# Fabrication of Folded Wave Guide Structure by Laser Micromachining

**Mounashree B S[1], Mr Sudhir B S[2]**

[1]Department of Mechanical Engineering, GMIT, Bharathinagara, Karanataka-571422, India,

[2]Associate Professor, Department of Mechanical Engineering, GMIT, Bharathinagara, Karanataka-571422, India

**Abstract:** ***In this thesis, a folded-waveguide slow-wave circuit working on 220GHz central frequency is targeted for investigation. The thesis includes two major parts, i.e. the theoretical study and electromagnetic field simulations; Our cold-circuit analysis reveals that the pass-band of the 220GHz central frequency folded waveguide is ~80GHz, which is between the cut-off frequency and the first stop-band. Parametric cold-circuit study provides better knowledge about how the varying structural parameters can influence the cold- circuit parameters. Optimization of cold-circuit properties via simulation also indicates ~20GHz bandwidth of the circuit, and this is used as the basis of further beam interaction circuit simulations***

## 1. Introduction

### 1.1 Need of Micro Machining

The miniaturization of devices is today demanding the production of mechanical components with manufactured features in the range of a few to a few hundred microns in fields that include optics, electronics, medicine, biotechnology, communications, and avionics, to name a few. Specific applications include micro scale fuel cells, fluid micro chemical reactors requiring micro scale pumps, valves and mixing devices, micro fluidic systems, micro holes for fibber optics, micro nozzles for high-temperature jets, micro molds, deep X-ray lithography masks, and many more. As a response to this demand, various micro manufacturing techniques have recently emerged, such as X-ray lithography electro deposition molding (LIGA), deep reactive ion etching, deep UV lithography, electrical discharge machining, laser machining and computer numerical controlled (CNC) micromachining. Most of these techniques require in accessible, expensive, or time-consuming equipment. so one of the viable micro manufacturing techniques for creating three dimensional (3D) features on metals, polymers, ceramics, and composites is mechanical micro machining. Micromachining utilizes miniature milling, drilling and turning tools as small as 10 □m in diameter to produce micro-scale features. Although geometric and material capabilities of micromachining have been demonstrated by Industrial application of micromachining has been hindered by the lack of experience and knowledge on the micro-mach inability of materials.

### 1.2 Significance of Laser Machining

The excellence attributes of laser radiation combined with a high degree of flexibility, contact- and wear-less machining, the possibility of high automation as well as easy integration allows using this tool in a wide field of macro machining processes for many materials including silicon, ceramics, metal and polymer. The world of laser machining production is divided into micro- and macro machining. This classification is not based on the size of the work piece but rather the fineness of the impact caused by the laser tool. The lasers system used for micromachining employ normally pulsed beams with an average power of well Laser micromachining techniques are currently used by the automobile and medical industries as well as in the production of semiconductors and solar cell processing. Lasers for micromachining offer a wide range of wavelengths, pulse duration (from femtosecond to microsecond) and repetition rates (from single pulse to Megahertz). These attributes allow micromachining with high resolution in depth and lateral dimensions.

### 1.3 Other Fields of micro-machining

It includes manufacturing methods like drilling, cutting, welding as well as ablation and material surface texturing, whereby it is possible to achieve very fine surface structures ranging in the micrometre domain. Such processes require a rapid heating, melting and evaporation of the material. The use of extremely short nano- and pico- and even femtosecond pulse durations helps to minimize the thermal effects such as melting and burr formation thus eliminating the need for any post processing measures. Besides choosing the proper laser source, it is often necessary to employ specialized micromachining components in order to achieve a desired geometry.

### 1.4 Types of Laser Micro Machining

Currently, laser micromachining is accomplished with two technologies: (i) direct laser writing (DLW) using solid state lasers with a 2D galvanometer scan head, and (ii) mask projection technique (MP) using mostly Excimer lasers and conventional fixed masks. In DLW, hard or low-sensitive materials generally require solid state lasers in combination with galvanometer scan heads and focussing optics to minimize the beam diameter and guide it over the material surface (Fig. 1). Based on today's approved scan head technologies and software, even processing of threedimensional surfaces is possible.

### 1.5 Merits and Demerits of Laser Micro Machining

Advantages are simple programmability and the resulting flexibility. Generation of characters, barcodes and other patterns is easy. Compatibility to existing file formats like

‘‘DXF’’ (Drawing Interchange Format) or ‘‘PLT’’ (Plot File) is given by the software’s import features. In consequence, this process can be easily controlled, permitting a high flexibility. Limitations of the direct writing process are given by the inherent characteristic of the sequential information transfer and dynamics of the scan head. In consequence there is speed limitation that must be considered. A second and often even more important limitation is given by the generally high intensities, which result from high power and tight focusing of the laser beam. Therefore, marking of sensitive materials like paper or plastics is hard or even impossible. For sensitive materials (especially organic materials) often Excimer lasers are used. Compared to frequency tripled solid state lasers their benefit is that even shorter wavelength can be utilized which allows to permanently change the colour of UV-absorbing pigments like titanium oxide. These lasers are commonly used in mask projection techniques (MP). Like in photolithography, the mask projection technique enables to transfer all information contained in a fixed transmissive mask at once.

## 2. Job for Micro Machining

SS 304L is an austenitic Chromium-Nickel stainless steel offering the optimum combination of corrosion resistance, strength, and ductility. These attributes make it a favourite for many mechanical switch components. The low carbon content reduces susceptibility to carbide precipitation during welding.

### 2.1 Types of SS 304

There are 3 types in SS304 namely SS304L, SS304LN, and SS304H

- *SS 304* is the standard “18/8” austenitic stainless; it is the most versatile and most widely used stainless steel, available in the widest range of products, forms and finishes. It has excellent forming and welding characteristics.
- *SS304L:* the low carbon version of 304,does not require post-weld annealing and so is extensively used in heavy gauge components(about 5mm and over).
- *SS304H:* with its higher carbon content finds application at elevated temperatures. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures. Grade 304 can be severely deep drawn without intermediate annealing, which has made this grade dominant in the manufacture of drawn stainless parts such as sinks, hollow-ware and saucepans.
- *SS304LN*: Stainless steel grade 304 is the most commonly used stainless steel. Stainless steel grade 304LN is a nitrogen-strengthened version of stainless-steel grade 304.

**Table 1:** Composition of workpiece-SS304L [2]

| S. No | Alloys | % |
|---|---|---|
| 1. | Chromium | 18.2% |
| 2. | Silicon | 5% |
| 3. | Nickel | 8.5% |
| 4. | Carbon | 015% |
| 5. | Manganese | 1.6% |
| 6. | Iron | Balance |

**Table 2:** Mechanical Properties of workpiece-SS304L [2]

| Mechanical Properties | Annealed | Cold Rolled |
|---|---|---|
| Ultimate Tensile Strength | 100,000 PSI | 210,000 PSI |
| Yield Strength (.2% Offset) | 40,000 PSI | 190,000 PSI |
| Elongation in 2” | 40% | 2% |
| Modulus of Elasticity (Tension) | 28 x 10 6 PSI | 25 x 10 6 PSI |
| Poisson’s Ratio | 0.29 | |

### 2.1 Machinability

Type 304/304L is a tough austenitic stainless steel subject to work hardening during deformation and, unless modified for improved machining response, is resistant to chip breaking. The best machining results are achieved with slower speeds, heavier feeds, excellent lubrication, sharp tooling, and powerful, rigid equipment.

### 2.2 Corrosion performance of stainless steel

Type 304 with other stainless steels in a variety of common corrosive environments. The table shows the lowest temperature at which the corrosion rate exceeds 5 mph. All testing was done in accordance with the requirements of the Materials Technology Institute of the Chemical Process Industries (MTI).

### 2.3 Workability

*Cold Working*: Type 304/304L is readily formed and fabricated through a full range of cold working operations. It can be used in heading, drawing, bending, and upsetting. Any cold working operations will increase the strength and hardness of the material, and may leave it slightly magnetic.

*Hot Working*: Type 304/304L can be forged in the 1700-2200°F range. For maximum corrosion resistance, forgings should be annealed at 1900°F minimum and water quenched or rapidly cooled by other means after hot working operations.

### 2.4 Heat treatment

*Annealing*: Type 304/304L should be heated to 1900ºF minimum and water quenched or rapidly cooled by other means.
*Hardening*:Type 304/304L cannot be hardened by heat treatment. However, Type 304/304L can be hardened by cold working.

## 3. Influencing factors in Selection of Job SS304Lfor Machining

Stainless steel with excellent corrosion resistance and good resistance to intergranular corrosion. Oxidizing acids, such as concentration 65% below the boiling temperature of nitric acid, with strong corrosion resistance. Most of the alkali solution and organic acids and inorganic acids also have good corrosion resistance.Excellent hot and cold forming process and performance. Better low temperature performance. At -180 °C condition, strength, elongation, area reduction rate is very good. In the absence of brittle transition temperature often used at low temperatures.Has good weld ability. Welding method can be used often, both before welding without heat treatment after welding.

## 4. Laser Micro Cutting Process

Industrial laser cutting of steel with cutting instructions programmed through the CNC interface Generation of the laser beam involves stimulating a lasing material by electrical discharges or lamps within a closed container. As the lasing material is stimulated, the beam is reflected internally by means of a partial mirror, until it achieves sufficient energy to escape as a stream of monochromatic coherent light. Mirrors or fiber optics are typically used to direct the coherent light to a lens, which focuses the light at the work zone. The narrowest part of the focused beam is generally less than 0.0125 inches (0.32 mm) in diameter. Depending upon material thickness, kerfs widths as small as 0.004 inches (0.10 mm) are possible. In order to be able to start cutting from somewhere other than the edge, a pierce is done before every cut. Piercing usually involves a high-power pulsed laser beam which slowly makes a hole in the material, taking around 5–15 seconds for 0.5-inch-thick (13 mm) stainless steel, for example. The parallel rays of coherent light from the laser source often fall in the range between 0.06–0.08 inches (1.5–2.0 mm) in diameter. This beam is normally focused and intensified by a lens or a mirror to a very small spot of about 0.001 inches (0.025 mm) to create a very intense laser beam. In order to achieve the smoothest possible finish during contour cutting, the direction of beam polarization must be rotated as it goes around the periphery of a contoured work piece. For sheet metal cutting, the focal length is usually 1.5–3 inches (38–76 mm).

## 5. ND: YAG Laser Specification

**Table 3:** Specification of ND: YAG LASER [7]

| Software | Laser engraving |
|---|---|
| Version | 1.24 |
| Max capacity of energy | 75W |
| Wavelength | 1.06µm |
| Beam | 20µ |
| Focal length | 163mm |

### Selection of Machining Parameters

Ten Experiments were conducted by taking consideration of inclination, Speed, Power Supply, Frequencies and Pulsed duration as shown in Table 4. By employing fractionated factorial designs, we can choose the Optimum Machining Parameters. Benefits of this technique are Conclusions valid over the entire region spanned by the control factorsand their settings, Large saving in the experimental effort and analysis is easy.

**Table 4:** Machining Parameters

| S. No | Hatch 1and distance | Angle 1 | Angle 2 | Power % | Speed mm/sec | Frequency KHz | Pulse duration |
|---|---|---|---|---|---|---|---|
| b1 | 0.01 | 0 | 90 | 70 | 350 | 20 | 10 |
| b2 | 0.01 | 0 | 90 | 80 | 500 | 30 | 10 |
| b3 | 0.01 | 0 | 90 | 80 | 500 | 20 | 15 |
| b4 | 0.01 | 0 | 90 | 75 | 350 | 20 | 10 |
| b5 | 0.01 | 0 | 90 | 90 | 900 | 20 | 10 |
| b6 | 0.01 | 0 | 90 | 90 | 350 | 20 | 10 |
| b7 | 0.01 | 30 | 150 | 70 | 500 | 30 | 10 |
| b8 | 0.01 | 0 | 90 | 80 | 500 | 20 | 10 |
| b9 | 0.01 | 0 | 90 | 80 | 500 | 10 | 10 |
| b10 | 0.01 | 0 | 90 | 80 | 800 | 20 | 10 |

### Images

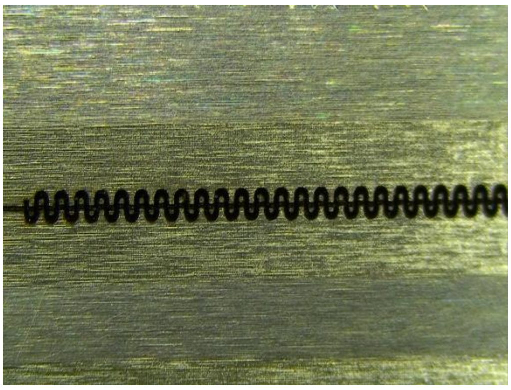

**Figure 1:** Image of Micro Machined Job

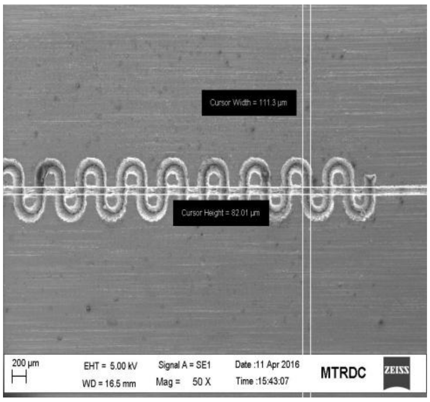

**Figure 2:** Quality Check of Job

## 6. Conclusion

Laser micromachining technique was successfully used tofabricate an array of CTLM patterns on Al/n-type SicOptimum laser energy used was 0.3 microns for this purpose and relatively low DC, 19x10-4 cm2However, when the laser energy was further increased, atremendous increase of ḍc which was up to 20 timeshad occurred. This phenomenon could be attributed to thedegradation of Al/3C-SiC surface. Thus, an optimum laserenergy used is crucial to produce a low specific contactresistant of an Al/3C-SiC systems comparable to the oneproduced from standard photolithography technique was observed from this study. We described our computational design, MEMS fabrication, and RF measurement analysis on a 0.22 THz sheet beam travelling wave tube amplifier. The idea behind this work is to be able to scale the vacuum integrated power amplifier technology into the THz range of the electromagnetic spectrum. This region of the electromagnetic spectrum 100 GHz-1 THz and beyond has the potential for fundamental research that can culminate into commercial devices and applications including security imaging and advanced communication systems. The utilization of MEMS based technologies that originally came about from the semi-conductor industry, has been an enabling factor in moving towards the goal of compact portable (?) device with practical power 0.01 W-tens of watts with an efficiency of >

1% and an instantaneous band width of 0.01.We are currently preparing for the exploratory hot test employing the MEMS fabricated circuits in a fixture assembly with the electron beam assembly and magnetic focusing structure. We hope that after this proof of concept experiment, we can scale this SBTWTA design to even higher frequencies to potentially fill the so-called THz gap.The efficiency of the TWTA for actual device applications can be as high as ~ 12% by employing depressed collector with a nominal recovery efficiency of ~ 50%. The peak in the Pout versus frequency curve is being studied in more detail to preclude any high order parasitic oscillations.

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