

# MICRO/NANO WELDING-CURRENT STATUS AND FUTURE TRENDS

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**Abstract**—The present work critically reviews the current state of the art in micro/nano welding and its future applications in various micro systems. New developments such as the electron beam microwelding, leaser microwelding resistance microwelding, solid state ultrasonic welding, microjoining by adhesive bonding, micro-electromechanical systems, micro-total analysis systems. Micro/nano welding of dissimilar materials have been discussed. These techniques are promising and are expected to be used in future joining applications. As micro/nano techniques are affected by even minutest particles of dust special considerations need to be given to the development of improved machines for nano welding.

**Index Terms**—micro-welding, nano-welding, dissimilar materials nano-welding, plasmonics . (key words)

## I. INTRODUCTION.

New developments in the area of micro/nano welding have opened new avenues to fabricate electronic optical, magnate and biological devices. Nanojoining enables the direct joining and assemble of low dimensional nanostructures components for nano devices with functional prefabricated components.

It is important in the present context to emphasize that there is an urgent need to join nano scale building blocks for example the nano-particles and nanowires to themselves or dissimilar nano-components or even molecular components to

produce functional nano devices/system and to integrate them into micro and macro-system. As the solid-state devices are becoming increasing smaller their assemble and joining at nano level pose difficulties to the designer. Methods are therefore need to be developed to strongly and safely assemble these miniature modules/building blocks. When these modules shrink to nanoscale such as nanomechanical engineering systems, the melting depth needs to be controlled within a few nanometers. Ultrafast pulsed laser is a recently developed new tool for such nano scopic processing [11,12]. Femtosecond laser irradiation can be used to obtain ultrafast non thermal melting of solid materials. This is a novel joining technology for nano and molecular devices [13] with the introduction of nano fabrication technologies, nao scopic joining is finding wider applications. In the following paragraphs new development in this area are discussed in bried.

## II. CLASSIFICATION

Classification of micro/nano joining process is shown in Fig. 1

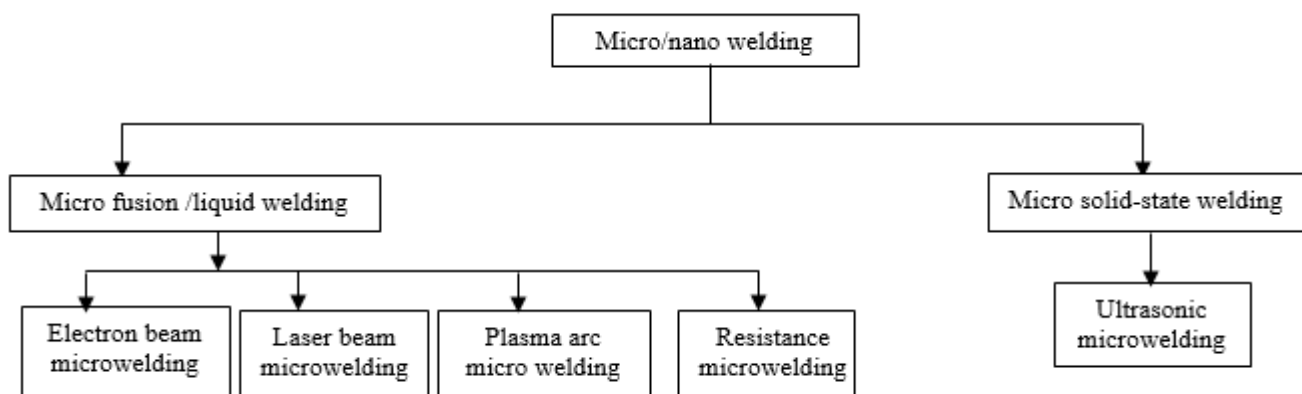


Fig.1 Classification of micro/nano joining process

#### A. Electron beam microwelding(EBMW)

EBW is popular for macro applications and it is characterized by low thermal load precise energy input, and fine beam manipulation capabilities. However, this method is also gaining importance in micro and nano applications because of its capability to focus the beam exactly within a diameter of a few microns. The most common industries that employ EBW are the aerospace, automobile, nuclear and the manufacturers of electronics, consumer products and medical devices.

EBMW is also capable of joining **dissimilar metals**. This process has certain limitations, such as high equipment cost and limited work chamber size. X-rays produced during welding are harmful to the operator and the rapid solidification rates may cause cracks in some materials.

#### B. Laser Beam Microwelding(LBMW)

In LBMW the highly concentrated ( $10^8$ - $10^{10}$ W/cm<sup>2</sup>) laser beam forms a tiny weld pool in a few microseconds. Solidification of the weld pool surrounded by the cold metal occurs as fast as the melting. No shields (neutral gas, flux) and required because no contamination occurs owing to the very short exposure time of the molten metal to the atmosphere. Laser welding is a noncontact process that requires only single-sided access. Materials that can be microwelded using laser beam are: stainless steel, inconel, aluminium, titanium, copper, refractory alloys, and tool steels. LBMW is widely used for micro manufacturing in industries such as electronics, communication, aerospace, and medicine, and in those that produce scientific instruments.

#### C. Resistance microwelding

Resistance microwelding is mostly used to join nonferrous materials in the fabrication of precision components and devices (such as sensors, actuators and medical devices). Resistance welding uses the high resistance of a weld interface to create heat by passing current through the parts to be joined. The circuit is created by electrodes that contact both parts either from the same side or from the opposite sides of the workpiece. Force is applied before during and after the application of current to prevent arcing. Unique microresistance welding techniques have been developed for attachment of wires/foils which range in thickness from 12.5 to 750µm.

Materials that can be microwelded using resistance microwelding are nichrome, nickel stainless steel, inconel, copper alloys and precious metals. The process requires comparatively low investment, and it is more environmentally friendly. However, it may not be recommended when the parts are mechanically delicate.

#### D. Solid state microwelding

Solid state welding is a group of welding processes that produce those product temperatures essentially below the melting point of the base materials being joined, without the addition of filler metal. In these processes time temperature and

pressure individually or in combination produce coalescence of the base metal without melting. Some of these processes offer certain advantages since the base metal does not melt and form a nugget. When dissimilar metals are joined their thermal properties are of less importance for solid-state welding than for the arc welding process. However for microwelding, ultrasonic microwelding (UMW) is mostly used

The **Ultrasonic microwelding** is used for semiconductor chip-level interconnection using wire diameter typically less than 20µm but occasionally at a few hundred microns for power electronics applications. Ultrasonic bonding uses vibration energy at the joint interface to create the bond. Vibration energy is delivered to the interface by a horn that contacts that top part. The horn vibrations at frequencies of hundreds to thousands of time per second with motion amplitude between 10 100 µm.

Materials that are difficult to weld by other welding processes are commonly welded using UMW for example aluminium alloy, copper alloy and gold. A basic drawback of the UMW process is that the horn is consumable which requires timely inspection and replacement. Joint geometry is mostly limited to lap welding only.

#### E. Microjoining by Adhesive Bonding

For assembly of microparts the use of mechanical means is not common practice but microadhesive bonding is feasible solution in such cases. The desirable properties of adhesive when used for such subassemblies can be totally different from those in classical macroscopic dimensions. The handling of adhesive materials is also different. Only a small amount of adhesive is needed. It has to be placed very precisely and it may be swallowed by capillary action into the microstructure. The transport of a single drop with defined size must be provided.

This process has many applications such as in conductive joints in dynamically stressed systems such as electronics in automotive components thermal management, fiber-optic couplers, electro-optic transduced and high definition sealing in microfluidics.

New developments in the area of micro/nano fabrication have opened avenues to fabricate electronic optical magnate and biological devices ranging from sensors to control system. Now a Days semiconductor industries are concentrating on the development of micro/nano joining techniques. In the last 35 years the growth of semiconductor industries has rapidly increased.

### III. MICRO-ELECTROMECHANICAL SYSTEM (MEMS)

Micro-electromechanical systems, or MEMS is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. [1] The major aim of this system is to develop inexpensive and reliable tools for micro/nano manufacturing and joining technology by combining advanced micro/nano technology and electro-mechanical system. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres. These devices (or systems)



have the capability to sense, control and perform on the micro/nano scale, and generate effects on the macro scale.

MEMS are separate and distinct from the hypothetical vision of molecular nanotechnology or molecular electronics. MEMS are made up of components between 1 to 100 micrometres in size (i.e. 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometres (20 millionths of a metre) to a millimetre (i.e. 0.02 to 1.0 mm).[2]

MEMS devices are widely used in miniature robots, micro engines, sensors, micro transmissions, micro mirrors, locks, inertial, inkjet-printer cartridges, accelerometers, micro actuators, optical scanners, fluid pumps, transducers, and chemical, pressure and flow sensors.[3]

Fig.1 represents ADXL 345B which is used in a gyroscope robot chip, which is smallest sensors integrated circuits base, device. At their core are tiny vibrating tabs, built directly on the silicon chip. Their detection is based on vibrating ceramic pieces whose distortion is produced by changes in angular velocity. It aims to integrate mechanical elements, sensors, actuators and electronics on a silicon substrate using micro fabrication technology.[4]

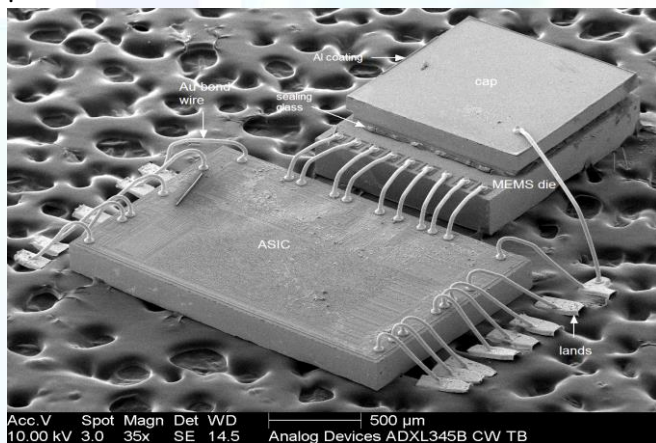


Fig.1 Analog device ADXL 345B

MEMS market is very fragmented, with a number of high volume MEMS applications still limited today. However, a whole range of new MEMS devices has now reached the market and new 'emerging MEMS' devices are coming up. Because of the significant impact that MEMS can have on the commercial and defence markets, The industry have taken a special interest in their development.

The MEMS market is on a growing trend again, and many changes are happening on the technical side, business model side and supply chain side. MEMS will continue to see steady, sustainable double digit growth for the next four-five years.

#### IV. MICRO TOTAL-ANALYSIS SYSTEMS ( $\mu$ TAS)

The area of micro total analysis systems, also called "lab on a chip", or miniaturized analysis systems, is growing rapidly. A new trend today is towards creating Micro Total Analysis Systems -  $\mu$ TAS. Such a system shall shrink a whole laboratory to chip-size lab-on-a-chip. Because of its very small

size, such a system can be placed close to a sampling site. It can also be very cost effective thinking of chip technologies, sample sizes and analysis time. [7]

The determination of the concentration of a chemical compound in a solution can be measured using micro total analysis system( $\mu$ TAS)In MAFIS system (Micro Ammonia Flow Injection Analysis System) a Typical  $\mu$ TAS. The concentration of ammonia can be measured optically. Fig.2 is the example of  $\mu$ TAS where MAFIAS – An integrated Lab-on-a-Chip for ammonium measurement" needs some explanation. The name of the project from which this thesis evolved is the MAFIAS project. MAFIAS is an acronym for Micro Ammonium Flow Injection Analysis System, i.e. a system for the measurement of ammonium concentration using the flow injection analysis (FIA) method, realized with the use of microtechnology techniques. The title also refers to the dream of a fully integrated chemical analysis system on a single chip. This system should be functionally equivalent to a conventional table-top system, but with dimensions that make it easily fit in ones hand. The downscaling of such a system results in a number of advantages. Not only becomes the system readily transportable, but also the consumption of energy (to drive the system) and the consumption of chemicals are significantly reduced. Also the small dimensions can considerably reduce the needed analysis time, opening the way to near real time measurements. Last but not least, the sample size needed for a reliable measurement is also smaller.[8]

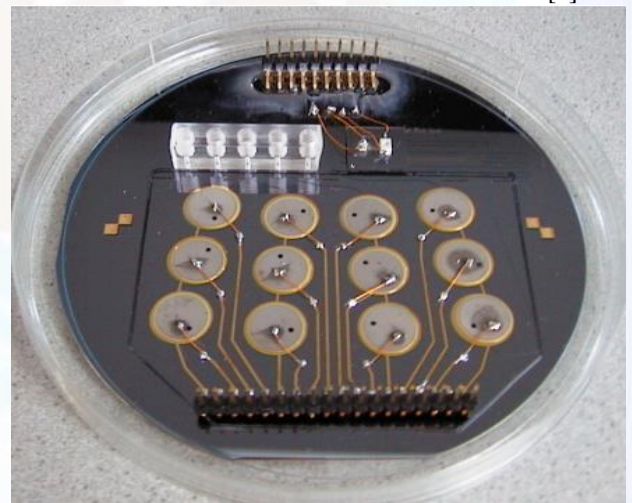
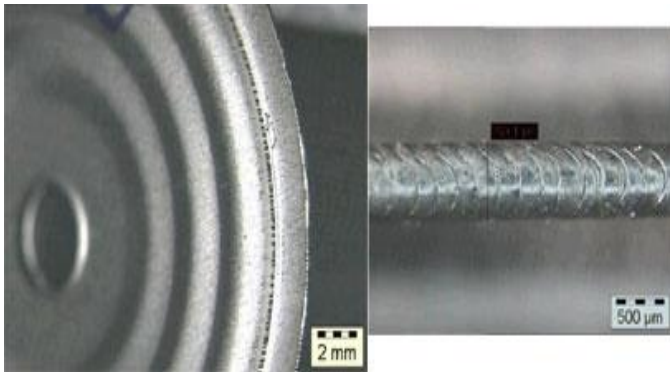


Fig.2 Micro Ammonia Flow Injection Analysis System

#### V. LEASER MICRO/NANO WELDING

Laser micro/nano-welding provides a means for joining of a wide range of metal and organic materials. Potomac often utilizes its pulsed infrared lasers in welding of metals and thermoplastics. Careful adjustment of laser energy and pulse duration is required and suitable part fixturing is essential.[10] It is a process performed by a computer controlled fiber optic laser that is focused onto a small spot of a particular item. It is ideal for joining small components, providing cylindrical welds, and fabricating tubular assemblies.



**Fig.3. Laser micro welding with aluminium**

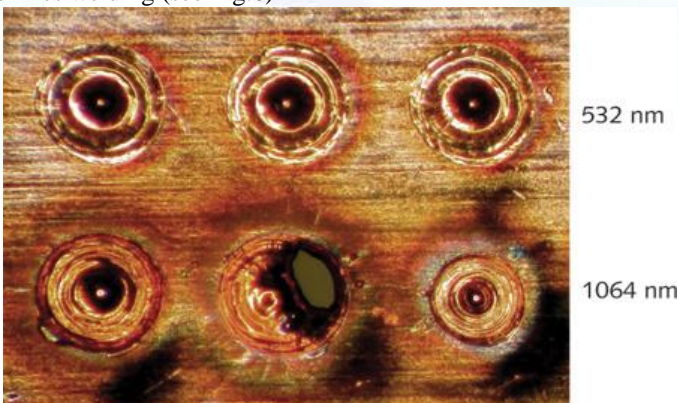
#### A. Micro/nano spot welding

Micro/nano spot welding set-up is shown in Fig. 5 and the spot welds produced are shown in Fig.6



**Fig.5 micro/ nano resistance welding setup [14]**

Reducing the laser wavelength from 1064 nm to 532 nm significantly reduces the reflectivity of copper and other conductive materials (see table). The 532 nm (green) wavelength enables consistent coupling into the copper and stabilizes welding (see Fig.6)



**Fig.6 Typical spot welds on bare copper are large and irregular when using a 1064 nm Nd: but are much better controlled and uniform when using a 532 nm wavelength**

#### B. Micro/nano welding of dissimilar material

When welding materials with different levels of absorption, there is a tendency to overheat the more absorptive materials, causing excessive spatter and porosity. This is usually overcome by favoring one material. However, for small parts, this may not be sufficient because even the tiniest absorption imbalance can create an overheated weld. At 532nm wavelength, the reflection of both parts becomes closer, therefore the weld energy balances more consistently, significantly improving weldability. Figure 6 & 7 shows a seam weld between two very different materials.



**Fig.7 This photo shows a seam weld between aluminum and titanium. With the green laser, there's no need to favor one of the materials.[25]**

### VI. CONCLUSION

This paper welding process employed for micro/nano welding have been discussed with their application. As the devices being developed in electronic industries are becoming increasingly smaller, their safe welding technologies have been presented. Micro-electromechanical systems. Micro total analysis system, indicating micro/nano spot welding, and welding of dissimilar material have also been discussed.

### VII. SCOPE FOR FUTURE WORK

In this interesting and promising field the work is in process in the direction of joining carbon nanotubes. Gong et al. are working on mechanical clamping methods using carbon nanotube films to wrap the carbon nano tube standards[35]. Both strong mechanical joining and electrical interconnection have been achieved. Yung et al. have used two carbon nano tube array to realize the flip chip packaging[37]. The interwall von der waats interaction provided robust mechanical joint and good electrical contacts. These developments come under mechanical joining. Work is still in progress in solid state joining which includes diffusion nano bonding, ultrasonic and electron beam bonding. Diffusion nanobonding uses nano particles as bond layers is currently under study. Here nanoparticles are sintered to form networks which are joined to form substrates assisted by diffusion with driving force to reduce surface area which in effect increase specific surface energy resulting in decrease of sintering and bonding



temperature.[22,23,42]. Low temperature joining processes for polymeric based microelectronics applications

Ultrasonic nanowelding is being developed to join CNTs to Ti electrodes for the development of carbon nanotube based photovoltaic cell with high energy conversion of carbon nano tube based photovoltaic cell with high energy conversion of carbon nanowelding process and being developed and also non thermal nano welding is a topic of recent research interest[39,41]

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