SWTW 25TH ANNIVERSARY 2015
SW Test Workshop
Semiconductor Wafer Test Workshop
June 7 - 10, 2015 | San Diego, California

High Throughput Laser Processing of Guide Plates for Vertical Probe Cards

Rouzbeh Sarrafi, Dana Sercel, Sean Dennigan,
Joshua Stearns, Marco Mendes

IPG Photonics - Microsystems Division

Outline

- **Introduction - Industry trends**
- **Processing methods and materials**
- **Laser workstation design challenges**
- **Laser processing capabilities**

  < 1 second per hole up to 250 μm thick SiN

  < 2 seconds per hole up to 381 μm thick SiN
- **Conclusions**

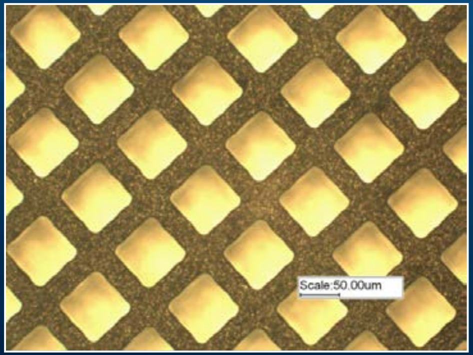
Industry Trends – Advanced Probe Cards

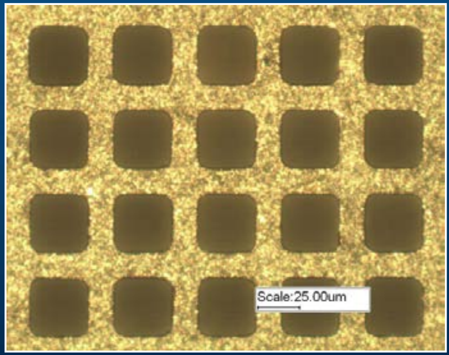
Market Growth – Sales of Probe Cards

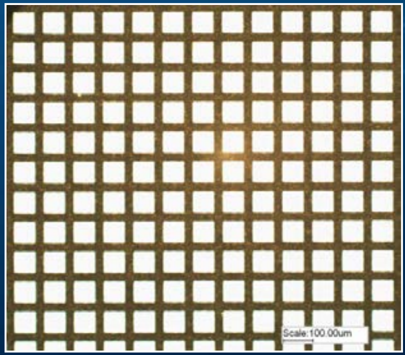
- $1.25 Billion in 2014 – $1.7 Billion in 2019 according to VLSI research
- Advanced probe cards are a primary growth driver
  - Vertical, Vertical-MEMS

Industry Trends – Machining Challenges Following Roadmap

Probe Card Feature	Guide Plate Machining Challenge
Increasing pin count	Longer machining time Placement accuracy
Smaller pins/guide holes	Maintaining dimensional accuracy and shape
Reduced pitch	Maintaining sidewall integrity
Thicker substrates (For strength) - Pin gliding/sliding	Keeping high throughput - Control of taper/profile/sidewall
Variable hole geometries, materials	Tool flexibility with no re-tooling required







Guide Plate Machining Methods

- **Mechanical Drilling:**
  - Minimum hole size is typically
    - > 100 microns for shaped
    - > 38 microns for round
  - Minimum pitch is typically > 50 microns
  - Time per hole is approximately 15 seconds
  - Taperless holes
  - Materials: machinable ceramics (Photoveel, Macerite)
- **Laser Drilling**

Laser Drilling Advantages

- **Repeatability of hole quality**
- **Higher throughput and yield**
- **Easier to get small shaped micro holes (< 100um)**
- **Versatility:**
  - Multi-use tool functionality (marking, cutting large features only through "soft tooling")
  - Various materials can be processed
- **Non-contact process**
  - Absence of tool wear/wandering/breakage

Guide Plate Machining Methods

- **Laser Drilling:**
  - Excimer
    - Minimum hole size is limited by taper and thickness, < 10 microns with 1 micron feature resolution
    - Minimum pitch is typically < 10 microns wall thickness, material dependant
    - Time per hole is approximately 4 seconds, thickness dependant
    - Hole taper is contoured for pin insertion
    - Wide range of materials including Silicon Nitride, Alumina, Polymers, Machinable ceramics
    - Disadvantages include cost of operation, maintenance intervals of large FOV, industrial excimer, exit chipping for > 30 micron holes

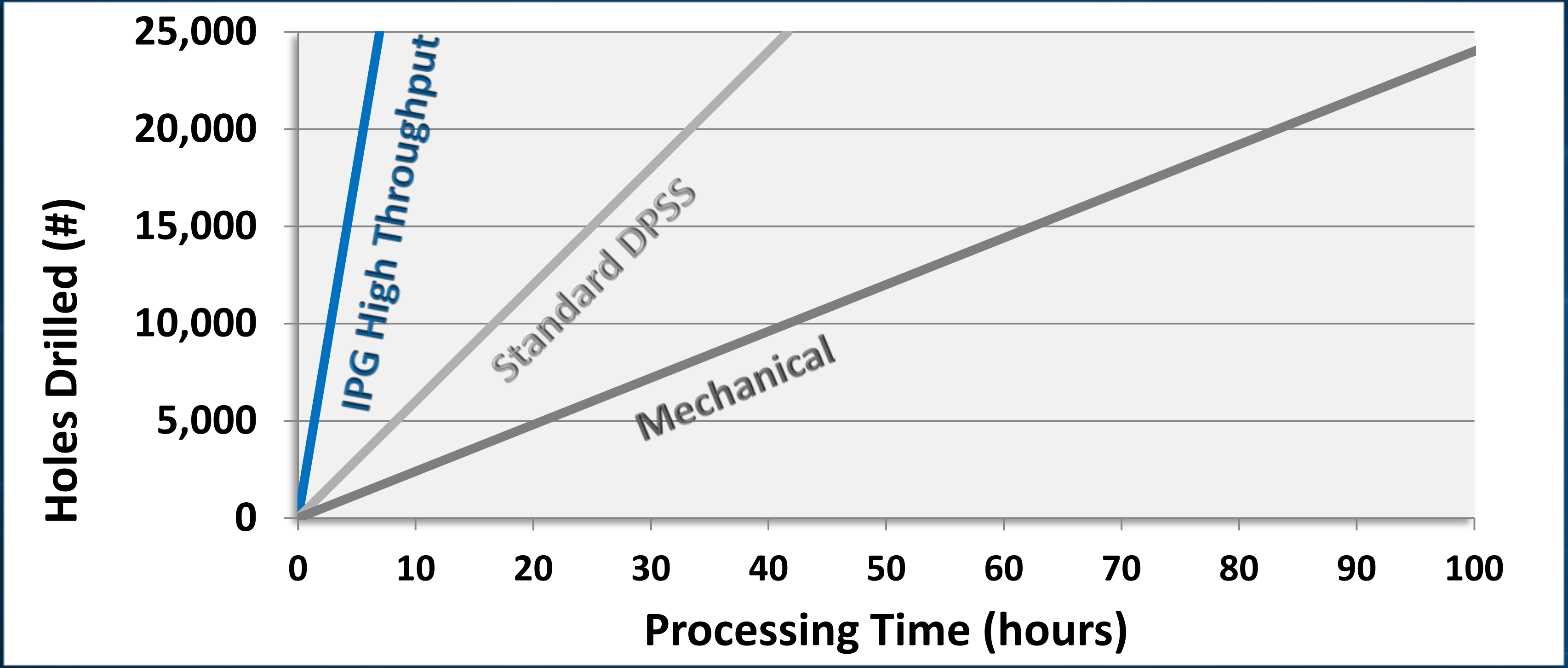
Guide Plate Machining Methods

- **Laser Drilling:**
  - Excimer
  - Solid State/ Fiber
    - Standard DPSS
      - Minimum shaped hole size is typically > 50 microns
      - Minimum round hole size is typically > 30 microns
      - Throughput 4-6 seconds per hole, materials dependant
    - **IPG High Throughput**
      - **Minimum shaped hole size is typically ≥ 30 microns**
      - **Minimum round hole size is typically > 20 microns**
      - **Throughput of 1-2 seconds per hole, materials dependant**

Guide Plate Machining Methods

	Mechanical Drilling	Excimer Laser Drilling	Standard DPSS Laser Drilling	IPG High Throughput Laser Drilling
Minimum Hole Size	>100 µm shaped > 38 µm round	< 10 µm, shaped and round (Material and Thickness Dependant)	> 50 µm shaped > 30 µm round (Material and Thickness Dependant)	> 30 µm shaped > 20 µm round (Material and Thickness Dependant)
Minimum Pitch	>50 µm	< 50 µm (Material Dependant)	40-45 µm	< 35 µm (Material Dependant)
Taper	Taper less	Contoured for Pin Insertion	Contoured for Pin Insertion	5 to 8% of Thickness Contoured for Pin Insertion
Time Per Hole	15 seconds per hole	> 4 seconds per hole, typical	4-6 seconds per hole	**< 1 second per hole**

Guide Plate Machining Methods- Time per Hole



Time per hole reduction enables high pin counts

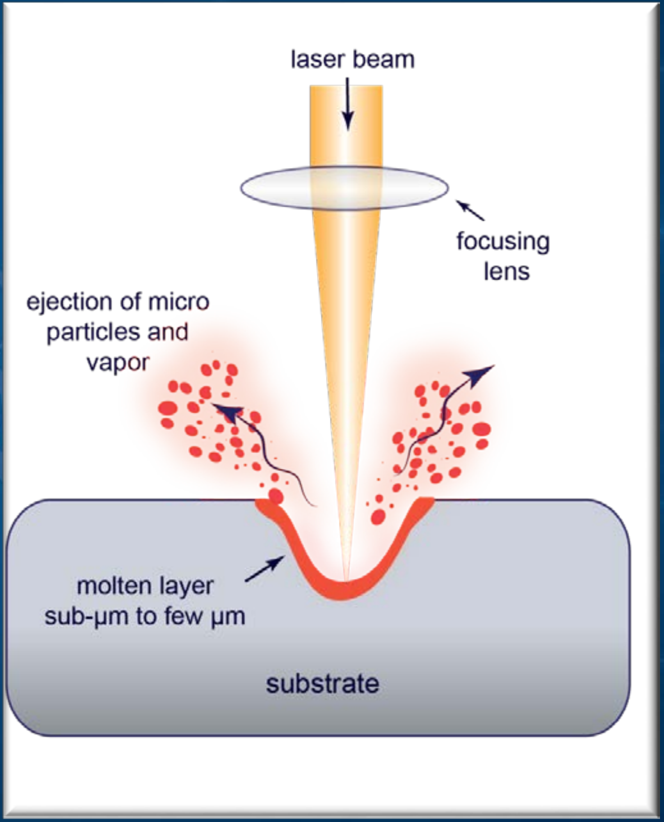
- Under 10 hours for 25,000 holes in SiN up to 250 microns thick with IPG High Throughput drilling ; > 80% reduction over conventional DPSS laser drilling technology

IPG High Throughput Laser Drilling

Significantly lowers the time and cost of drilling probe card guide plates, while improving on dimensional and positional accuracies

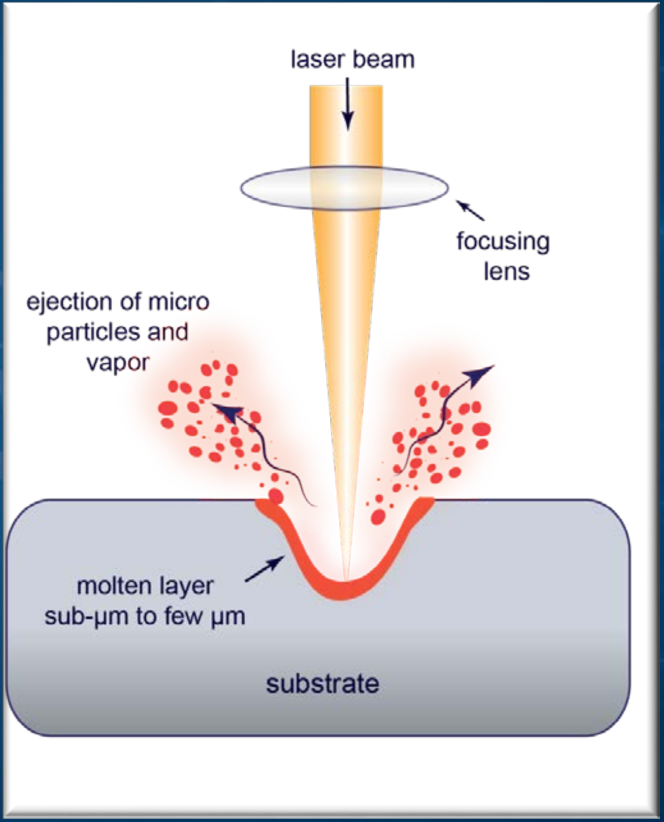
Introduction to Laser Ablation

- **Laser Ablation is the process of removing material by irradiating it with a laser beam.**
  - The surrounding material absorbs little heat, making it possible to process delicate or heat-sensitive material at fine pitch
- **Photon Energy → thermal energy → sublimation, vaporization and melting**



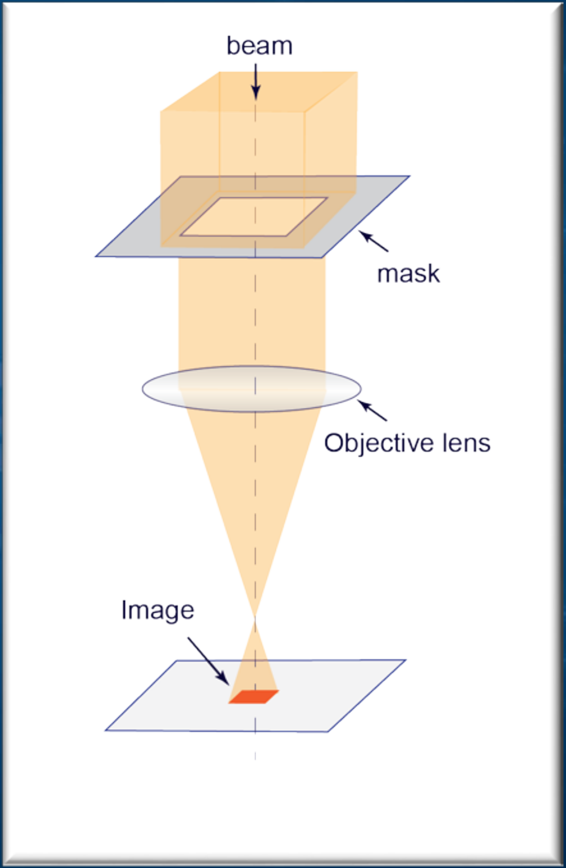
Introduction to Laser Ablation

- **For ceramics, material is removed through:**
  - Sublimation
  - Vaporization
  - Melt expulsion
- **The amount of material removed per laser pulse depends upon:**
  - Material properties
  - Laser characteristics such as: wavelength, pulse duration, fluence (J/cm^2)
  - Other processing factors, e.g. pulse overlap, vacuum or assist gas, etc.



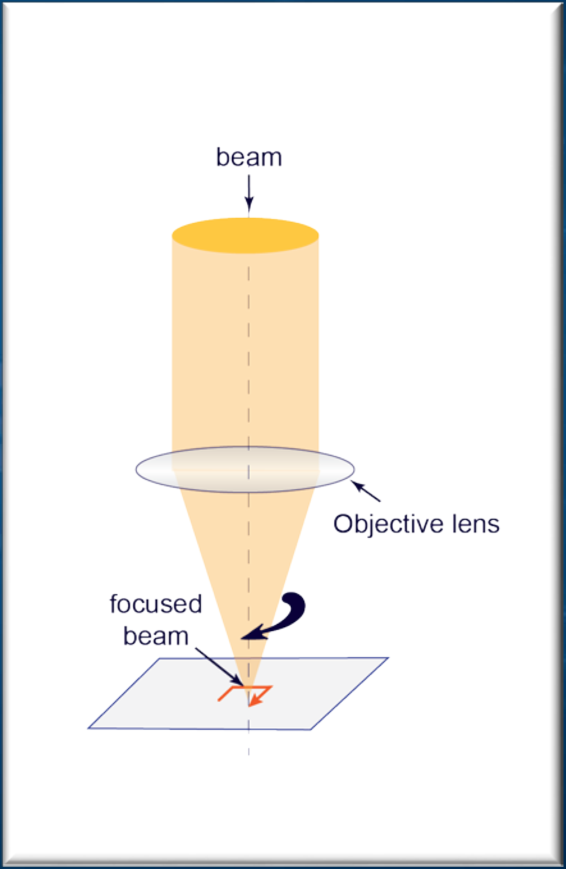
Introduction to Laser Ablation

- **Imaging/Percussion**
  - Typically excimer
  - Top hat with large FOV
  - Entire feature drilled in one step



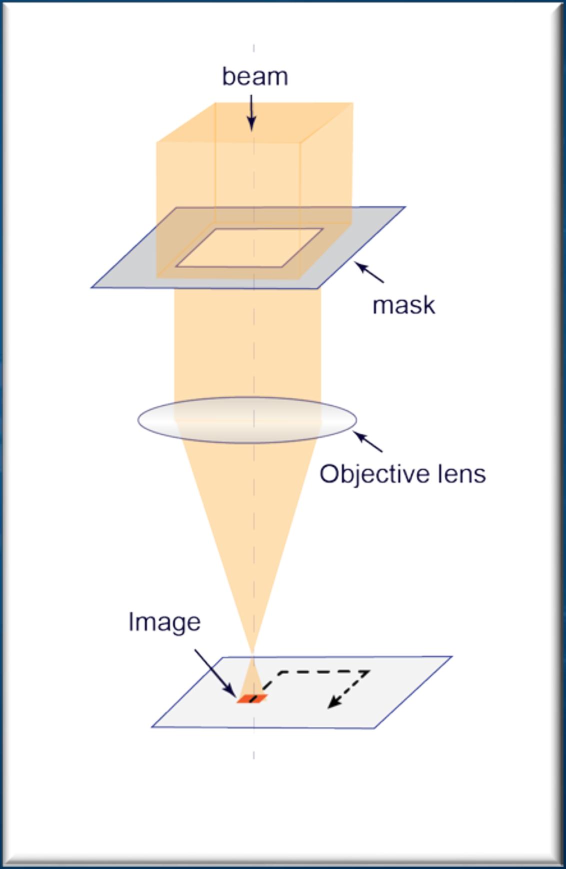
Introduction to Laser Ablation

- **Imaging/Percussion**
  - Typically excimer
  - Top hat with large FOV
  - Entire feature drilled in one step
- **Direct-write**
  - Typically solid-state/fiber
  - Gaussian beam used at focus
  - Optics or part holder moved to define feature shape



Introduction to Laser Ablation

- **Imaging/Percussion**
  - Typically excimer
  - Top hat with large FOV
  - Entire feature drilled in one step
- **Direct-write**
  - Typically solid-state/fiber
  - Gaussian beam used at focus
  - Optics or part holder moved to define feature shape
- **Hybrid**
  - Shaped beam moved for customized profiles, corner radii (rectangular hole)



Probe Card Guide Plates

Common Materials:

- **Silicon Nitride**
- **Alumina**
- **Polyimide**
- **Zirconia**
- **Photoveel I and II**

  "Machinable" ceramics

  - Designed to be **mechanically** machinable. Usually not the best choice for laser machining.

Reasons for Selection:

- **Temperature range**
- **CTE and other thermal properties**
- **Mechanical Properties**
- **Electrical properties**
- **Chemical stability**
- **Manufacturability**
- **Other specifics of design**

Design for Laser Drilling

- **Materials selection drives:**
  - Sidewall surface and exit hole quality
  - Maximum hole density
    - Sidewall integrity, micro-cracking

      The minimum pitch does not necessarily equal [hole size + taper]. The minimum pitch could be more than [hole size + taper] based on thermal condition of process and material type
  - Maximum throughput
  - Laser complexity/ cost

Design for Laser Drilling

- **Thickness selection drives:**
  - – Maximum throughput
  - – Taper and exit hole quality
  - – Maximum hole density
    - Taper increases due to thickness increase, increasing the spacing requirement
  - – Laser and/or beam delivery complexity/cost at > 400 µm

Design for Laser Drilling

- **Hole geometry drives:**
  - Beam delivery complexity/cost
  - Throughput
  - Sidewall quality, debris/ plume concerns

Guide plate design for laser compatibility is key to high quality, low cost holes, especially in thick material.

IPG Workstation Versatility

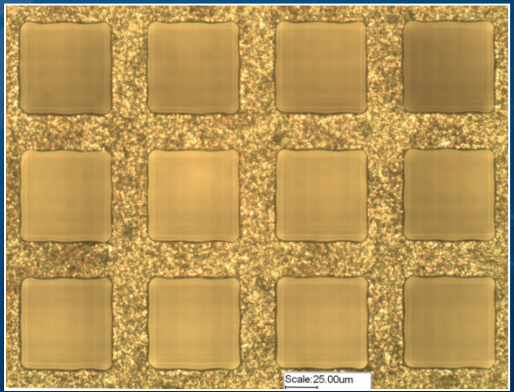
- **High compatibility with Standard Equipment:**
  - Silicon Nitride
    - Very high quality of laser-drilled holes
    - Maintains sidewall integrity in high-density, high throughput laser drilling
    - **Micro holes in thicknesses < 100 to 400 microns (.015”) machined with the same setup**
  - Alumina
    - Good quality of laser-drilled holes
    - Low taper
    - Integrity in high-density laser drilling manageable
    - Allows intermediate throughput
  - Polyimide
    - High throughput
- **Compatibility optimized with custom laser equipment:**
  - Zirconia - Photoveel I - Photoveel II – Other “machinable” ceramics

IPG High Throughput Laser Drilling

- **Standard configuration** **Optimized for high hole counts in:**

  Silicon Nitride - Alumina - Polyimide

- **Customized configurations** **Laser selection and beam preparation can be tailored to:**
  - Guide plate materials selection
  - Hole geometry
    - Corner radii: <6 microns
    - Feature size: < 30 microns
  - Pitch Reduction: sidewall < 10 microns
  - New fiber lasers being developed (ns and ps)
  - New techniques under development



Laser Workstation Design

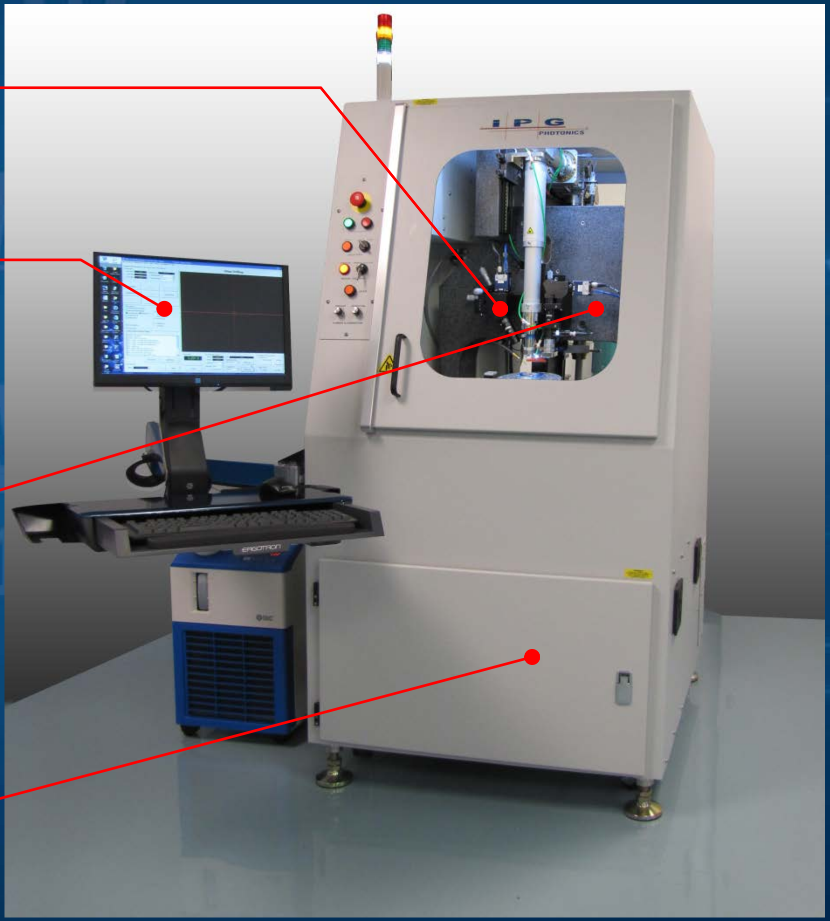
High resolution inspection system with integrated machine vision for automated part alignment and metrology

Software integrates laser, motion control, digital I/O, and optional machine vision

Granite structure for high accuracy and beam pointing stability

High Precision Motion Stages provides better long term accuracy for long run parts

Integrated design allows for minimal floor space, Laser mounted internally. CDRH Class-1 Safety



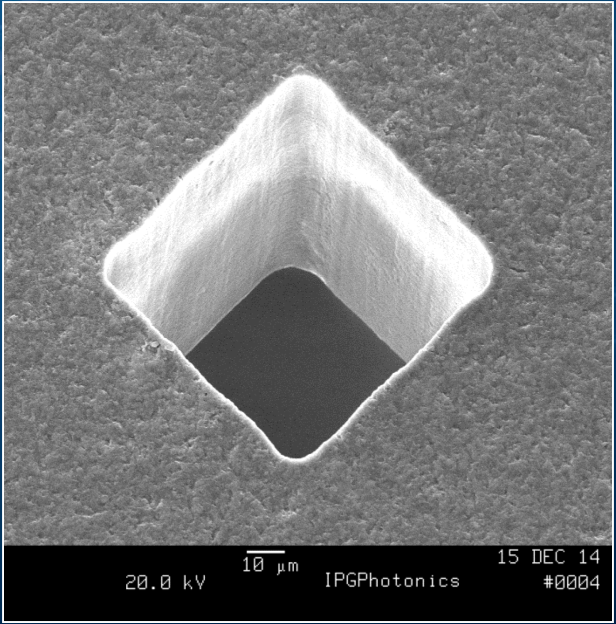
Laser Workstation Design

- **Unified Setup- Standard Configuration**
  - Single layout for multiple thicknesses and shapes
  - Compatibility with multiple materials but optimized by laser selection
- **High Precision Motion Control**
  - Commutatively supports DTP of < 6 microns
- **Process Monitoring**
- **Thermal Management**
  - Granite Support Structure
    - Better long term accuracy and beam pointing stability
  - Class I enclosure with air flow control

Laser Machining of Silicon Nitride

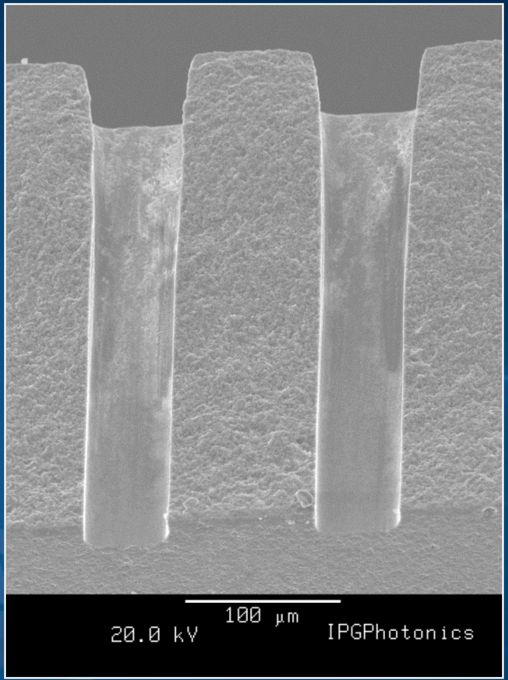
- **Industry leading throughput**
  - Less than **1 second per hole up to 250 μm thick**
  - Less than **2 seconds per hole up to 381 μm thick**

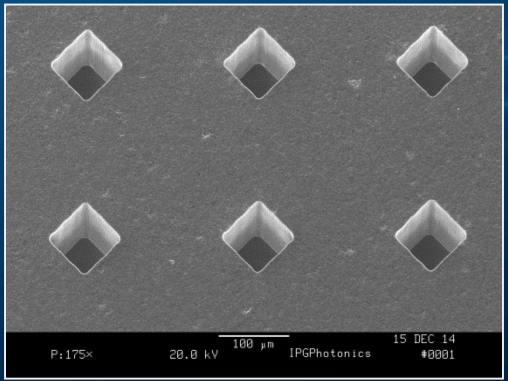
While maintaining repeatable high quality

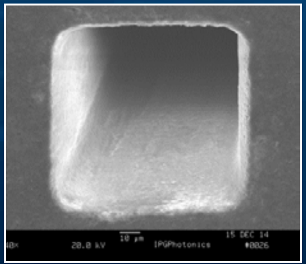


Laser Machining of Silicon Nitride

- **Hole Geometry**
  - Taper
    - Entrance as pin guide; most taper within first 50 microns leading to near taperless hole
    - Specified as difference between entrance size and exit:
      - ≤ 15 microns for thicknesses up to 250 µm
      - ≤ 20 microns for thicknesses up to 381 µm

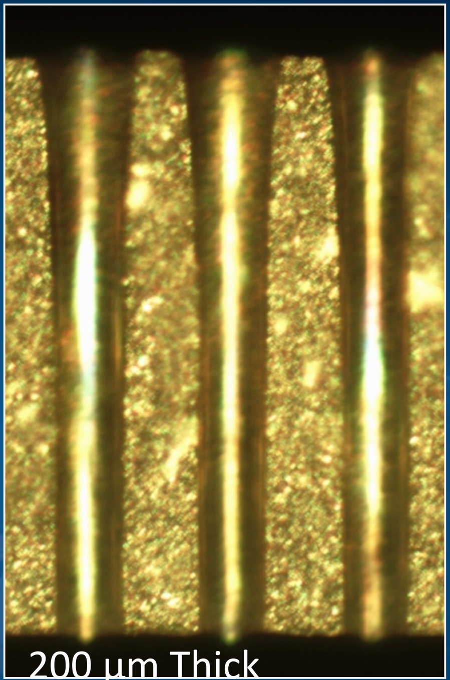


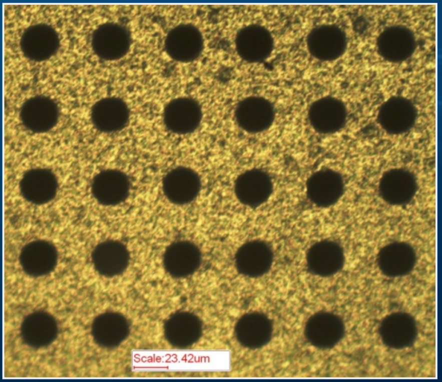




Laser Machining of Silicon Nitride

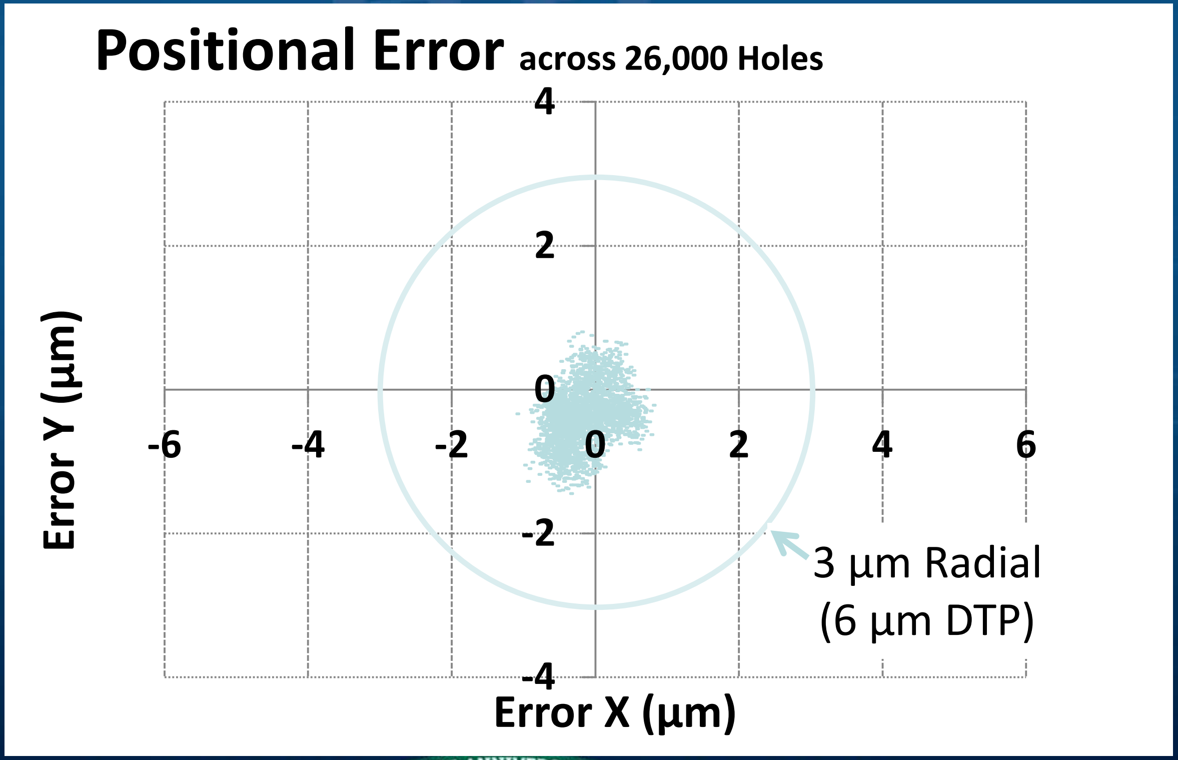
- **Hole Geometry**
  - Exit hole
    - Size variation
      - 200 µm Thick: All holes within ± 2 µm
      - ≥ 250 µm Thick: All holes within ± 2.5 µm
    - Shaped hole capabilities
      - Round and rectangular are typical
    - Achievable size range, Unified Setup
      - 30 x 30 µm rectangular exit minimum
      - < 30 µm round holes feasible
    - Custom solutions, Laser selection drives:
      - Minimum hole size
      - Corner radii





Laser Machining of Silicon Nitride

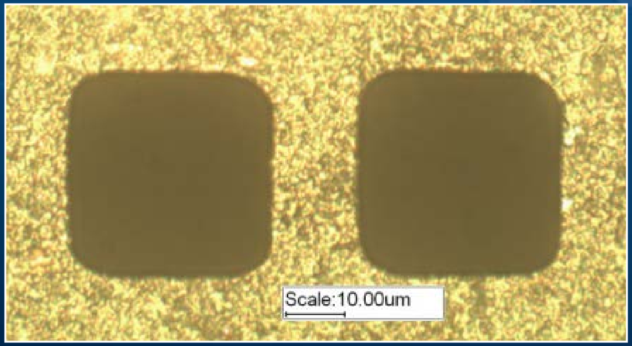
- **Positional Accuracy**
  - Diametric True Position, 3 Sigma
    - ≤ 6 microns for thicknesses up to 250 µm
    - ≤ 10 microns for thicknesses up to 381 µm



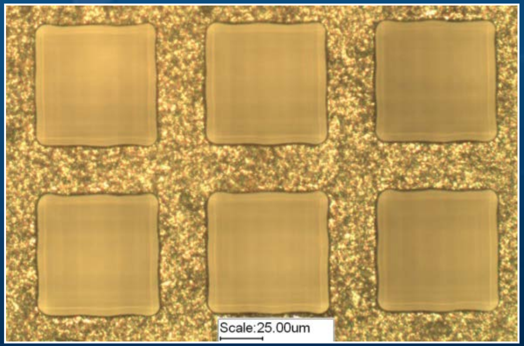
Better 6 µm DTP is routinely achievable

Laser Machining of Silicon Nitride

- **Density**
  - Hole Count
    - >25,000 holes per part
  - Pitch
    - ≤ 15 microns of "wall" for thicknesses up to 250 µm
    - ≤ 20 microns of "wall" for thicknesses up to 381 µm



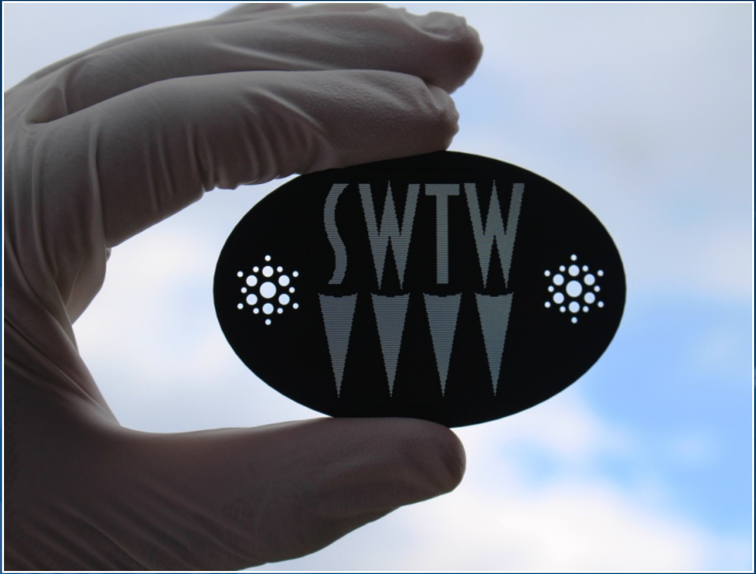
35 x 35 µm holes

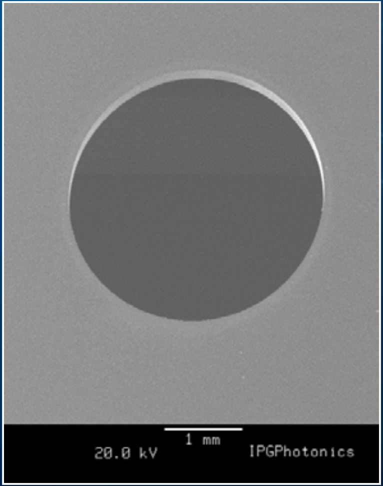


70 x 70 µm holes

Laser Machining of Silicon Nitride

- **Additional capabilities**
  - Cutting of large features
    - Precision alignment features
    - Outside cutouts
  - Milling
  - Marking

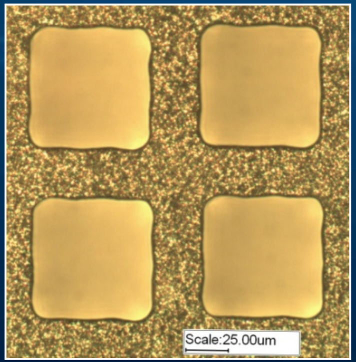


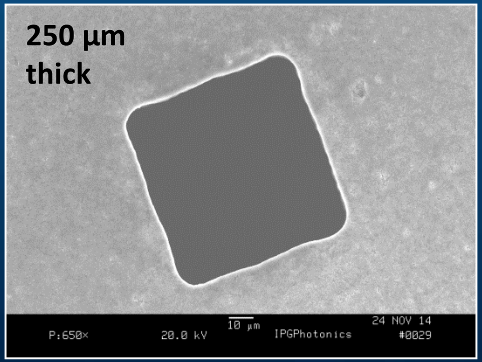


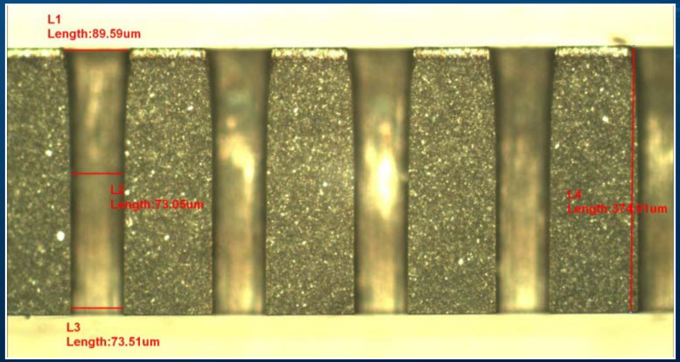
Laser Machining of Silicon Nitride

Thickness	200 µm	250 µm	381 µm
Minimum rectangular micro hole size (typical)	30×30 µm	40×40 µm	50×50 µm
Minimum micro hole pitch (typical)	15 µm wall	17 µm wall	22 µm wall
Micro hole maximum taper	< 15 µm (12-13 µm typical)	≤ 15 µm	< 20 µm
Micro holes size variation (at exit)*	± 2 µm	± 2.5 µm	± 2.5 µm
Maximum diametric true position error*	≤ 6 µm	≤ 6 µm	≤ 10µm
Drilling time per micro hole	< 1 sec	1 sec	2 sec

*3σ

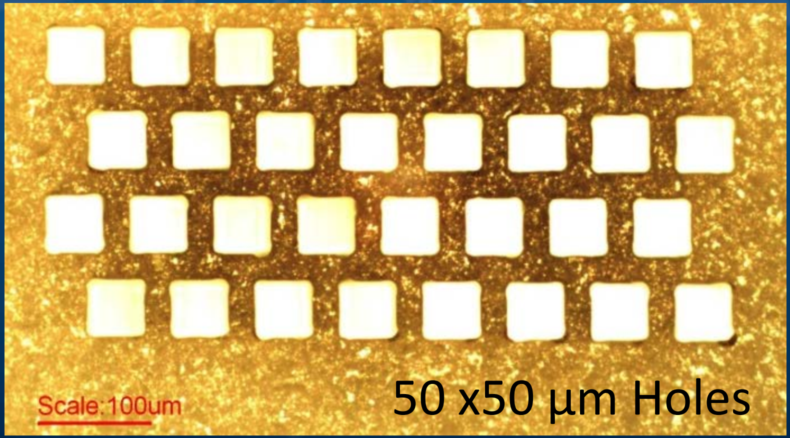






Laser Machining of Alumina

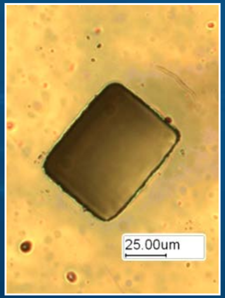
	Alumina		
Thickness	200µm	300µm	400µm
Minimum rectangular micro hole size (typical)	40×40 µm	45×45 µm	50×50 µm
Minimum micro hole pitch (typical)	25 µm wall	30 µm wall	35 µm wall
Micro hole maximum taper	≤ 6	≤ 12 µm	≤ 16 µm
Drilling time per micro hole	2 sec	3 sec	3.5 sec

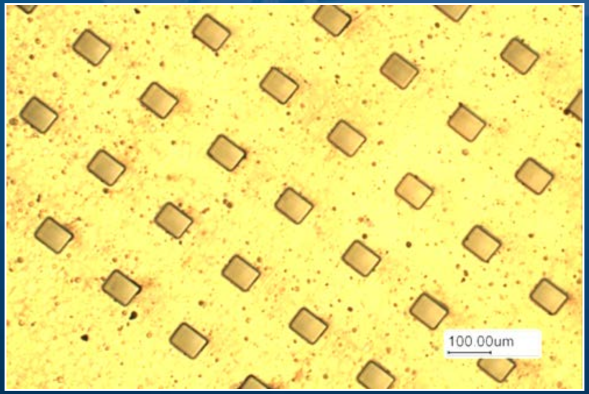


Laser Machining of Additional Materials

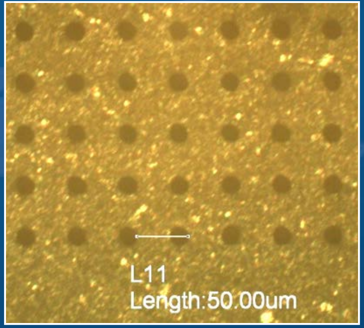
Polyimide

- Throughput, taper depends upon thickness

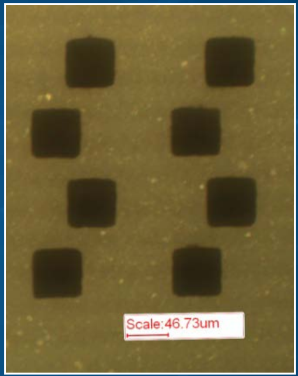




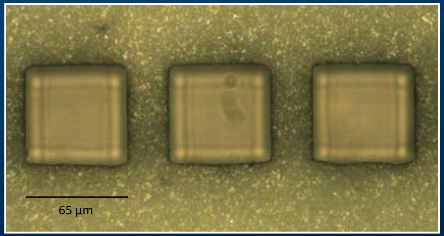
… And more



Macerite



Photoveel I



Photoveel II

Conclusions

- Laser technology is essential for advanced vertical guide plate manufacture
- Guide plate materials selection is important for maintaining high quality at fast speeds
- IPG High Throughput machining allows for < 1 second per hole, an 80 % reduction over known fastest DPSS technologies
- High process speed enables lower cost of manufacture, lead time reduction

Thank you!