



Ion Beam Milling for MEMS Applications

Presented to iMAPS New England 2018 Symposium

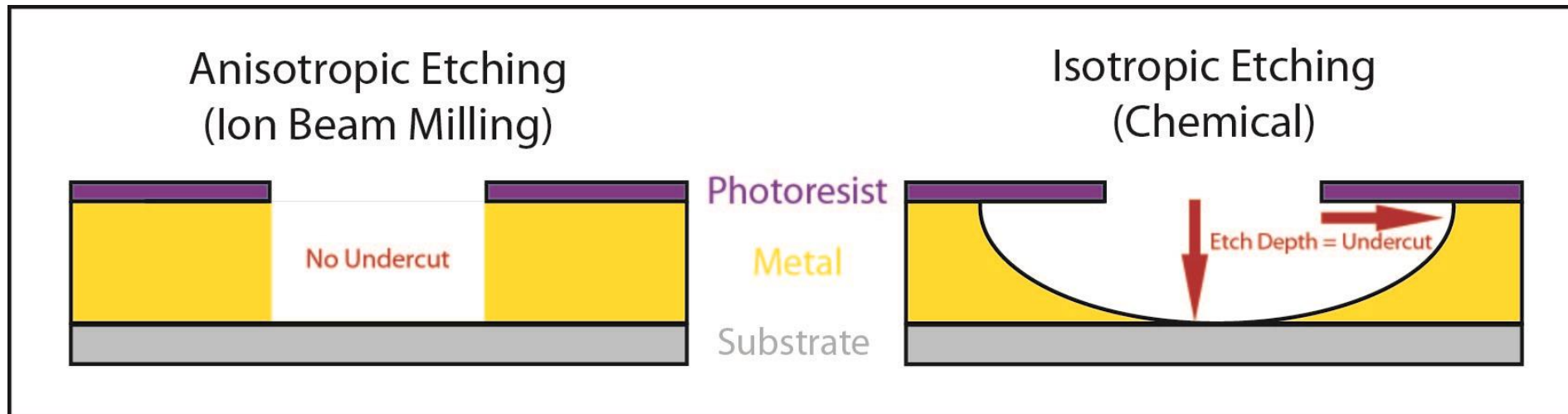
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Etching Fundamentals

Any etch process is characterized by certain properties

- Profile
 - Isotropic – Etching proceeds at equal rates in both horizontal and vertical direction
 - Anisotropic – Etching proceeds faster in one plane than in another
- Selectivity
 - The ability of the etch process to distinguish between the layer to be etched and the material not to be etched
- Etch Rate
 - How Fast Something etches
- Uniformity
 - Is the etch depth consistent across the surface of the etched material?
 - Is etch depth consistent from part to part?

Etch Profiles



Selectivity & Etch Rate

Ion Etching

- Non-selective
 - Will etch whatever material is present for as long as the beam is on
 - Coupons are commonly used if precision etching is required
- Etch rate is slow, controlled process
 - Over-etching is uncommon
 - Each material has constant, reliable etch rate

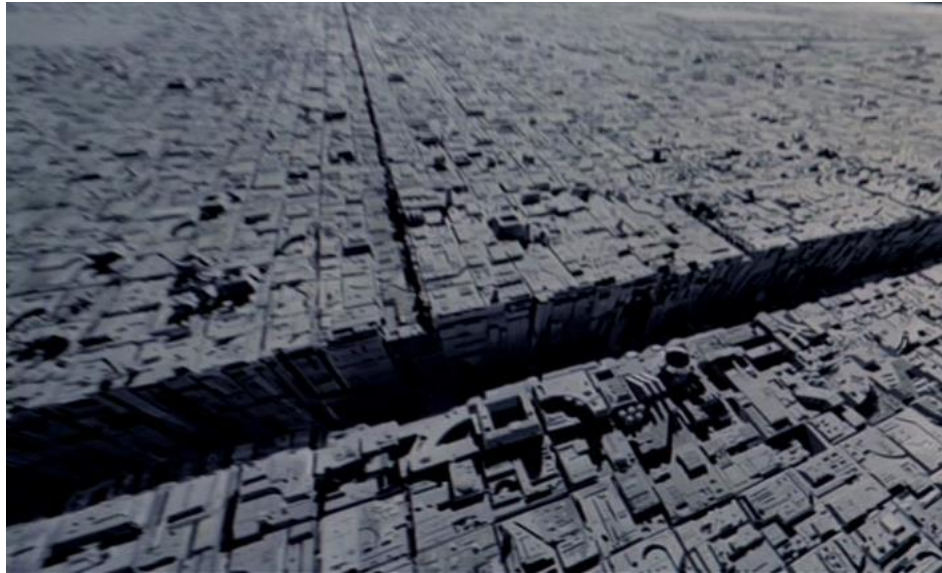
Chemical Etching

- Semi-selective
 - Some etchants are specific to one material while others affect multiple materials
 - Additive effect of etchants must be taken into account when etching dissimilar materials
- Etch rate governed by material and etchant used
- Some etchants affect more than one element (ex: Cu etch also impacts Ni)
 - May require 2 step process to etch Cu then deposit Ni

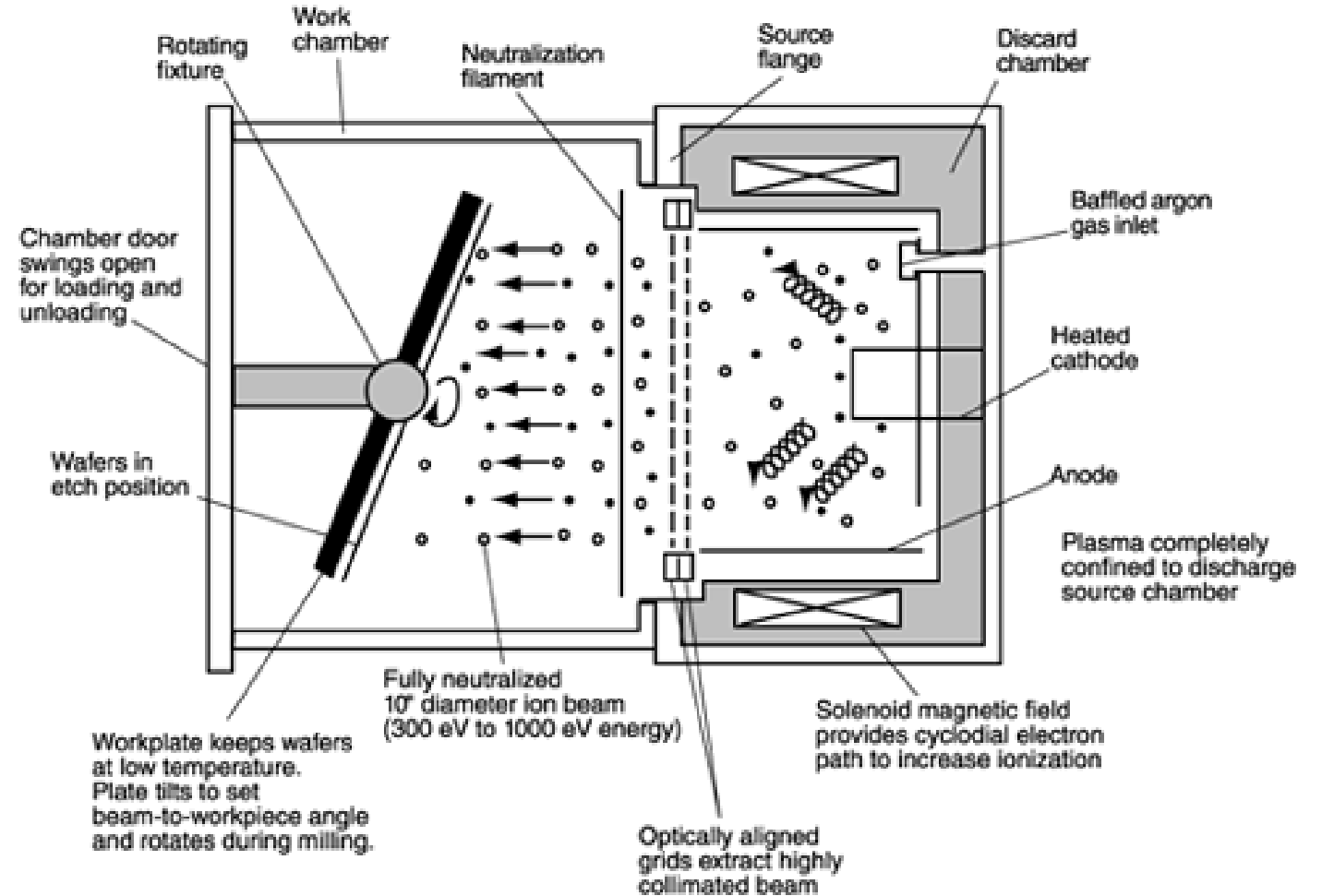
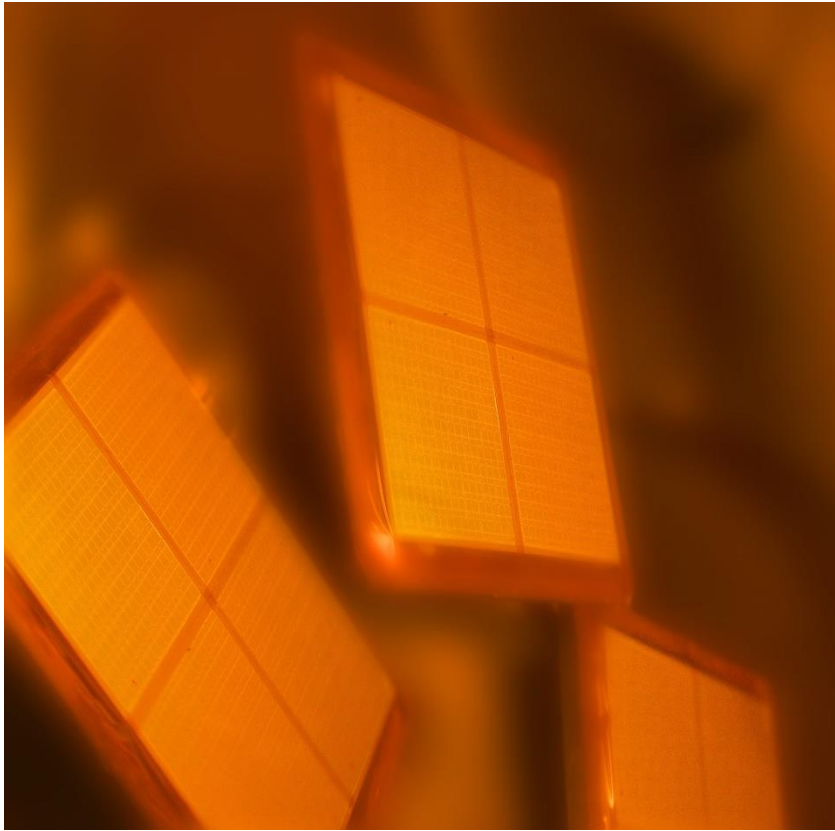
Uniformity

- Refers to two areas of concern:
 - Uniformity of etch across the surface of the wafer/substrate
 - Uniformity of etch from wafer to wafer
- Ion Etching
 - Wafer/Substrate is mounted on a planetary that rotates target into and out of the ion beam equalizing exposure time to ensure uniformity
 - As etch rate does not change from run to run, once etch timeframe for given material/thickness is determined, subsequent runs exhibit high repeatability
- Chemical Etching
 - Circuit to Circuit performance will be randomized

Wet vs. Ion Etch Concepts



Kaufman Ion Source



Benefits of Kaufman Ion Source

- Cleaner process (vacuum)
 - Waste material literally blown away – ion engine design
- No waste products produced
 - Greener Process
- Etch variability eliminated
 - Near perfect circuit-to-circuit repeatability
- No undercut
 - Straight Sidewalls, consistent spacing of traces
- Feature sizes effectively limited only by photolithographic technology
 - Argon Ions are in the picometer (10^{-12}) range. This is compared to chemical etching which is limited to 3 microns (3×10^{-6})

Ion Etch Advantages for MEMS

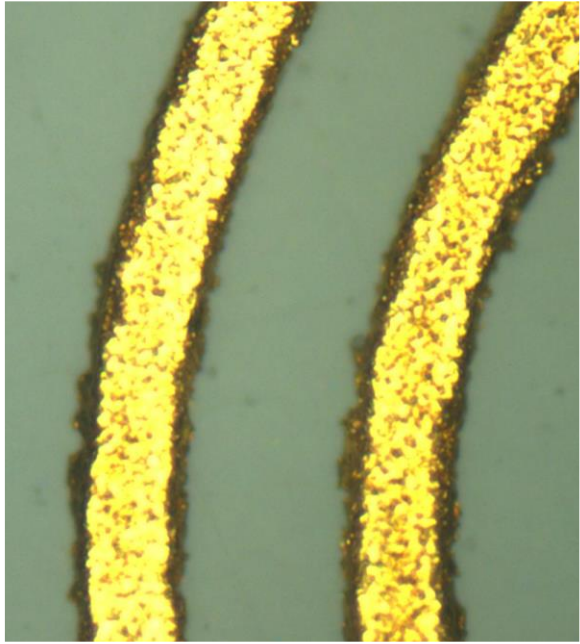
- Ion Beam Milling produces precise pattern replication
 - Photomask can be created directly from CAD design or simulation model
 - Generally does not require multiple mask iterations or tuning
 - Chemical Etching Photomasks require “etch factors” and may need multiple iterations
- Ion Beam Milling can etch any material
 - Chemical etching is limited to metals and some non-metallic substances
- Ion Beam Milling holds tighter tolerances (2.4 microns)
 - Chemical Etching’s inherent variability limits the ability to achieve similar tolerances to ion beam milling

What About Cost?

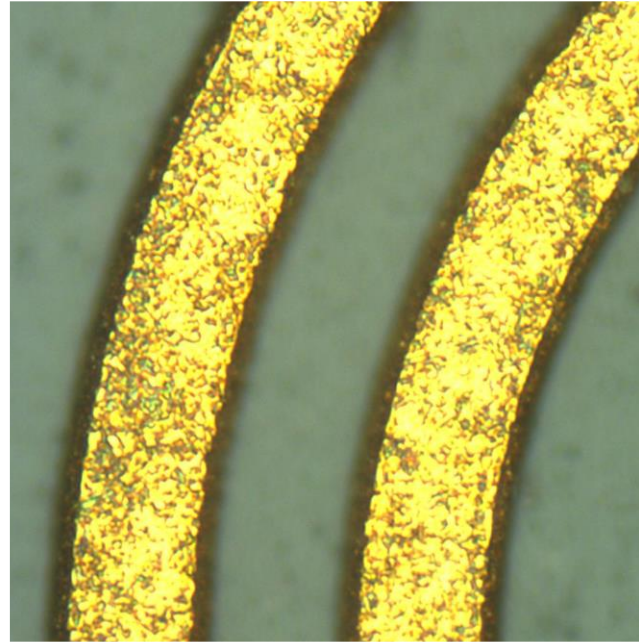
- Equipment
 - Chemical Etching equipment is inexpensive to acquire
 - As simple as some beakers, etchants, and DI water
 - Ion Beam Etching Equipment is much costlier
 - Ion Beam Etch Systems w/support equipment \$250K+
- Expertise
 - Basic Chemical Etching is easy to learn
 - Ion Beam Milling requires higher level of expertise to operate and maintain

Ion Beam Milling has been the leader in Ion Etch services for more than 35 years and can offer Ion Etch services that are cost competitive

Examining the Evidence

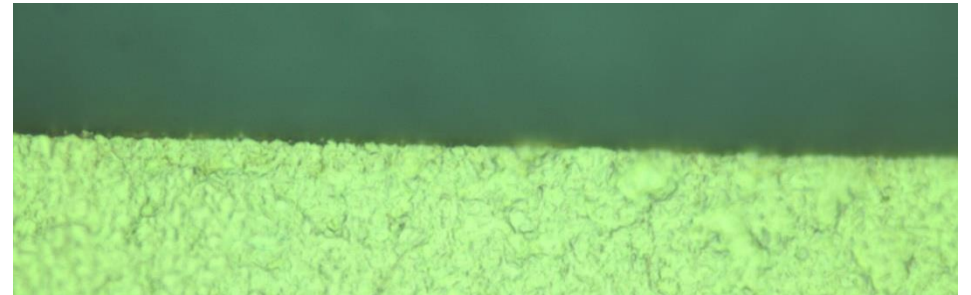
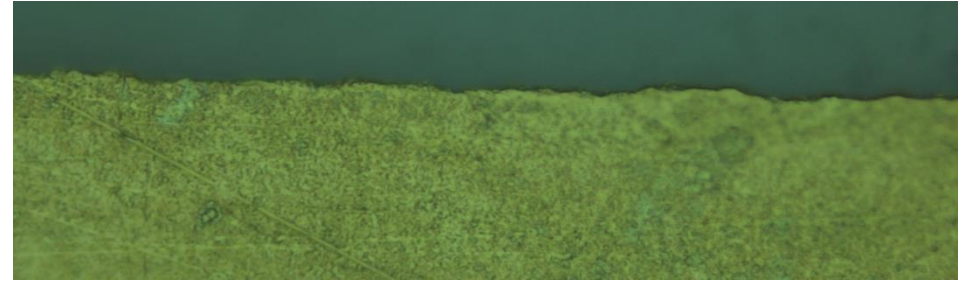


Chemical



Ion Beam

Chemical

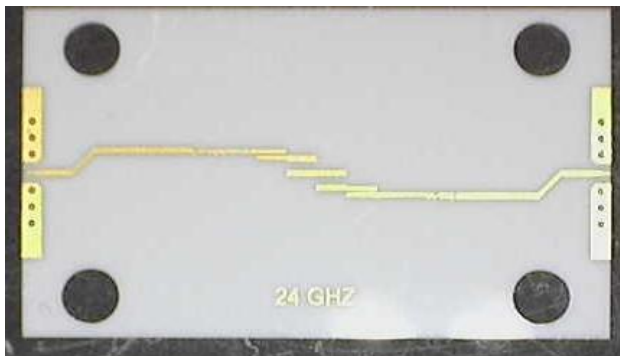
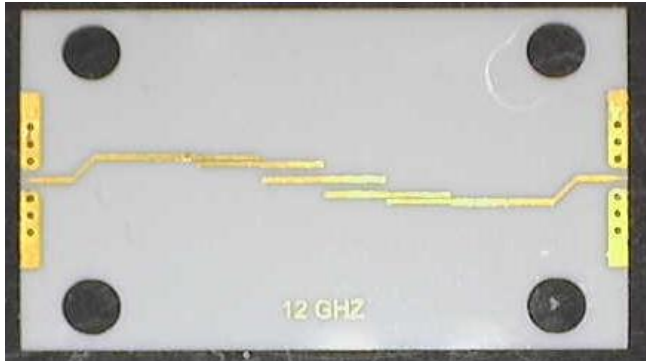


Ion Beam

The Challenge

- Devise an experiment with a test subject that is highly sensitive to line width and spacing
- Determine a means to measure the impact of etch imperfections
- The Solution: Microwave Filters
 - Initially designed several simple filters specifically for this test
 - Obtained permission for customer to use one of their designs in the test
 - Provided Ion Etched filters to third customer who conducted head-to head tests

The Experiment - Filters



- Chemical Etching Performed by 3rd Party with 20+ years of Chemical Etching experience to ensure accurate test results
- Initial tests were performed at 12 GHz and 24 GHz
- Circuits were designed to use Southwest Microwave Super SMA End Launch Connectors rated for frequencies up to 27 GHz

The Experiment (test system)

- Anritsu provided MS46322B Vector Network Analyzer for testing



The Experiment (test method)

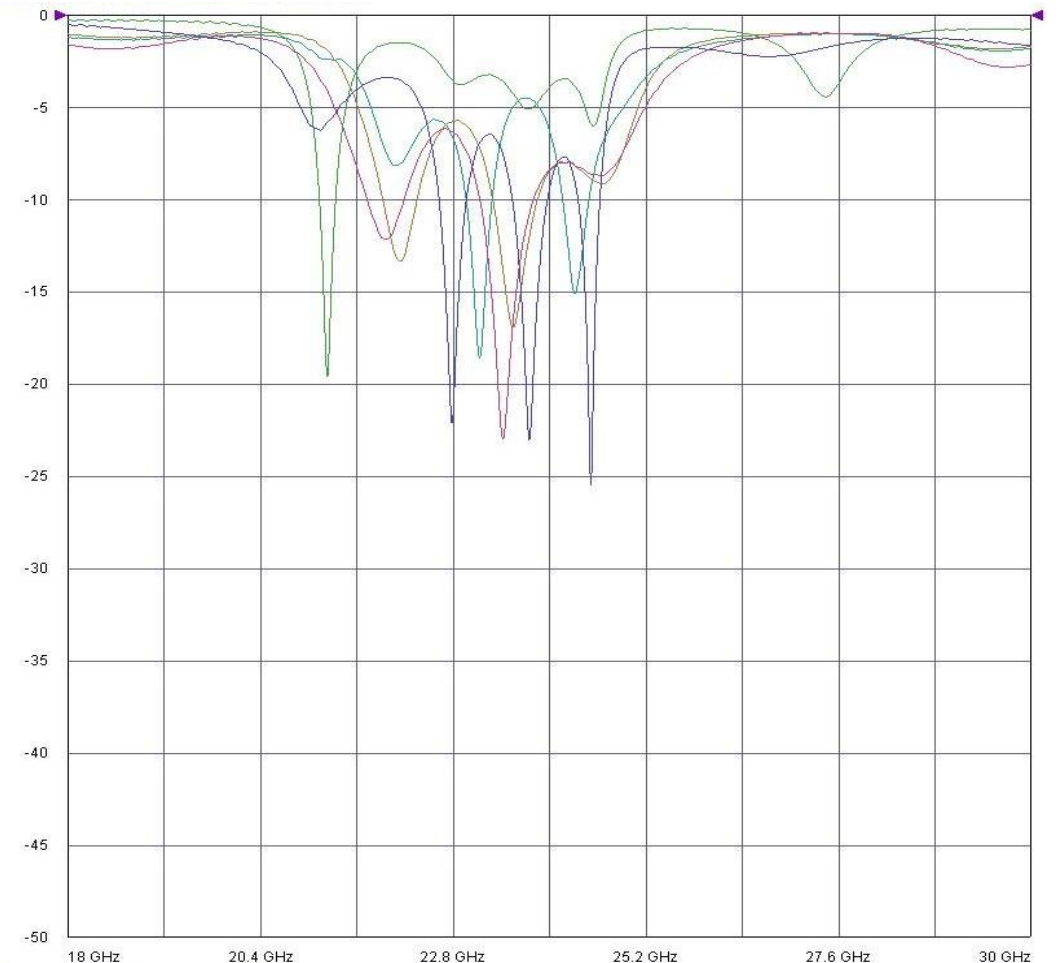
- Five examples of each etch method selected and fitted with Southwest Microwave End Launches
- Frequency sweep conducted on each circuit
- No simulators were used for test filter designs so these are not perfectly tuned to the target frequencies
- Aside from Etch Method, there are no other differences between Chemical and Ion Etched circuits

Five Sample Ion Etch vs. Chem Etch at 24 GHz

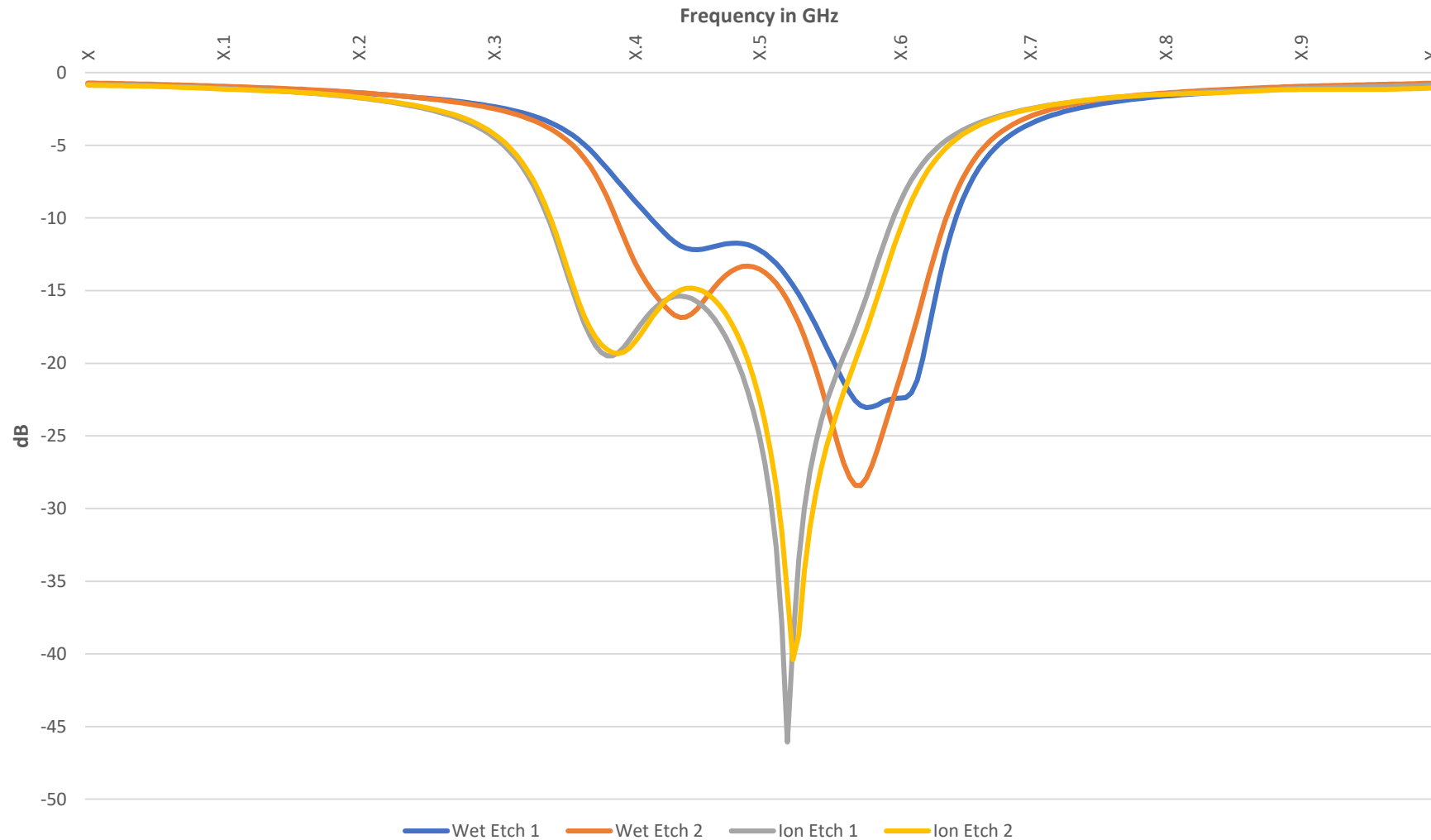
Ion Etch Return Loss



Chem Etch Return Loss



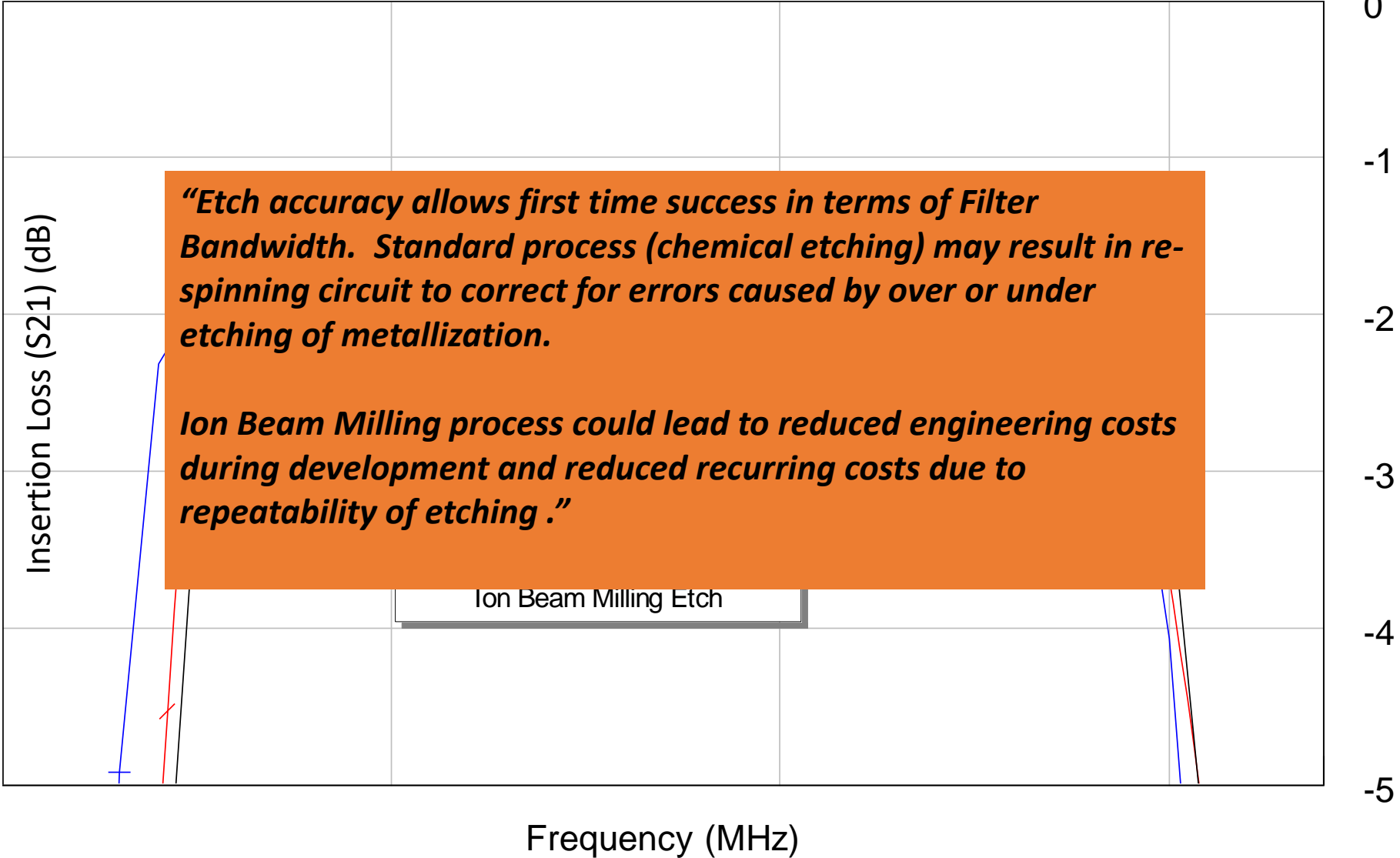
Return Loss (S11) over 1 GHz Range



Customer Evidence

- While we were conducting our own testing, a customer challenged us to prove there was a measurable difference between Ion Etching and their current Chemical Etching process
 - They asked us to demonstrate using one of their designs
 - They would then measure the completed circuits against their target design
- Customer was amazed at how closely the performance of the Ion Etched circuits matched the “best case” design from the simulator
- The following slides were sent to us by the customer and represent their own conclusions

Filter Simulation vs Realization

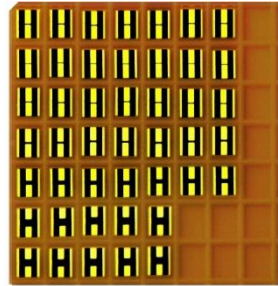
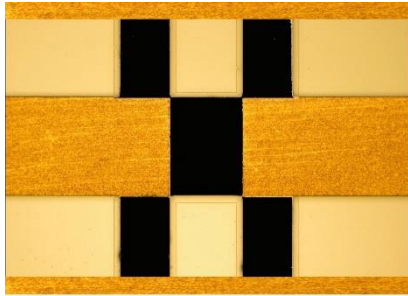


Take-aways

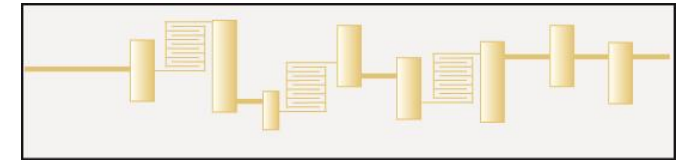
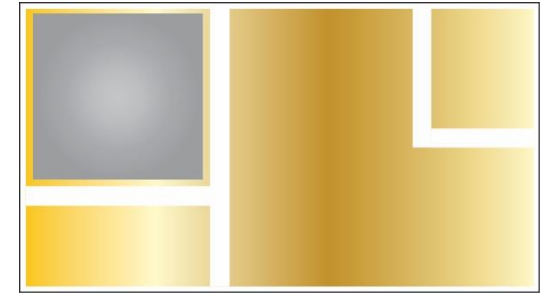
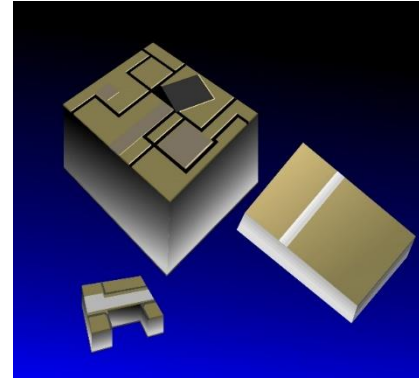
- Ion Etching delivers a more faithful reproduction of the product design
- Ion Etching holds tighter tolerances and can etch a greater variety of materials than chemical etching
- Filter experiment demonstrates performance advantage of Ion Etching
- Ion Etching delivers better circuit-to-circuit consistency
- **Ion Etching Cost is competitive with Chemical Etching**
 - Ion Beam Milling has been doing this for 35 years. We can provide ion etch quality at costs competitive with inferior chemical etch processes
- Ion Etched circuit performance more closely aligns with simulated performance targets
 - Minimal to no tuning required
 - No need to discard circuits that fall outside of target performance range



Standard Products



Custom Products



Capabilities

- Photomask Design & Layout
- Resolutions down to ½ mil lines and spaces (without holes)
 - 1 mil lines and spaces with unfilled via holes
- Can etch both planar and odd sized products
- Plated and Filled Via Holes (Au, Cu, Polyimide)
- Pre-and Post- Laser Cutting (Slots, Cutouts, and other shapes)
- Manufacture Products on Al₂O₃, AlN, Quartz, BeO, Si, others
- Au/Sn deposition

About Ion Beam Milling

- The Ion Beam Etch Experts for more than 35 Years
 - Founded by Electrical Engineer with significant Microwave experience
 - Engineering Staff with many years of process design experience
- Qualified Supplier to nearly every major aerospace/defense firm
 - IBMI Products are in many major defense platforms in operation today
- ISO 9001 Certified / ITAR Registered
- Experienced with **Class K Space Qualified Component Requirements**
 - IBMI Products are in use in Satellite and Missile Systems