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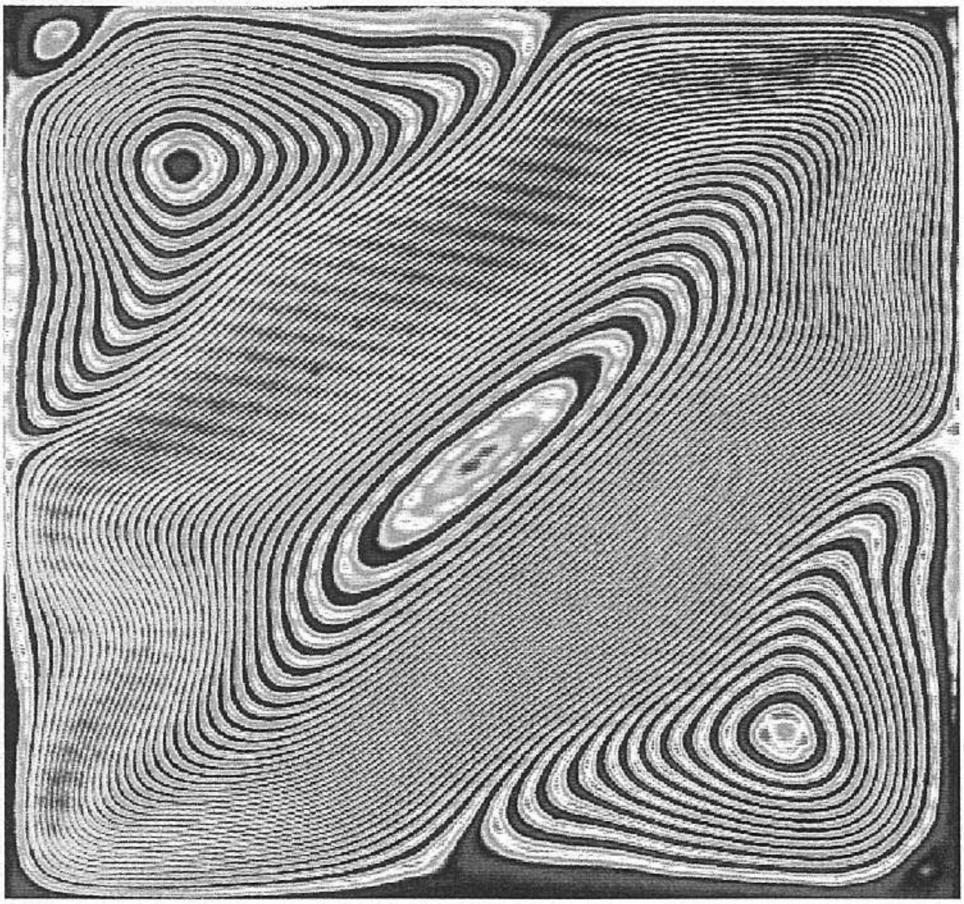

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Mask Materials in Powderblasting

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SUMMARY

Powderblasting has the opportunity to become a standard technology in micromachining. To machine small details with powderblasting, it is necessary to use a suitable mask. In this paper four mask types are examined. BF400 resist foil is most suitable for standard use in powderblasting for reason of simplicity. A simple metal plate can be used with less accurate dimensions (≥1mm) but having the advantage of being reusable. Electroplated copper has the opportunity to be a suitable mask for machining lateral dimensions of 50µm and less. These mask materials show that there are many ways of using powderblasting as a microtechnology.

Keywords: Powderblasting, Micromachining, Mask materials.

INTRODUCTION

Powderblasting is a technology in which a particle jet of a few centimeters cross-section is directed towards a substrate for mechanical material removal. The substrate is moved under the jet several times to achieve an evenly etched surface. The wide and inhomogeneous jet alone is not capable of blasting fine structures. So it is necessary to place a mask on top of the substrate which will specify small details. This also allows the use of multiple nozzles to reduce the process time. Powderblasting is currently used for e.g. device demarking in electronic industry, surface preparation prior to plating (without mask) and decorative etching/frosting on arts glass and flat panel display production [1] (with mask). In research, powderblasting is mainly used to determine the wear rate of industrial materials, but it can also be used for micromachining.

Powderblasting has several advantages compared to other micromachining techniques. Being an IC technology spin off, micromachining is best performed on silicon whereas other materials are much harder to process. Powderblasting however can be used on silicon and glass, but also on any other brittle materials like silicon nitride, other ceramics or even Perspex. Powderblasting is performed outside the cleanroom with relatively cheap equipment. It does not use hazardous chemicals and removing the powder from the substrate after blasting is not a problem.

Up to now, the minimum structure size is limited to about 100µm. This is partly due to the lack of a suitable resist layer that can define smaller structures. This paper looks at mask materials in general and for the possibility of making smaller dimensions in particular.

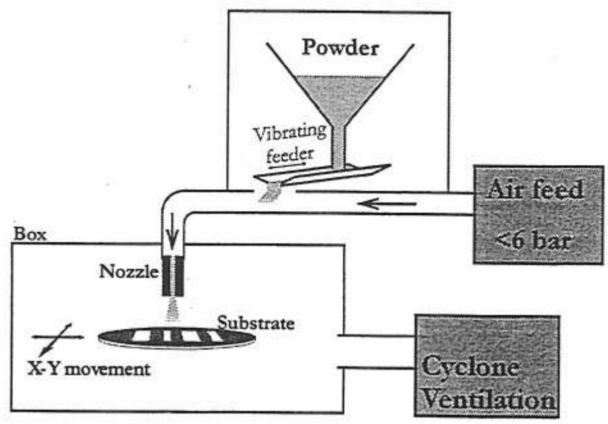

Figure 1. Powderblast equipment.

EQUIPMENT

The alumina particles are accelerated towards the substrate with a high-pressure airflow (Figure 1). The airflow is mixed with the particles by a vibrating feeder (in a HP-2, Texas Airsonics). The mixture is directed through a nozzle at the end of the tube. The particles (average diameter 30µm) hit the substrate with a speed of 100-200 m/s in an isolated box. This box is ventilated by a cyclone, which separates the powder from the airflow. The X-Y movement of the substrate ensures an evenly etched surface. Figure 2 shows a typical result of powderblasting in silicon.

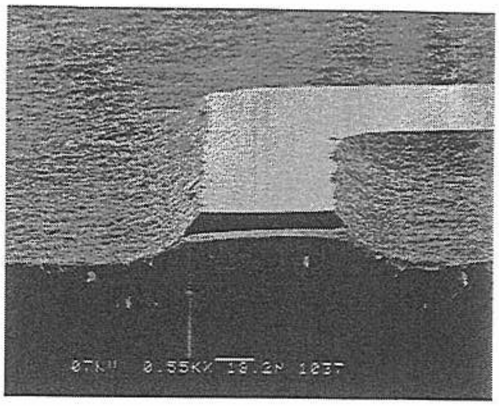

Figure 2. Typical etch result with powderblasting.

ETCH MECHANISM

There are two basic etch mechanisms in powderblasting namely ductile and brittle erosion. Ductile erosion is to be found with metals and brittle erosion is seen with glass and other brittle materials. The difference manifests itself in the shape of the impact angle dependent etch rate (Figure 3.).

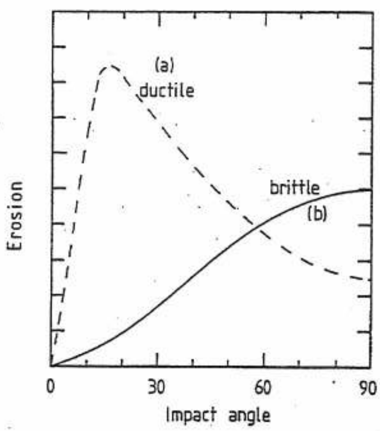

Figure 3. Two basic etch characteristics in powderblasting (90° is perpendicular impact) After [2].

When a sharp particle hits a brittle surface it induces a high compressive stress which plastically deforms the substrate. This creates large stresses that result in lateral cracks (Figure 4). Ductile materials have minimum erosion at 90° impact angle. Since the particle jet is directed perpendicular towards the substrate during blasting for maximum brittle erosion, a ductile material can be used as a mask material. Elastic polymers absorb the kinetic energy of the particles and are less damaged by them. Therefore, such materials can also be used as a mask in powderblasting.

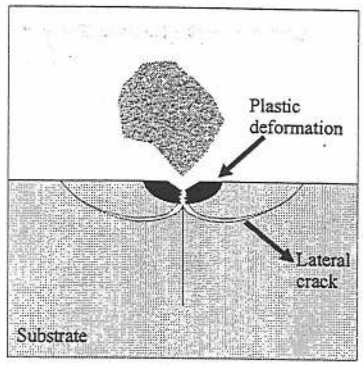

Figure 4. Etch mechanism in powderblasting.

PATTERN TRANSFER

Besides having a low etch rate, a suitable mask material in powderblasting should also be easily defined into small structures for a good pattern transfer. We first tested two elastic polymers that are lithographically defined.

Spin coated resist

Many negative resists are elastic. Because they are applied by spinning, the thickness can be adjusted to meet the process requirements. We tested the negative resist Waycoat SC resist 450 which had a reasonable low wear rate (a selectivity of 20 with respect to glass). However, it appears to be very difficult to create thick layers of resist (>10µm) because the layer cracks during development. This makes it unattractive to be used as a mask in hard powderblasting conditions.

Powderblast foil

Ordyl BF 400 is an elastic negative resist foil, specially developed for powderblasting. There are two types: 50µm and 100µm thick, we tested the first one. Up to an etch depth of 250µm, the foil has an average selectivity of about 25 with respect to glass. However, the selectivity decreases during etching. First, the foil is degraded by the impacts without actually being removed. At some point the damage becomes so severe that further blasting does decrease the resist thickness, and the selectivity declines. That makes the 50µm foil just thick enough to etch through a 500µm glass wafer. Also due to the degradation of the resist, some particles are able to penetrate the foil deep enough to hit the surface. Figure 6 shows such a damage. Another disadvantage is

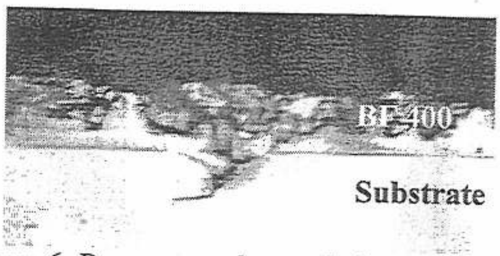

Figure 6. Damage underneath the mask.

that due to the thickness of the resist, only trenches of more than 50μm wide can be made. So BF 400 is very useful for standard blasting conditions, but cannot be used to machine trenches of 50μm wide and less.

Metal plate masks

Metals have a low erosion rate when the particle impact is perpendicular and therefore it is a good candidate for a masking material. A metal plate (≥1 millimeter) on top of the substrate can be used as a mask. The pattern in the mask can be created by drilling and/or milling. This thick metal layer stands powderblasting very well, and a mask can be used several times. The mask can simply be clamped directly to the substrate. However, since a plate is never completely flat, there will be voids between the mask and the substrate (Figure 8). This will allow the particles to get into the voids and damage the substrate. To prevent this, an intermediate

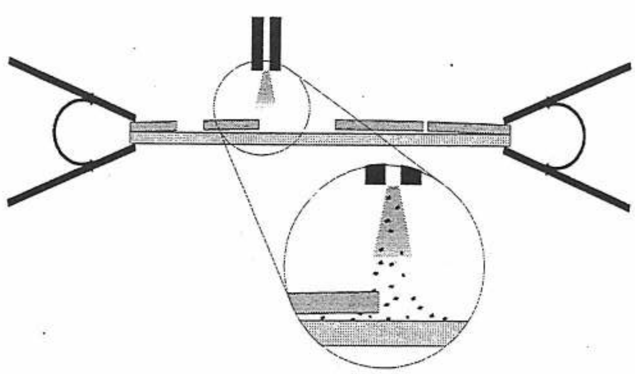

Figure 8. A metal plate mask clamped to the substrate.

protection layer must be applied. In case this extra layer also covers the blast area, it should easily be removed by powderblasting. The layer also prevents the substrate to be damaged by the mask.
Wax seal meets these requirements. This is a brittle material, which becomes soft at higher temperatures. At a temperature of 150°C the wax can be spread on the (also heated) mask. The substrate is put on the mask and the stack is cooled down to room temperature. This results in a very tight and strong connection. Since the wax is brittle, it is very easily removed by sandblasting and it has practically no influence on uniformity (Figure 5). After blasting, reheating can separates the mask from the substrate and both can be cleaned with chloroform. The positive effect of an

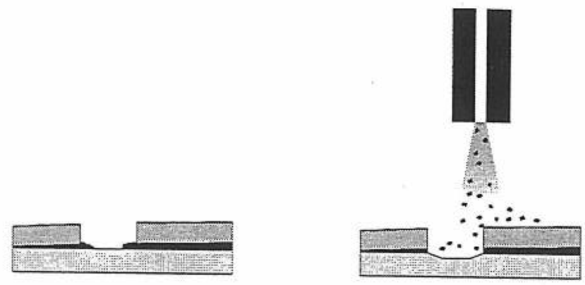

Figure 5. Metal mask on a substrate with interconnection layer.

intermediate layer is clearly seen in Figure 7. This mask type can be used on any kind of material. However, complex designs are not suitable for metal plate masks. Also, the

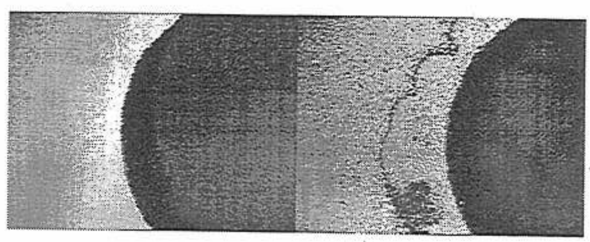

Figure 7. Etching using a metal mask. Resulting top view when etched with (left) and without a connection layer.

maximum resolution depends on the mask thickness and the technique to make the structures into the mask. It is clear that in a relative thick plate, small patterns cannot be made (≥1 millimeter depending on the mask fabrication process).

Copper

To use a metal mask with smaller dimensions, it has to be applied in a different way. One possibility is by electroplating it on the substrate. This makes an intermediate layer unnecessary, and the metal layer can be made as thin as is required. Figure 9 shows how copper is applied as a mask. First a thin copper seed layer of 100 nm is sputtered on

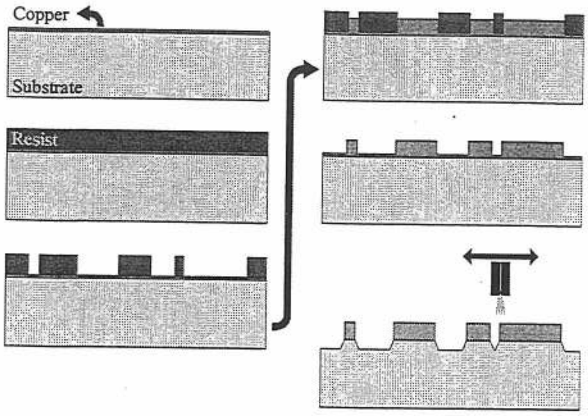

Figure 9. Using copper as a resist in powderblasting.

the whole wafer (a 15 nm chromium layer is used to improve the adhesion). Second, a thick resist layer is deposited and structured. Now the substrate is plated with copper and the thick resist is removed. The thin seed layer remains on the whole wafer, but is easily removed by powderblasting due to its low thickness.

The copper has a high selectivity (about 50 with respect to glass) and offers a good protection to the shielded substrate. A 20 µm layer of copper is enough to etch though a 360µm silicon wafer. In glass however, it appears that the adhesion of the mask is a problem. The copper mask buckles during blasting and is released very easily. A lower adhesion force between the copper and the glass may cause this. Since glass is a very bad heat conductor, there can be some unwanted temperature effects. Fortunately, there is less buckling of the mask at lower energy (speed) of the particles. Since powderblasting of smaller structures requires smaller particles (large particles simply do not fit into small trenches), copper can be very suitable in that case because smaller particles are also less energetic.

CONCLUSIONS

A mask has to be used to machine small structures with powderblasting. In this paper, several mask types have been tested for this application. An overview of their properties is listed in Table 1. For standard use in powderblasting with structures of more than 50µm, BF400 is most suitable for easy and quick use. For less accurate dimensions, a relatively thick metal plate can be used. With wax seal as a connection layer to prevent damage of the substrate under the mask, a good pattern transfer can be achieved. From the tested mask types in this paper, only electroplated copper has the opportunity to be a suitable mask for machining lateral dimensions of 50µm and less. Whether the adhesion of copper on glass is sufficient in that case, has to be tested with the appropriate smaller particles. However, the selectivity of copper is high and it can be applied in any thickness.

This paper shows that there are many possibilities with pattern transfer in powderblasting, which gives this micro technology the perspective to become a new standard tool in micromachining.

ACKNOWLEDGMENTS

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REFERENCES

[1] H.J. Ligthart, P.J. Slikkerveer, F.H. int't Veld, P.H.W. Swinkels, M.H. Zonneveld, Glass and glass machining in ZEUS panels, *Philips J. Res.*, 50, (1996), pp.475-499

[2] John E. Ritter ed., Erosion of ceramic materials, Trans Tech, Zurich, (1992)

Table 1 Mask type overview

Mask type	*Min. dimension*	*Selectivity*	*Advantages*	*Disadvantages*
BF 400	>50µm	25	Easy to apply.	Dimensions of 50µm or smaller are not possible.
Waycoat	-	20	Adjustable thickness.	Hard to create thick layers.
Metal plate	≥1 mm	-	Easy to use, reusable mask, can be applied to any material.	No small dimension possible, not suitable for complex designs.
Copper	Determined by lithography	50	Small dimensions possible, adjustable thickness.	Some adhesion problems on glass.