Method for Attaching Fluidic Interconnects using Resistively Heated Gold

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Abstract

Two methods of attaching fluidic interconnects are presented. By using gold to gold fusion bonding and copper to gold fusion bonding, micro-scale tubes are attached to a MUMPS fabricated fluidic channel. The fusion bonding is done by resistively heating a gold layer on top of the poly 2 layer, so that the gold melts. A range of different heater geometries is presented. The tensile and shear strengths of the resultant bonds are then tested.

Introduction

Microfluidic chips continue to grow in complexity and ambition of goals. Edge mounted tube attachment systems, o-ring interconnects, chip to chip interconnects, and interconnects via drilled holes have been reported. In addition designs utilizing high aspect ratio processes have been developed that take advantage of a larger contact surface for the tube. Currently, some difficulty exists in creating simple and small fluidic interconnects on the surfaces of microfluidic devices.

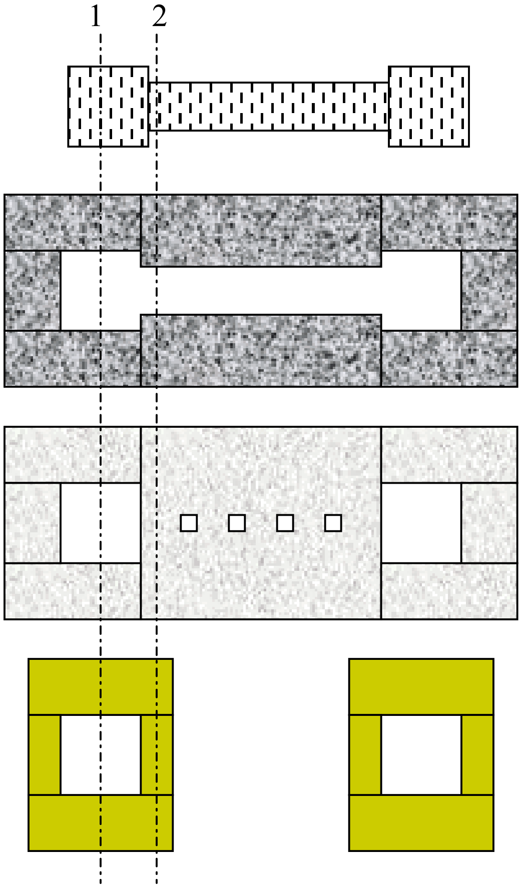
Materials

Two material systems were chosen for the attachment of the tube. The first employs copper tubing being bonded to a gold heater on the surface of the MEMS device. The tubing used is 32 gauge copper hypodermic tubing (100 micron ID, 250 micron OD) [www.accutube.com]. The gold heater is fabricated on top of poly 2 in the MUMPS process, and is placed around the orifice of the fluidic channel. By applying an alternating voltage across the ends of the gold heater via bond pads, the gold is heated to facilitate bonding to the copper tube. The Au-Cu phase diagram indicates that, at the ranges of atomic percent copper present in the interface between the tubing and heater geometries used (~50-67%), the mixture will liquefy at about 950°C. By applying a short pulse of voltage, the gold is heated to this temperature so that it mixes and bonds to the copper tube.

The second material system consists of composite tubing that has been sputter-coated with gold at the tip and the same gold heater. The tubing used is a syringe needle made of fused silica, polyimide, and polyolefin (20 micron ID, 90 micron OD) [world precision instruments]. This tubing is heat resistant, but testing is necessary to see if the resistance of the quartz component is sufficient to maintain the tubing integrity. In this case, the bond is made between the gold heater and the coated gold tip of the tube. The heater is brought to the melting point of gold (1064°C) and the two are joined.

Layout

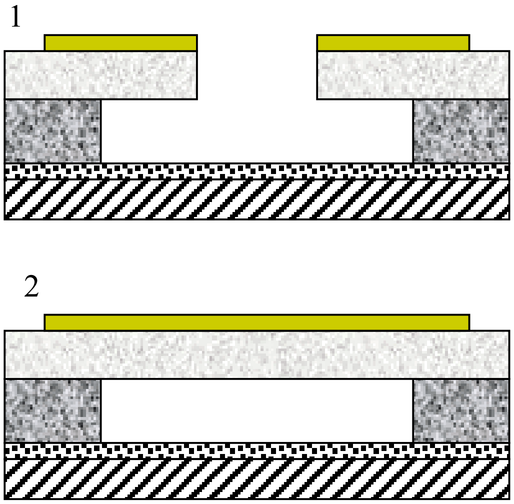
This device is created in the MUMPS process flow, although this method should work with other processes in an analogous fashion. The masks used are similar to those shown below. Note that all layers are drawn as deposited. The layers are the PSG1, Poly1, Poly2, and Gold respectively. In this layout, the two ends correspond to the fluid connect points, and the strip of PSG in the middle is the fluid channel. The voltage would be connected to the top and bottom portions of the gold surface.



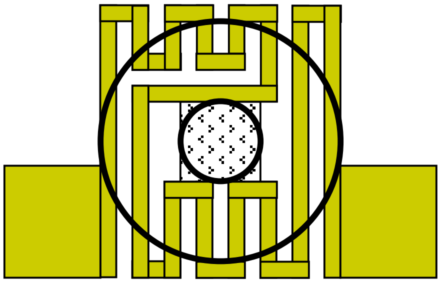
masks for MUMPS process

Heater Design

The gold heaters are designed as a single resistor that covers as much of the surface of the bonding site as possible while minimizing the unevenness of the heating. The result is two designs. The first is a simple rectangle of gold that encompasses the bond pads and leaves only the hole for the fluid inlet open. The other design is that of a serpentine resistor of three-micron width that covers roughly half of the bonding
surface.



cross sections from layout



serpentine heater

The resistivity of gold jumps from about 22 μΩ cm in the solid phase to 32 μΩ cm in the liquid phase at the melting point. The result of this is that there will be a tendency of the current to pass through gold that has not melted yet as opposed to gold that has. This may have the effect of making the temperature distribution of the bond more uniform as the gold melts. In order to characterize the effect of heater geometry on bond strength, the test structures are varied across the range of heater designs from the simple sheet to the serpentine coil.

Modeling

Since the heaters are on such a small scale, dissipation of heat is very rapid, especially because they are in such good contact with the polysilicon layers. This results in the simplification of the modeling of the temperature of the heaters. By using short periods of AC voltage, the temperature is rapidly brought to the bonding temperature (950-1100°C). Joule heating gives a good approximation of this type of heating, as long as the voltage pulses are sufficiently short and powerful. In addition, the conversion of the heat into a temperature can be estimated with the specific heat.

$$E = \frac{V^2}{R} t = m c_p \,\mathrm{dT}$$

Assuming a specific heat for gold of 0.128 J/g K, the minimum time required for each voltage pulse is determined for all heater geometries. For example, the serpentine resistor for the gold-gold system of 3 micron width has a total length of resistor of about 15 X 90 microns = 1350 microns. This corresponds to a resistance of about 135 ohms. This would mean that to heat the gold to its melting point in one microsecond, a voltage of 27 V would be needed. In reality, the amount of voltage required to bring the heater to the proper temperature will be larger than the ideal due to non-uniform heating and some conduction. This means that the device will operate at voltages somewhat higher than the predicted values.

The force of fluid entering the joint is primarily due to the momentum change of the fluid.

$$F = \dot{m} \,\mathrm{dv} = \left(\rho \,\mathrm{A\,v}\right)\mathrm{v}$$

For example, when water is flowing through the copper tubing at 1cm/s, the force is about 0.8 nano-newtons. By comparing these predicted flow forces to the tested strengths of the tubes in tension, it is determined if the forces from the fluids flowing through the joints could break the joints.

The strength of the bond at the heater is ideally computed from the tensile and shear strengths of the gold-gold or gold-copper metal systems. Since the bond will not be uniform, the bond strength will be somewhat less than the predicted maximum. Therefore, the degree of uniformity of heating is judged based on how close the actual strength of the bond is to the ideal strength.

Test Structures

In order to find the configuration that provides the strongest bond, an array of test structures is created. Each element consists of two bonding points connected by a fluidic channel. These structures are varied across the range of heater geometries and for both material systems. The test consists of first bonding each tube onto the corresponding heater. This is repeated for a few different values of voltage for each heater geometry and material set. The etch holes are then sealed (either with an epoxy, or thermal oxide). Then, water is made to flow through the tubes and flow is measured. One of the tubes in each unit is then given a tension strength test, while the other is given a shear strength test. The results are plotted versus the parameters and the optimum design is determined.

Expected Results

As resistor width is increased, the surface area of the bond increases. Therefore, given sufficient time and energy to bond fully, the heater with the 90 micron width should make a stronger bond. The resistance of a 90 X 90 micron sheet is 0.3 ohms. Therefore, the resistance of the heater increases when the resistor width is reduced. This causes the power to drop as 1/R. Since the fill factor of the heater is dropping as the width is reduced, it gets hard very quickly to make a good bond as the heater width is reduced. Therefore, the optimum point should be closer to the 90 micron width heater.

Summary

Although many methods of bonding fluidic tubes to MEMS devices exist, the method detailed in this paper may add a new capability to this field. It would allow compact, very small tubing connections to the surface of a wafer without the need fro high aspect ratio MEMS. However, testing is necessary in order to establish the validity of the predictions of this study.

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