WAFER LEVEL PACKAGING WITH WEDGE SEAL METHOD

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Abstract: Wafer level packaging could reduce the cost of MEMS based sensors through simplified processing and inexpensive components. A novel vacuum tight seal referred to as the wedge seal method is proposed in this paper. The seal consists of a silicon wedge forced into a pliable material (typically a metal) that is attached to the component wafer. The wedge-seal addresses some of the requirements of micro-bolometer packaging in that it provides a vacuum tight seal at low temperatures with tolerance to surface finish and topography. The concept was evaluated with regards to manufacturability, material suitability and performance. A demonstrator model was manufactured with Complementary Metal–Oxide–Semiconductor (CMOS) compatible processing equipment and procedures. The wedge effectively penetrated the metal base and showed promising leak rates.

Key words: Wedge seal, anisotropic etching, vacuum-tight and low temperature.

1. INTRODUCTION

Micro Electro Mechanical Systems (MEMS) are comprised of small fragile structures which typically sense mechanical movement, pressure differences or electromagnetic radiation.

Each sensor type has unique packaging requirements with regards to sensor exposure and isolation. In the case of a micro bolometer, suitable thermal isolation and sufficient Infrared Radiation (IR) exposure both affect the performance of the sensor. Thermal isolation is effectively ensured with a vacuum inside the package around the sensor and IR radiation requires a transparent medium that allows the radiation to penetrate the packaging and reach the sensor.

Many successful bolometers have been developed and deployed commercially, and due to a competitive market the unit price is under continued downward pressure. Since packaging could account for up to 75% [1] of the device costs, new low cost packaging techniques are required.

MEMS have gained much support as it builds on the well-established silicon wafer processing industry. Current packaging research focuses to build on the bulk silicon processing capabilities and to perform packaging on wafer level, before separating the devices, known as Wafer Level Packaging (WLP) or Zero Level Packaging.

Current WLP bonding techniques include: electric field assisted adhesion (anodic bonding), direct binding and joining with an intermediate layer (metal-eutectic/solder etc) [2].

Currently only plasma activated Silicon Direct Bonding (SDB) allows for a vacuum compatible joint that requires processing at temperatures below 200 °C. But this process has further limitations in that it is very sensitive to particle contamination and requires a surface roughness of less than 2 nm [2].

In this paper we propose a wedge-seal method that promises to be a low cost, low temperature (< 200 °C), Ultra High Vacuum (UHV) seal joint (Leak rates <1E-15 mbar.l/s) that can accommodate surface roughness variations in the order of 1 μm. The manufacturing requirements are also compatible with Complementary Metal–Oxide–Semiconductor (CMOS) processing equipment and procedures.

2. WEDGE SEAL DESCRIPTION

The wedge-seal joint builds on the Con Flat (CF) vacuum seal that uses two knife edges which are forced into a copper ring, with the knife edges deforming the copper ring and thus forming the seal [3]. We deployed the same principle on wafer level with a knife edge etched into a silicon wafer and a base wafer that was coated with a metal layer. The lid with the knife edge was then forced down onto the base with the metal layer so that a vacuum joint was formed (see Figure 1).
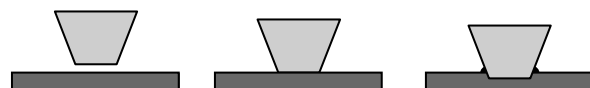

Figure 1: Wedge forming seal with metal base

3.   IMPLEMENTATION

This concept was evaluated by processing a lid with a wedge seal protruding from the surface and a flat base covered with indium.

The wedge component of the seal is formed from a Silicon wafer that has a <100> crystal orientation and by using an anisotropic wet etch (see Figure 2). The seal layout must be composed of straight lines due to this process with proper corner compensation structures.
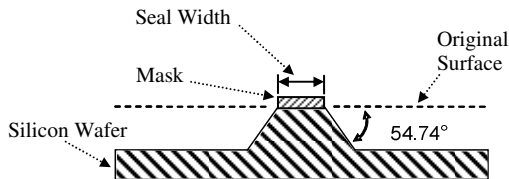

Figure 2: Anisotropically etched edge features

Photolithographic processes are used to define a mask for a nitride passivation layer, during plasma etching. The nitride then provides the masking material for the anisotropic etch. The photolithography limited the width of the seal face and the minimum width obtained was 16 um. The width could be significantly reduced by using reticles and a wafer stepper. The anisotropic etch consists of potassium hydroxide (KOH), water and isopropyl alcohol (IPA). The wedges were etched until they protruded a height of 27 µm (see Figure 3).
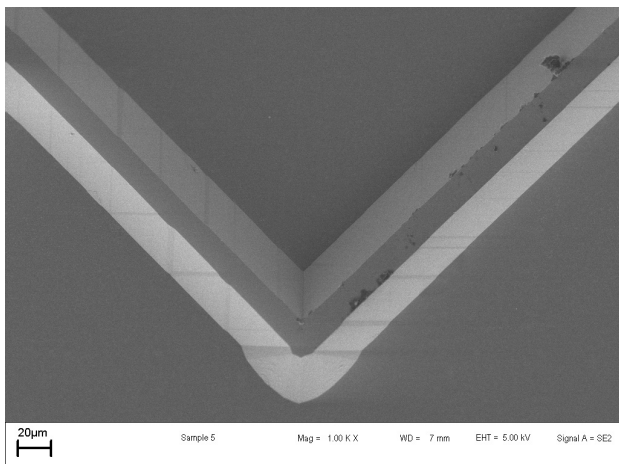

Figure 3: Scanning Electron Microscope (SEM) image of wedge structure

The base layer should provide a pliable interface to the wedge, which needs to deform the material to conform to the shape of the wedge and thereby create an intimate joint. Since the pliable base layer is exposed to the vacuum inside the cavity it must be stable at very low pressures and thus a metal is preferred. Various metals are suitable for this application but only those compatible with wafer processing are considered for the proposed wedge-seal. Some examples include aluminium, indium and gold. For our experiments a layer of indium was used to test the concept since it is very ductile at ambient. This was deposited with an evaporation process to a thickness of 1.5 µm.

The metal wedge joint has numerous factors that influence its design and processing. The wedge itself could be varied in its depth and seal width. The wall angles are fixed due to the anisotropic etching characteristics. The seal width depends on the processing capability and should be as thin as possible.

The metal base has two major properties to consider – these are the thickness of the layer and the type of material. The thickness should be at a minimum to save costs. The material itself has thermal (melting point) and mechanical characteristics (yield stress and ductility). The melting point of the material must be considered when reviewing all the post processes. If this temperature is exceeded the seal will be destroyed. The bonding process itself has three main variables namely; force, temperature and duration, apart from all the basic mechanical requirements of flatness and parallelism.

The ideal wedge seal characteristic is one where sufficient material has been displaced along the entire wedge section to form a vacuum tight seal. The wedge should however not push through the metal layer so as to damage the underlying structures or touch the base wafer and possibly destroy the seal integrity.

Metal-wedge joint processing involves the contact of the wedge seal surface with the metal layer and forcing the wedge into the metal layer so that the layer is permanently deformed (see Figure 4). Material ductility is a function of temperature and lowers until the material reaches its melting point where all mechanical strength is lost [5]. An increase in temperature should reduce the force required to penetrate the base material and increase the impression depth.
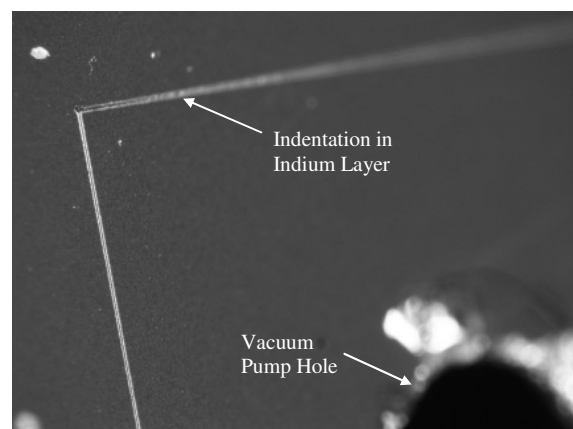

Figure 4: Indented indium surface, showing hole for vacuum pumping

As the force is increased the pressure is raised above the material yield strength, the material deforms and yields sideways as it makes way for the wedge. The material pushed away is further deformed by the slanted wedge sides which forces it further to the sides. This ensures that the seal surface and the sides make intimate contact. The vacuum joint is then established between the newly exposed metallic material and the wedge itself.

4.   SEAL TEST SETUP

The wedge seal performance was based on the hermiticity of the joint between the lid and the base wafer. The joint should be vacuum tight which is verified with a helium leak tester.

The connection to the leak test equipment requires a hole in the silicon base wafer which can be drilled with either a tungsten-carbide or diamond-impregnated drill bit. Both drill processes induce micro-cracks in the single crystal structure and they were etched to remove stress concentrations (see Figure 5). After the base wafer is covered with a metal layer and the lid with the wedge seal joined, the aluminium pump post is attached with vacuum grease and the test performed.
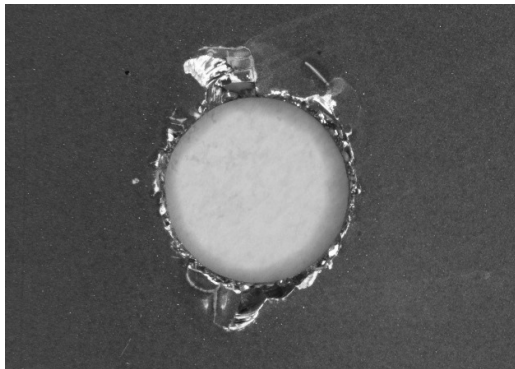

Figure 5: Hole drilled in silicon wafer

The wedge seal was defined on the lid wafer as a 1 x 1 cm square which was then bonded over the hole in the base wafer to create a cavity with an access portal. The bonding of the lid and the base was performed in a flip chip bonding machine. This allowed for the accurate and consistent bonding of the lid to the base wafer by controlling; the lid and base temperature, the force applied and the duration of the wait, ramp-up, hold and ramp-down phases. The flip chip bonding machine system calibration procedure ensures parallelism before each bonding run. After the lid was bonded onto the base wafer, the aluminium pump post was joined to the wafer with a thin layer of vacuum grease.
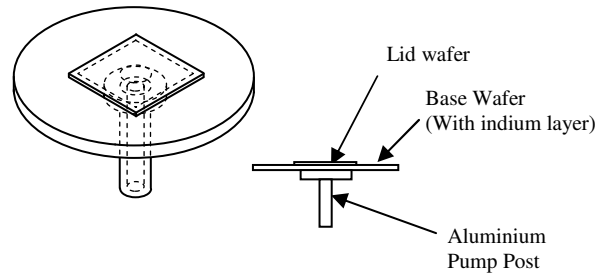

Figure 6: Wedge seal test layout

The wedge seal bonds were formed at different temperatures and forces. Initially the lids were removed to evaluate the uniformity of the indentation and to determine if the wedge had pinched through the metal layer. Depression uniformity was visually inspected under a microscope and pinching evaluated with a Near Infra-Red (NIR) light source and a camera sensitive to this bandwidth. The camera detects IR light that is not blocked by indium which should cover the entire seal length. If the camera senses IR light then the indium was totally removed or pinched so thin that it becomes transparent. Both cases constitutes as a poor bond.

Secondly after the indentation seems acceptable the packaged component is leak tested with helium to determine the hermiticity of the joint.

5.   TEST RESULTS

The 16 µm seal width showed even indentation from the wedge, this confirms that the flip chip bonder has been suitably calibrated with regards to parallelism and that the flatness of the bonding tools is acceptable.

The indentation depth could be varied significantly with different temperature and force combinations. High temperatures (> 120 °C) and high forces (>5000g) resulted in some of the seal sections pinching through with seal a width of 16 µm.

The indents of the 16 µm showed that a high force (7000 g) with a low temperature (40 °C) did not penetrate through the indium (1.5 µm thick). Wedge profiles with a seal width of greater than 16 um showed poor and uneven indentation even with forces up to 7000g. Higher forces should improve the indentation but it is not feasible.

The wedge seal hermiticity was tested after bonding (@ 40 °C, 7000 g) and showed leak rates of 1.2E -10 mbar l/s with Helium. This leak rate is close to the lowest detectable leak rate of the equipment and due to the vacuum, outgassing could become significant.

The joint has poor mechanical strength since no chemical bonds are induced.
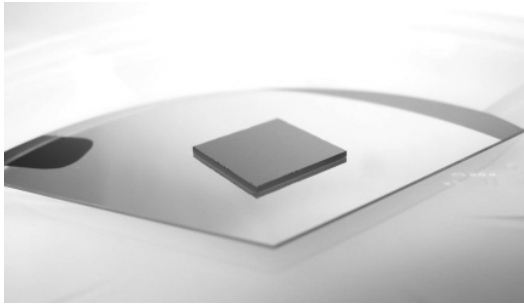
Figure 7: Bonded wedge seal lid joined to the indium covered bottom wafer.

6. CONCLUSIONS

The wedge-seal concept was proposed as a wafer level packaging, lid to base, vacuum tight seal.

The components for this seal consists of a wedge, etched from a silicon wafer with a specific crystal orientation and a base covered with a pliable material namely indium. Both components were manufactured with CMOS compatible materials and processes. Forming the wedge seal requires mostly force and heating in between parallel and flat surfaces.

The wedge-seal performance relates to its ability to ensure that the vacuum, within the sealed cavity, isn't compromised and is quantified with a leak rate measurement.

The wedge seal components were manufactured from silicon wafers and bonded together. The silicon wedge effectively penetrated the indium base.

The vacuum was drawn through a portal in the base wafer. The leak rate test experiment showed promising results although the measurements were limited by the equipment and surface outgassing.

The wedge showed poor mechanical strength and for a sensor application it must be supported to withstand vibration and shock.

7. REFERENCES

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