Micromachining Techniques for building RF-Components

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ECE 6450

Silicon wet etching techniques

- Wet etching employed as an alternative way to conventional machining
- Main disadvantage of this technique is that one is forced to follow the <100> or <110> crystal plane in the silicon. That limits the types of structures that can be produced
- We can fabricate wide angle pyramidal horns antennas or straight sections of single height waveguide
- We cannot make waveguide structures in which the height is stepped down (e.g. an impedance transformer) or tapered (either rectangular or circular)

Motivation to new fabrication techniques

- The majority of radio receivers, transmitters that operate at millimeter and sub-millimeter wavelengths utilize waveguide structures

- At frequencies above 1THz, waveguide dimensions become too small (less than 0.23 by 0.116mm)

- Fabrication utilizing conventional machining and electroforming techniques becomes extremely difficult, expensive or impossible

- At these frequencies a new way of machining waveguide structures is needed so as to reap the benefits of waveguides at THz frequencies

Laser induced Microchemical Etching of Silicon

- High focus-ability of laser light and the ability to deliver intense sources of energy with high precision allow us to fabricate smaller feature sizes

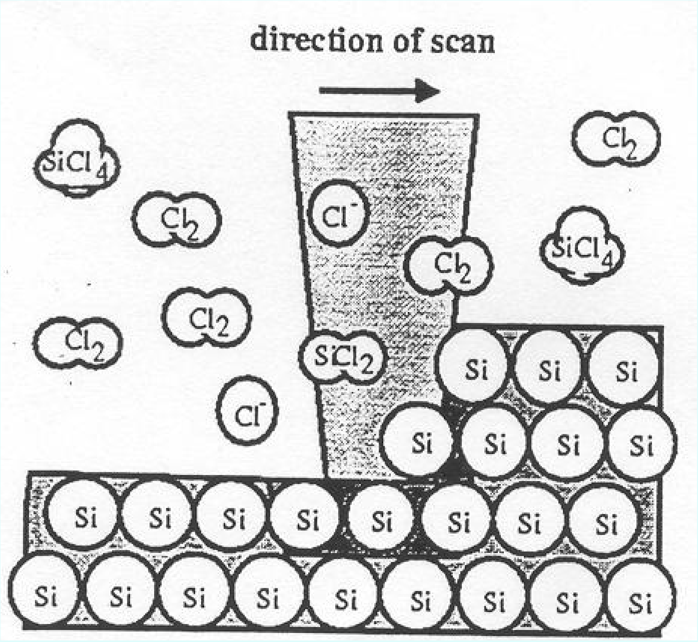
- Laser machining is a non-contact process. So there is no mechanically-induced material damage, tool wear, or machine vibration from cutting forces. This lead to finer finishes, improved accuracy and less process overhead.

- Different materials ranging from metals and polymers to composites and ceramics have been successfully machined using lasers with ablative techniques.

The basic process

➢An Argon-ion laser is used to locally heat a portion of the silicon substrate in a chlorine ambient.

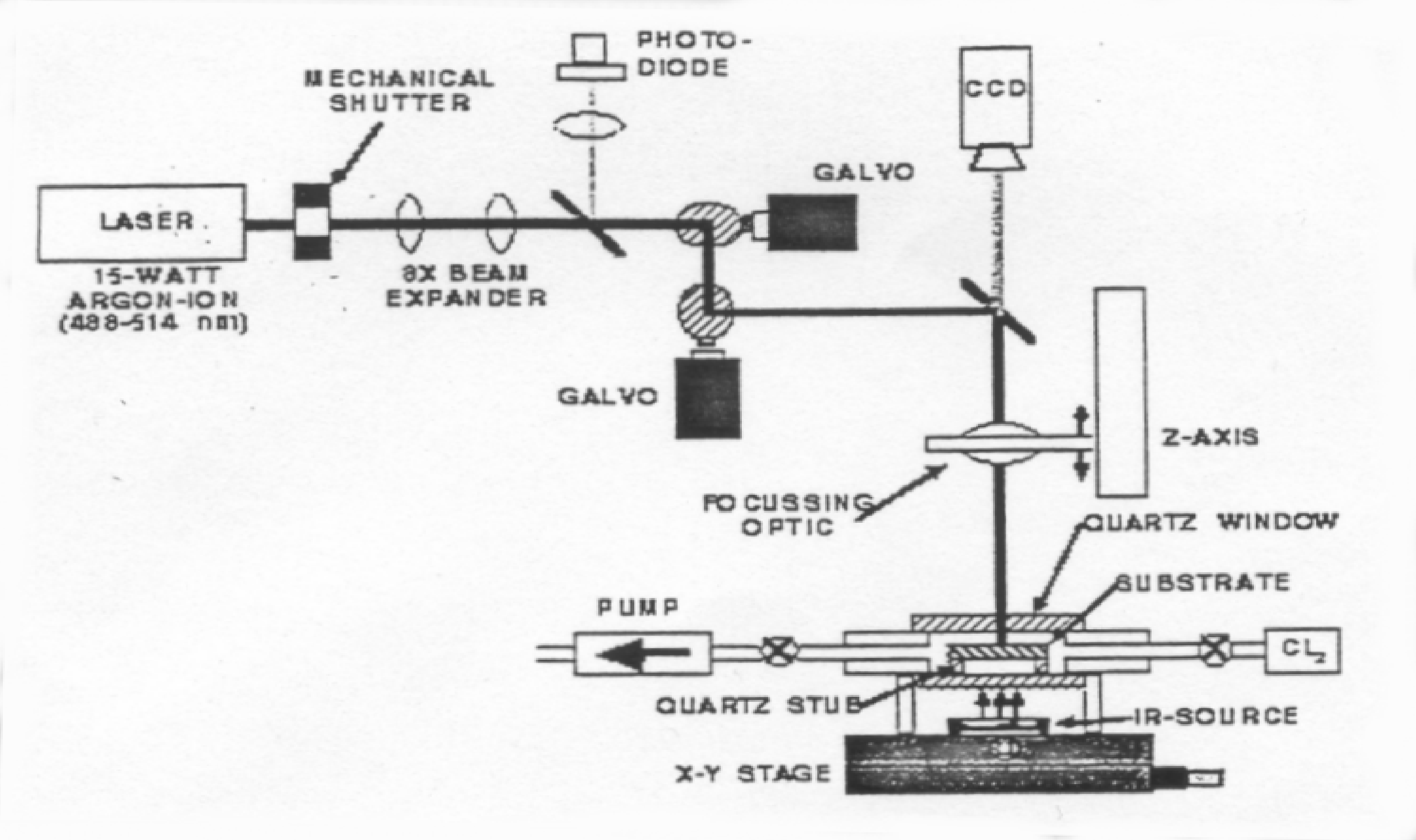
➢At the onset of melting, volatile silicon chlorides are formed. The reaction is confined exclusively to the molten zone.



➢Chemical activation reduces the energy requirement for removal and minimize the potential for cracking. Crystalline materials, such as Silicon, have the benefit that unetched portions of the molten zone regrow epitaxially to crystalline quality. This allows controlled thin shavings to be removed plane by plane with fixed etch rate.

➢Structures can be built up by limiting etch depth at each scan plane

How we are doing laser micromachining



The etch depth can be maintained to approximately one micron shavings using low-inertia galvanometers to rapidly reflect the beam

Some details about this process

- A 15-Watt argon ion laser is expanded to a 16mm beam using an 8× telescope. An achromatic lens serves as the focusing element. The focused beam is introduced through a quartz cover-glass into a stainless-steel vapor cell containing the sample

- The vapor cell has ports for gas inlet and outlet, pressure head and thermocouple. The wafer surface is typically biased to approximately 373ºK using an IR-illumination source incident on the substrate from the backside

- Filtered, 99.9% pure research grade chlorine is slowly flowed over the wafer surface at 20 sccm to limit the build-up of products. A cold trap is also placed before the vacuum pump to protect it from the corrosive gas.

- The reaction is observed through the focusing optics with a CCD camera. A high power 50× objective is also mounted on a linear translation stage containing the focusing element allowing details on the surface to be more closely examined in-situ

The Volumetric Removal Rate

- This rate defines the throughput of the system. It defines how fast we can etch our structures.

- It is found experimentally to scale according to:

$$Vol.Rate = 10^4 \frac{\mu m}{\sec} \cdot \left(\frac{T_A}{300\,K} \right)^{0.8} \omega_m$$

where T_A is the temperature of the ambient gas and ω_m is the diameter of the molten zone

- Smaller, higher frequency waveguide components can be fabricated in *even less* time since volumetric removal rates scale linearly with melt zone diameter, or resolution, while the total volume of the device scales cubically with length scale.

Typical Volumetric Removal Rates

- The melt zone diameter is dependent on the laser power, optical coupling and thermal properties of silicon.

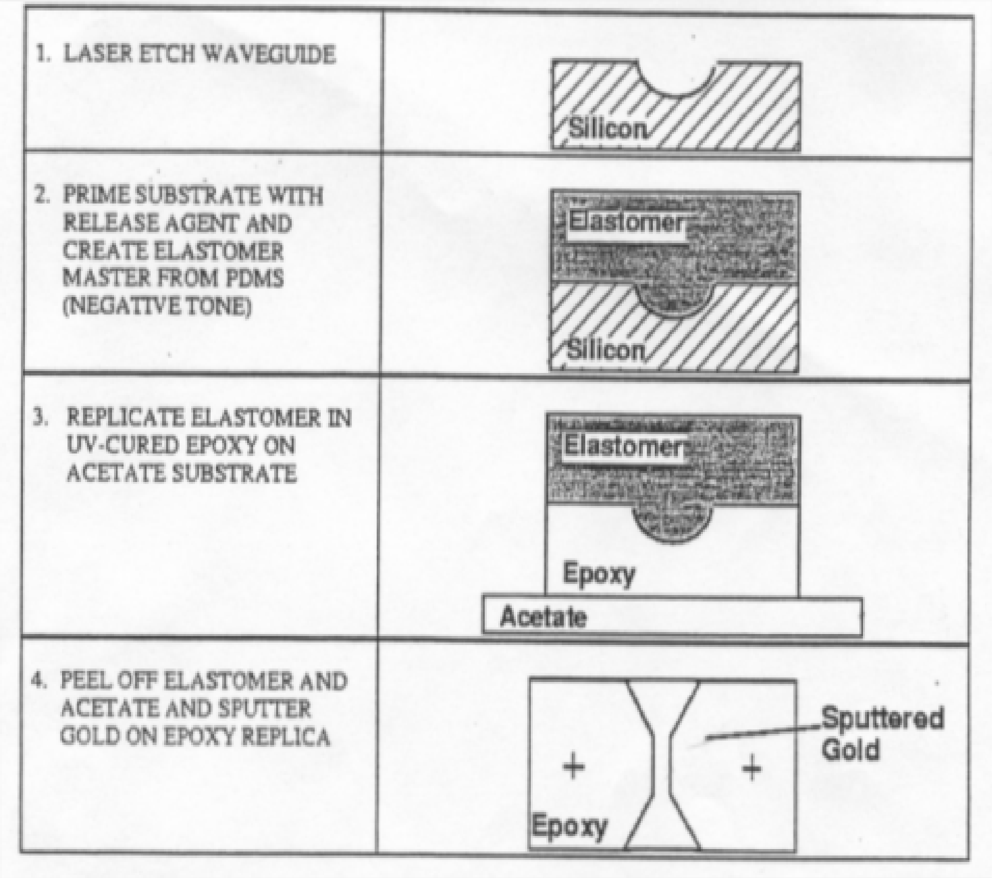
- In practice, the melt zone can be varied from 1 to 25 µm using a 15Watt Argon-ion laser running multi-mode.

- So typical values for removal rates ranging from 10^4 $\mu m^3/s$ ($0.036 mm^3/hr$) to 5×10^5 $\mu m^3/s$ ($1.8 mm^3/hr$)

- A similar 1.62 THz waveguide at 4-µm resolution can be etched in one-fourth the time of an 810 GHz version etched at 8-µm resolution

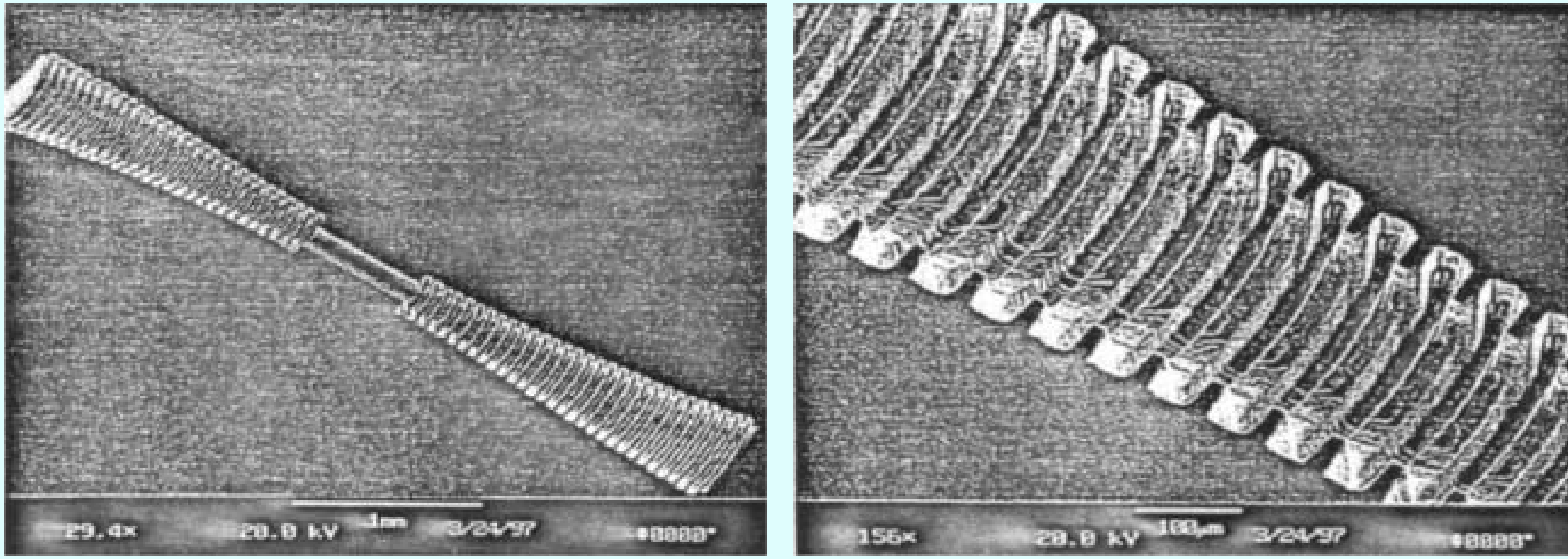
Device Replication

- To produce large arrays, it becomes more practical to replicate the etched devices
- A negative of the silicon etched master is first made by casting PDMS over the etched surface which has been first fluorinated with TDTS
- A low viscosity polymer precursor is then flowed over the elastomer negative, filling the structure through capillary action



- After replication, 0.3µm of gold are sputtered onto the waveguide surface and then structures mated using uv-cureable epoxy in a double sided aligner

Structures built with this technique

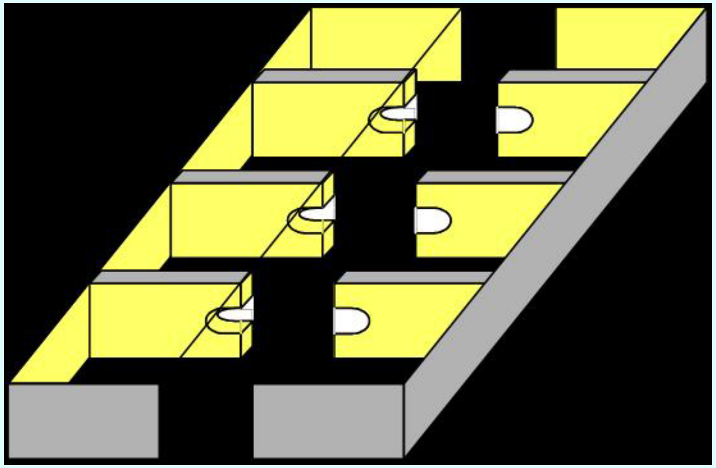


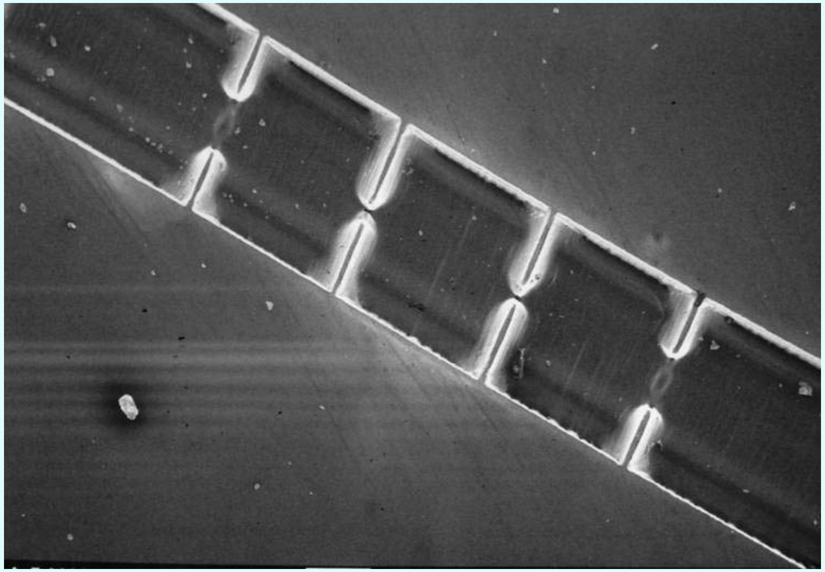
➢SEM micrograph of replicated version of 2 THz back-to-back corrugated horn antennas with a circular waveguide between them. The original structure was etched using 3 Watts of laser power focused into a 4 μm spot in 200 Torr of chlorine gas

➢The laser beam was scanned at 4 cm/s and incrementally moved 2 microns between line scans removing 0.65 μm shavings per pass of the laser over the surface

A low THz filter built with this technique

- Each half will be metalized with gold using a sputtering technique
- These halves will be bonded together using a Carl Suss bonding machine
- The assembled filter will be mated with traditional waveguide flanges for measurement at Jet Propulsion Laboratories.
- This design will be scaled to low THz





Split Block Style Design

Summary & Conclusion

- A new technology for the fabrication of waveguide devices which are difficult or impossible to manufacture using conventional techniques. Structures operating at 1 through 10 THz (feature sizes 300-30 micrometers) can be fabricated with this technology

- With this technology it is now possible to construct large format, waveguide imaging arrays at THz frequencies

- Waveguide surface roughness values measured with atomic force microscopy are typically on the order of 200 nm RMS. This quality is already sufficient to provide low loss waveguide performance to up 10THz

- Accurate measurements in the above frequencies is a really complicated issue and the measurements equipment is too expensive. Many people doing research on how we can measure the performance of those devices