurance process is smoother, and customers reject fewer parts and components because the manufacturer pays more attention to the project at the start.

CHAPTER THREE

BENEFITS OF RAPID PROTOTYPING

Every defense and aerospace manufacturer aims to move from concept to final product as quickly as possible. One sure way to speed up this process is to utilize rapid prototyping in the early stages of product development.

Quick-turn design reviews and manufacturing technologies, ideal for prototyping, allow engineers to quickly create functional prototypes of essential parts and components without traditional tooling or molds.

LEADING PROTOTYPING METHODS

Leading defense and aerospace manufacturing companies often utilize these prototyping methods:

01

PHOTOCHEMICAL ETCHING

Ideal for producing thin, complex metal components with tight tolerances and high precision.

02

3D PRINTING

Used for plastics and metals, allowing for fast iteration and testing via additive manufacturing.

03

PRECISION MACHINING & LASER CUTTING

Can create highly durable prototypes closely resembling the final product.

BENEFITS OF RAPID PROTOTYPING

- Accelerated time to market
- Cost efficiency
- Enhanced design flexibility
- Improved accuracy and precision
- Facilitation of regulatory compliance

When it comes to working with a precision manufacturing center for prototyping, select one that can work quickly, produce prototypes economically, deliver accurate parts for verification, and has experience in the industry.

CHAPTER FOUR

MODERN MANUFACTURING PROCESSES

Defense and aerospace companies have several options for fabricating parts and components for critical applications. It is crucial to select the one that offers precision, durability, and reliability. Let's look at some of the most common and the benefits of each.

PROCESS OVERVIEW

PROCESS	DESCRIPTION	BEST FOR
Photochemical Etching (PCE)	Subtractive manufacturing using chemical etchants; produces thin metal parts to exacting tolerances at ambient temperature	Complex geometries, tight tolerances, high volume, material integrity
Laser Cutting	High-powered laser beam cuts or engraves materials with high precision via CNC-directed optics	Thicker materials, intricate single-part designs, lower volume
Stamping	Reshapes flat metal sheets using specialized tools and presses; includes blanking, piercing, bending, embossing	High-volume simple shapes; typically requires post-process deburring

PCE VS. LASER CUTTING: KEY DIFFERENCES

Of the three, laser cutting and photochemical etching offer the highest level of precision, making them suitable for intricate designs and tight tolerances. Both can handle various materials and are non-contact processes — resulting in burr-free and stress-free parts.

> *PCE offers distinct advantages in material integrity, burr-free edges, design flexibility, scalability, cost efficiency, and material versatility — making it an excellent choice for high-precision, intricate parts in defense and aerospace applications.*

FACTOR	LASER CUTTING	PHOTOCHEMICAL ETCHING (PCE)
Heat	Uses heat to vaporize metal; risk of thermal distortion and slag	Chemical process at ambient temperature; preserves material integrity
Edge Quality	Often leaves burrs requiring additional finishing	Produces clean, burr-free edges
Volume	Only one feature cut at a time	Multiple parts etched simultaneously
Waste	Produces melted metal burrs on exit side	Clean removal of unprotected metal only

CHAPTER FIVE

WHAT IS PHOTOCHEMICAL ETCHING?

Photochemical etching, also known as precision chemical machining, photochemical machining, or chemical blanking, is a highly precise, cost-effective metal removal process used to produce complex components from a wide range of metals.

The intricate process removes selective areas of the metal sheet using chemical etchants. First, a light-sensitive photoresist is applied to the metal surface. Then, a detailed pattern of the desired part is transferred to the material via LED printers, which offer exceptional tool alignment accuracy and repeatability. When exposed to light, photoresist hardens, protecting some areas while leaving others exposed. Chemical etchants are then applied to dissolve the unprotected metal, leaving the component with its precise, intricate shape.

THE PCE PROCESS STEP BY STEP

1 APPLY PHOTORESIST

Light-sensitive photoresist is applied to

2 PATTERN TRANSFER

Part pattern transferred via LED printers with exceptional alignment accuracy.

3 LIGHT EXPOSURE

Photoresist hardens where exposed, protecting select metal areas.

4 CHEMICAL ETCHING

Etchants dissolve unprotected metal, leaving the precise final shape.

COMMON PARTS PRODUCED BY PCE

Microwave Antennas
Clips & Springs
RF/EMI Shields
Screens & Contacts
Shims
Step Lids Encoders
Encoders
Microwave Circuit Stators

ADVANTAGES OF PHOTOCHEMICAL ETCHING

- Fast turnaround times
- Competitive costs
- Tight tolerances
- Precise, complex geometries
- Burr-free, stress-free parts
- Low-cost tooling
- Design flexibility
- Material optionality
- Production scalability

CHAPTER SIX

PCE DESIGN GUIDES FOR THE DEFENSE & AEROSPACE INDUSTRY

Here are some guidelines for designing or specifying photochemically etched parts or components. The data presented here apply to a variety of metal thicknesses and are generally applicable to the equipment, processes, metals, and configurations. However, these guidelines do not define the ultimate capabilities of photochemical etching.

GENERAL TOLERANCES

± 10% material thickness. No less than ± 0.0005"

HOLE DIAMETER & FEATURE RELATIONSHIPS

In general, the diameter of a hole (D) cannot be less than the metal thickness (T). This relationship varies with metal thickness:

METAL THICKNESS (T)	SMALLEST HOLE DIAMETER (D)
0.0003 in. – 0.0040 in. (0.00762 mm – 0.1016 mm)	0.0050 in. (0.1270 mm)
METAL THICKNESS (T)	**SMALLEST HOLE DIAMETER (D)**
0.0050 in. (0.127 mm) or over	At least 110% of the metal thickness

PRACTICAL HOLE SIZES BY SAMPLE THICKNESS

METAL THICKNESS (T)	SMALLEST HOLE DIAMETER (D)
0.001" – 0.006"	0.008" Ø
0.007" – 0.012"	≈ 1.2 × T
0.013" – 0.020"	≈ 1.4 × T
0.021" – 0.040"	≈ 1.6 × T
0.041" or over	≈ 1.8 × T

Basic features such as length and width follow similar rules. When in doubt, consider 1.2 × T for dimensions and 15% of T for tolerance. Tighter tolerances can be achieved.

LINE WIDTH RELATIONSHIPS

The width of the metal between holes is not a particular problem in chemical etching. However, when this space is the remaining surface area in a large field of slots or holes, there are limitations:

METAL THICKNESS (T)	SPACE BETWEEN HOLES (W)
Less than 0.0050 in. (0.127 mm)	At least the metal thickness
0.005 in. (0.127 mm) or over	At least 120% of the metal thickness

CORNER RADII

INSIDE CORNER RADIUS

The smallest corner radius is approximately equal to the metal thickness (i.e., for a 0.002-in. [0.0508 mm] metal, the corner radius would be 0.0020 in. [0.0508 mm]).

OUTSIDE CORNER RADIUS

Outside corners tend to etch more sharply than inside corners. Therefore, radii less than the metal thickness can be obtained. As a general rule, outside radii are considered to be at least 75% of the metal thickness (T).

FEATHER

Etchant attacks the material laterally as well as vertically. Assuming the material is etched equally from both sides, a feather is produced. As a general rule, when etching from two sides, the feather (F) is approximately 10% of the metal thickness.

CENTER-TO -CENTER DIMENSIONS

Center-to-center tolerances are often gauged photographically, typically within ±0.0005 inches (±0.013 mm) over 6 inches (152 mm):

CENTER-TO-CENTER DIMENSIONS	TOLERANCE
1.0 in. (25.4 mm) or less	+/- 0.0002 in. (0.00508 mm)
1.0 in. – 3.0 in. (25.4 mm – 76.2 mm)	+/- 0.0002 in. (0.00508 mm)
3.0 in. – 6.0 in. (76.2 mm – 152.4 mm)	+/- 0.0003 in. (0.0762 mm)
6.0 in. – 10.0 in. (152.4 mm – 254.0 mm)	+/- 0.0003 in. (0.0762 mm)

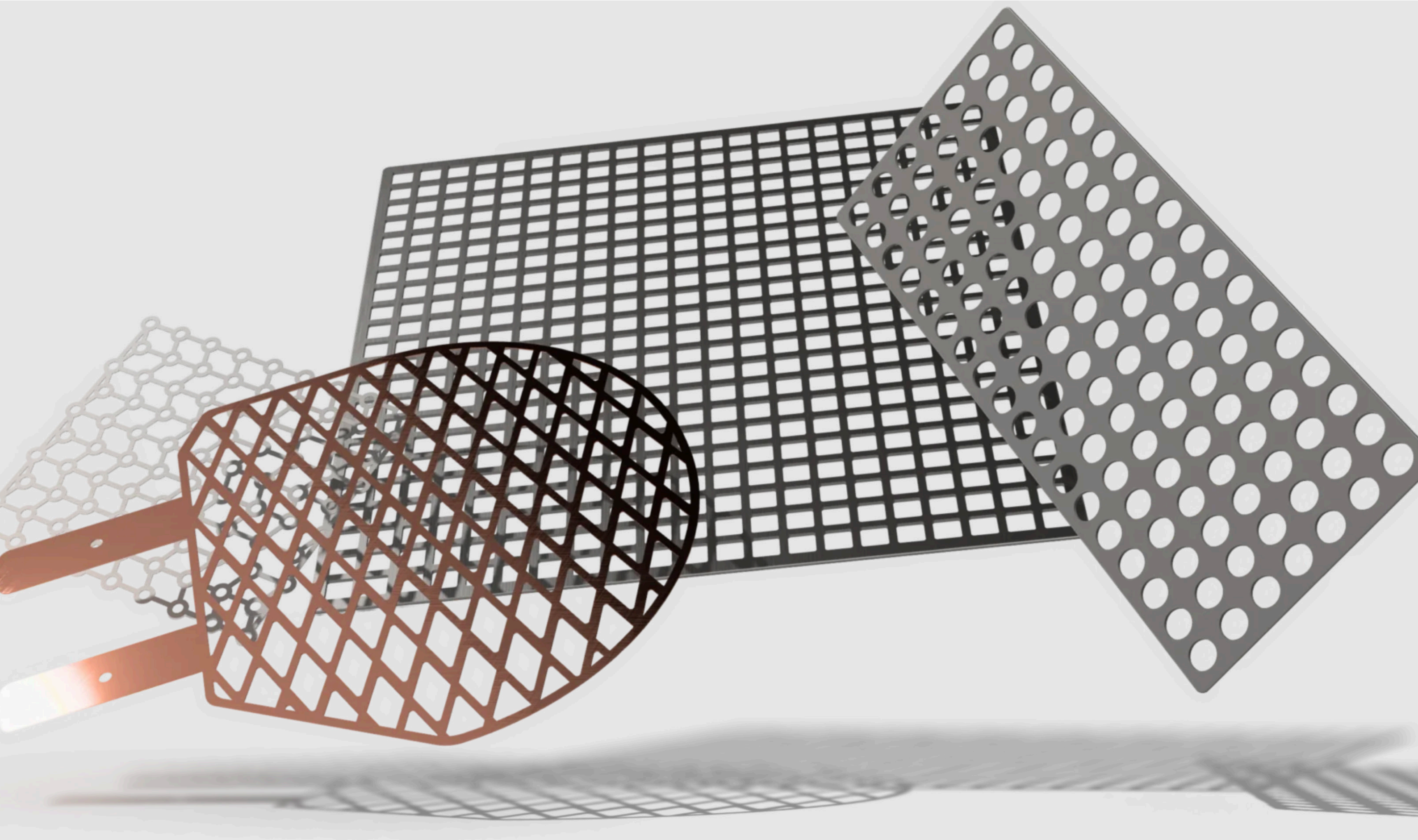
SLOT WIDTH & HOLE SIZE

The smallest slot width many etchers can produce is 90% to 120% of the metal thickness, depending on the design and metal thickness. The minimum practical slot that can be etched is 0.004" (0.102 mm).

The smallest hole width many etchers can produce is 90% to 120% of the metal thickness, depending on the design and metal thickness. The minimum practical diameter that can be etched is 0.004" (0.102 mm).

All corners in a part, within or along the outside edge, will have a radius. The smallest recommended inside radius is equal to the metal thickness. About 0.9 times the metal thickness for the outer radius is the smallest recommended.

> **NOTE**
> These are general design specifications. Consult with the precision photochemical etching company you choose to work with for their exact capabilities.



CHAPTER SEVEN

CONTROL GRIDS PART SPOTLIGHT:

Control grids for traveling wave tubes (TWTs) are becoming increasingly essential components for the defense and aerospace industries, given their use in high-power microwave systems and radio frequency (RF) power amplifiers. Control grids amplify RF signals and control the flow of electrons through the devices.

WHAT IS A TRAVELING WAVE TUBE?

A traveling wave tube (TWT) is a specialized vacuum tube that amplifies radio frequency (RF) signals in the microwave range. A vacuum tube controls the flow of electric current between electrodes to which a differential electric potential has been applied.

The control grid within a TWT plays a crucial role in managing the flow of electrons through the device. It directs electrons with high precision to a specified area or point. In fact, it can control, shape, and focus the electron beam inside TWTs or electron guns.

A user controls the electron beam with precision by varying the voltage applied to the control grid. Efficient amplification or focusing of electron beams within a device is crucial for optimal operation.

TWT APPLICATIONS IN DEFENSE & AEROSPACE

- Microwave receivers
- Communication satellites
- Radar systems
- Threat detection & deterrence
- Troposcatter communication

WHY PCE FOR CONTROL GRIDS?

Photochemically etched grids have straight side walls, are smooth with burr-free surfaces, and have accurately controlled features ideal for forming and assembly alignment.

Additional benefits include:

- Superior finish not available from electrical discharge machining
- Precise and repeatable processes
- Straight side wall surfaces
- Annular ring walls aligned to the radius of curvature
- Smooth and burr-free surfaces
- Center ring diameter and outside locating diameter are accurately controlled for assembly alignment

CHAPTER EIGHT

WHY QUALITY ASSURANCE IS ESSENTIAL

Manufacturing companies producing parts, components, and assemblies for the defense and aerospace industries must ensure compliance with the highest standards through stringent quality assurance processes.

Leading fabricators empower their production teams to check and verify product quality throughout the fabrication cycle rather than just as the final step. This philosophy creates a relationship of trust between the fabricator and manufacturer, enabling quicker implementation on the manufacturer's floor because every part is ready upon delivery. Active quality assurance reduces costs by driving fewer returns and faster turnaround times.

QUALITY ASSURANCE

Quality assurance technology includes optical measurement tools such as:

- Keyence CMMs
- OGP® SmartScopes
- XRF scanning machines to validate material properties and plating thickness
- Optical comparators
- Infrared guns & X-ray systems
- Rockwell Hardness testers
- Digital micrometers and digital calipers

INDUSTRY CERTIFICATIONS

All of the expertise and technology help fabricators adhere to the industry standards. At a minimum, manufacturers should be ISO 9001 certified, which demonstrates compliance with quality standards. Plus, manufacturers must be at least CMMC compliant.

AS9100D

ITAR

ISO 9000 / ISO 9001

CMMC COMPLIANT

> *Ensuring that any manufacturing partner under consideration has quality assurance as a core tenet is vital for any defense and aerospace company qualifying a new service provider. Not only will that partner keep your production floor humming, but you'll rest assured that you're shipping components that are safe and reliable.*

CHAPTER NINE

CHOOSING THE RIGHT MANUFACTURING PARTNER

Finding a company to meet the precision needs of engineers and the support requirements of buyers is essential to the success of any defense and aerospace manufacturing company.

Photofabrication Engineering Inc. (PEI) delivers solutions from concept to delivery. For over 50 years, defense and aerospace companies have relied on us to guide and produce complex thin metal parts, components, and assemblies used in hundreds of industry-specific applications.

Dozens of engineers, planners, operators, and quality assurance professionals work out of PEI's 40,000-square-foot manufacturing hub in Milford, Massachusetts. The facility features the latest technology and precision machinery to support our efforts to provide unparalleled accuracy, reliability, and partnership.

50+ YEARS OF INDUSTRY EXPERIENCE

40K SQ. FT. MANUFACTURING HUB

#1 WORLD LEADER IN TITANIUM PCM

Today, PEI is the world's leader in titanium precision chemical machining, delivering expertly engineered and manufactured shims, microwave antennas, step lids, RF/EMI shields, springs, encoders, and more.

PEI approaches every opportunity with the utmost dedication to communication, expertise, ontime delivery, and cost-effectiveness.

THE PEI NETWORK: ONE CONTACT, FIVE SUPPLIERS

PEI is part of a network of precision manufacturing centers that can go from prototype to highvolume runs in days, not months. Every center is AS9100D and ITAR certified, and CMMC compliant.

OUR NETWORK OF PRECISION MANUFACTURING CENTERS

PEI
Milford,
Massachusetts

ELCON PRECISION
San Jose,
California

E-FAB
Santa Clara,
California

FOTOFAB
Chicago,
Illinois

MICROPHOTO
Chelmsford,
Massachusetts

Elcon Precision in San Jose, CA, is the one company in the United States that can photochemically etch and form 3D grids used in TWTs.

We welcome the opportunity to discuss your next programs and how we can solve your biggest challenges, whether that's a tolerance you're hearing is unachievable, or a bottleneck in your current supplier's capabilities.

Please visit our website for more information: photofabrication.com

LET'S GET
TO WORK

Visit our website to learn more about PEI's capabilities, certifications, and how our network of precision manufacturing centers can support your defense and aerospace programs.

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