INFLUENCE OF SURFACE MATERIAL AND TOPOGRAPHY ON TRIBOLOGICAL BEHAVIOUR. MICROTEXTURING TECHNOLOGY (I)

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Abstract - It is well known that the tribological performance of materials is highly dependent on the surface topography. In this paper, well-defined surface textures were produced by photolithography and anisotropic etching of silicon wafers and, also, by photoetching a thin film of chromium deposited using a standard PVD process on a smooth (non-textured) silicon wafer.

Keywords - tribological performance, monocrystalline silicon, anisotropy.

1. INTRODUCTION

It is well known that the tribological performance of materials is highly depended on the surface topography [1,2].

The introduction of specific microstructures on a sliding surface, involving flat and smooth zones interrupted by local depressions arrays of quadratic openings, microgrooves or micropores, can improve the tribological properties. These textures act as lubricant pockets retaining the oil in the contact even under high pressures; they also trap wear particles generated during movement, reducing the ploughing component of friction. Thus the friction is reduced and the lifetime of components increased.

The high accuracy, high resolution and freedom in choice of shapes, make the etched silicon wafers an interesting alternative to study the effect of surface material and texture [3].

In this paper, well-defined surface textures were produced by photolithography and anisotropic etching of silicon wafers (only covered with a very thin layer of native oxide ~50 Å) and, also, by photoetching a thin film of chromium wear resistant, which was deposited using a standard PVD process on a smooth (non-textured) silicon wafer [4,5]. Friction coefficient determining tests for the textured silicon/chromium-ferodo disk interface were performed using an intermittent coupler by friction with flat contact surfaces.

The size and shape of the depressions were varied and their influence on the friction coefficient was studied. A smooth, chromium coated silicon wafer was used as reference surface.

2. MONOCRYSTALLINE SILICON

MICROMACHINING (BULK MICROMACHINING)

The principal aim of miniaturization is micro-mechanical structures integration in common structures with the electronic systems of signal processing and, that is why one of the most used materials at their execution is the monocrystalline silicon.

The monocrystalline silicon micromachining allows obtaining of various shape cavities, using for this purpose the wet chemical erosion, selective, anisotropic and with shape influence by controlled doping of the processed material.

Selectivity and anisotropy are two materials properties important for microstructures manufacturing, which means that the materials of the structural layers and the attack solutions can be “selected” so that their actions be convergent or divergent; based on the well-know anisotropy of the crystalline materials, the tendency of etching adequate to the crystal orientation can be increased or reduced.

A crystal plane is defined by three modes of the lattice and it is noted by the Miller indices (h, k, l) introduced in round brackets. They are obtained from the ratio l/the point coordinate in which the crystal plane intersects the axis of elementary cell.

For the cubic system and the structure of diamond type - fig. 1 – there is done nothing of the plane that includes the cube faces - (100), the plane that includes the face diagonal - (110) and the plane that includes the cube diagonal - (111).

Fig. 1 Crystal planes and structure of diamond type
Silicon crystallizes in keeping with cubic system and it has the diamond structure. Its elementary cell is an octahedron limited by the family of planes \{111\}, fig. 2, and so, one can explain the angles formed by the tapered walls of the cavities with the planes \((100)/(110)/(111)\) on which the wafers are cut.

Fig. 2 The diamantina lattice of the silicon crystal; \{111\} is a noting of the equivalent planes that include the diagonal of elementary cell of the cubic system.

In fig. 3, one can see what means the correlation between an ideal selectivity and an ideal anisotropy when obtaining a certain profile characterized by a dimension \(d\) in plane and a depth \(h\). In all presented cases, selectivity of the attack substance is maximum relative to the structure material and negligible with respect to the stop layer.

In case of silicon, the etch rate \(R\) is minimum for the directions \(<111>\), some higher for the directions \(<110>\) and maximum for \(<100>\): 
\[R_{100}/R_{111} = 25 \div 60;\] that is why the structure from results trapezoidal with an angle \(\zeta = 54-55^\circ\). When the layer of etching stop misses, the resulted cavity profile is that one of an overthrown pyramid (the etching is self-blocked, until the planes \{111\} meet).

### 3. TEXTURES PERFORMING

\(p\) – (100) silicon wafers of 3 inch diameter and 375 \(\mu\)m thickness were thermally oxidized in wet oxygen atmosphere to obtain a silicon dioxide (SiO\(_2\)) layer of about 1 \(\mu\)m thickness, used as a protective layer (mask) during etching process. The oxide layer was patterned with arrays of quadratic openings and microgrooves aligned along the principal flat \(<110>\) directions of the wafers, using a standard photolithographic technique. The silicon was then anisotropically etched in potassium hydroxide (KOH) \((40 \text{ g/100 ml})\) at 80\(^\circ\)C (etch rate of about 1.4 \(\mu\)m/min) to a depth varying with the time: 5 \(\mu\)m \((t_{\text{etch 1}} = 4 \text{ min})\), 20-22 \(\mu\)m \((t_{\text{etch 2}} = 15 \text{ min})\) and 50-80 \(\mu\)m \((t_{\text{etch 3}} = 40 \text{ min})\). The remaining oxide was removed in an HF – solution: first in “Buffered HF” solution \((\text{NH}_4\text{F - HF})\) \((6:1)\) at 32 \(\degree\)C (etch rate of about 0.1 \(\mu\)m/min) and, finally, in DIP solution \((\text{HF:H}_2\text{OD})\) \((1:10)\) at 25 \(\degree\)C. The walls of the depressions are slowly etching \{111\} planes with an angle of 54.7\(^\circ\) from the sliding surface.

Two smooth (non-textured) wafers were covered with a chromium thin film of 0.5 \(\mu\)m thickness using a standard PVD (Physical Vapour Deposition) process. Only one of them was patterned with microgrooves by chromium layer phototetching. A
typical etching solution of phosphoric acid and nitric acid for fine geometries (etch rate of about 350 Å/min. at 40 °C) was used [6].

The other chromium metallized wafer was kept as a flat reference surface.

4. RESULTS AND CONCLUSIONS

The patterns include squares placed in a rectangular grid and parallel grooves, fig. 4.

Fig. 4 Images obtained at an optical microscope

a) Si wafer protected by the SiO₂ mask having quadratic openings, before the etching in KOH solution

b) Si wafer protected by the SiO₂ mask having quadratic openings, after the etching in KOH solution

c) Si wafer protected by the SiO₂ mask having quadratic openings, after the etching in KOH solution to a depth of 5 µm

d) Si wafer protected by the SiO₂ mask having quadratic openings, after the etching in KOH solution to a depth of 20 µm
The squares were manufactured to a width of 1.55 mm being disposed at a step of 3.1 mm. The grooves have a width of 30 µm and are placed at a step of 60 µm. In both cases the placing step is twice bigger than the structure width.

The measurements have shown that the size and lateral distribution of the structures at the wafer surface was defined with micrometer precision by the lithographic and etching processes.

The surface roughness measured on wafers was $R_z=0.07-0.1$ µm between the structures. In cavities $R_z=0.03$ µm (depth of 5 µm), $R_z=0.02$ µm (depth of 20-22 µm) and $R_z=0.1$ µm (depth of 50-80 µm).

REFERENCES


