

DEVELOPMENT OF WATER-SOLUBLE COOLANT FOR MULTI-WIRE SAW SLICING OF 400mm-DIAMETER SILICON

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ABSTRACT

This paper presents the constituent features of the newly developed water-soluble coolant for multi-wire saw slicing of 400mm-diameter silicon, together with its characteristic requirements from a rheological viewpoint.

1. Introduction

In the shaping process of silicon substrate wafers, a major raw material for device chips, ID saw had exclusively been used to slice them for about 30 years and had caught up with wafer diameter growths by increasing its machine dimensions. However, the slicing method is changing to the multi-wire saw at 200mm-diameter as a turning point. And the wire saw seems the most realistic option for 400mm-diameter silicon slicing, too.^[1] In developing the slicing technology for 400mm silicon, the authors are pursuing an optimization of quality, productivity, and cost from the following 3 developmental points; (1) wire saw machine, (2) water-soluble coolant (slurry), and (3) slicing conditions (SOC). Among them, this paper presents the current developmental status of the water-soluble coolant.

2. Objective of a development of water-soluble coolant

For the wire saw slicing, a slurry with the mineral oil-based coolant is the most commonly used now for its stable slicing performance. On the other hand, a development of slurry with the water-soluble coolant will largely contribute to a realization of a safe and kind-to-environment operation of the wire saw slicing for its intrinsic merits such as; ① Non-flammable and suitable for a laborsaving or an automatic operation, ② Easy post-slice cleaning of a wire saw machine and wafers only with tap water, ③ Good bio-degradability for the used slurry. However, the water-soluble coolant has the following issues to be solved; ④ Difficult to secure a good abrasives suspension in the slurry, ⑤ Need to control water evaporation, ⑥ Some coolants have peculiar odor.

Due to the above issues, although the water-soluble coolant is used for 200mm slicing by some limited wafer manufacturers, it has proved to be insufficient to 300mm slicing which takes longer slicing time. And there was no water-soluble coolant available for 400mm slicing because of heavy segregation and settlement of abrasives from the slurry during the slicing.

3. Improvement of odor, bio-degradability, and water evaporation

(1) The new water-soluble coolant adopted Polypropyleneglycol as a base (approx. 75wt%). This chemical has no peculiar odor unlike mineral oils or fatty acids. And polypropyleneglycol is more bio-degradable than polyethyleneglycol which is also commonly used for other water-soluble coolants as a

base.

(2) Approx. 15wt% of water is added to the new coolant in order to give the non-flammability characteristic. The new coolant contains hydrophilic bentonite particulates to improve the abrasives suspension in the slurry. Being contained in these bentonite particulates as their crystal water, the added water has non-evaporative characteristic and the slurry has got rid of water supply to control its viscosity during the slicing operation.

4. Improvement of abrasives suspension

Approx. 0.5wt% of bentonite, clay mineral, is added to improve the abrasives suspension in the slurry. Fig.1 shows chemical structures of bentonite. It has a layered chemical structure as shown in Fig.1(b) which is composed of unit structures shown in Fig.1(a). A layered structure swells by taking in the water between the unit structures. This layered bentonite structure forms a cardhouse or a cross-linkage structure (a kind of shelves) and prevents abrasives from segregating and settling in the slurry as shown schematically in Fig.2.

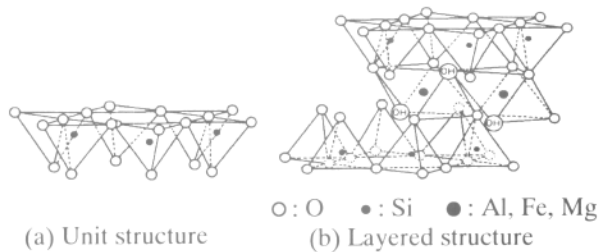


Fig.1 Chemical structure of bentonite.

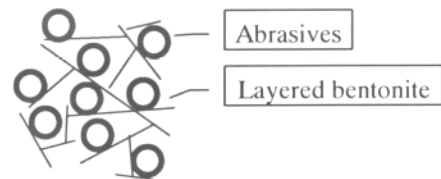


Fig.2 Schematic diagram of cardhouse or cross-linkage structure of bentonite.

5. Measurement of slurry rheology with respect to shearing speed

Wire saw slicing performance is largely affected by the slurry rheology. Among the rheological factors, a slurry viscosity is the most important as it governs the adhesion of slurry onto a wire and the supply of abrasives to grinding points. When a viscosity is too low, the slurry does not adhere to the running wire well. When it is too high, the slurry does not go into narrow wire grooves on the other hand. Both cases give poor wafer qualities and also become a cause of abrasives settlement where the slurry flow becomes stagnant in the machine or between wafers.

As slurries have non-Newtonian characteristic in which a viscosity changes largely with the slurry flow speed (shearing velocity), it is necessary to measure the viscosity at various velocities in order to correlate the viscosity with the slicing performances. Although the slurry viscosity measurement has been conducted at a certain shearing velocity using an axial cylinder viscometer in general, the authors have introduced the cone & plate viscometer (Fig.3) which can measure a viscosity at various velocities,

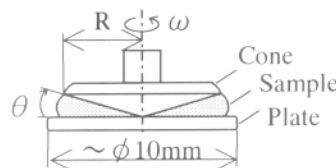


Fig.3 Schematic drawing of the cone & plate viscometer.

and quantified non-Newtonian characteristic of the slurries.

Fig.4 shows examples of the viscosity-shearing velocity characteristics of various slurries (including the oil-based slurry). The characteristics show various types such as the water-soluble slurry B, C which are close to Newtonian fluid, or as the slurry A and the oil-based slurry which are close to non-Bingham fluid. Comparing these measurement results with actual slicing performances experienced so far, it has proved that the most desirable non-Newtonian characteristic as a wire saw slurry lies roughly in a region shown in Fig.5, and has a low viscosity at a high shearing velocity and a high viscosity at a low speed. This characteristic becomes one of goals for new coolant developments. The following test coolants are prepared to have “Slurry A” characteristic.

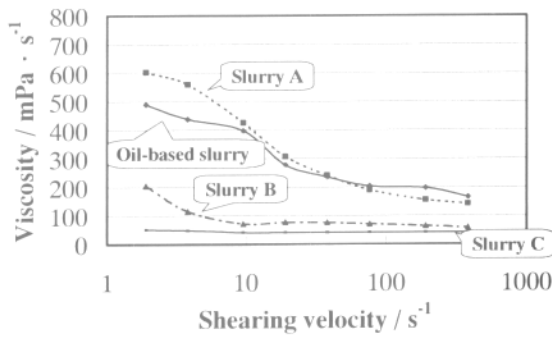


Fig.4 Viscosity characteristics of various slurries with respect to shearing velocities.

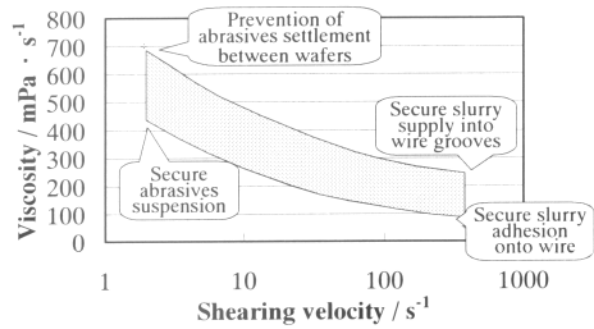


Fig.5 The most desirable non-Newtonian characteristic as a wire saw slurry.

6. Viscosity change of the water-soluble coolant

Fig.6(a) shows an example of viscosity changes of the water-soluble slurry developed in a first stage of the test. Viscosity which had been approx. 200mPa s before the test dropped to 60~100mPa s in a depth of 0~100mm work feed. Causes of a viscosity decrease and a deterioration of abrasives suspension are supposed as follows;

- ① Crushing of bentonite by shearing stress caused by a slurry stirring or an ingot slicing.
- ② Metasilicate ions generated from the silicon sludge adhere to the layered bentonite and decompose it chemically to unit structures, and thus loses the cardhouse structure.

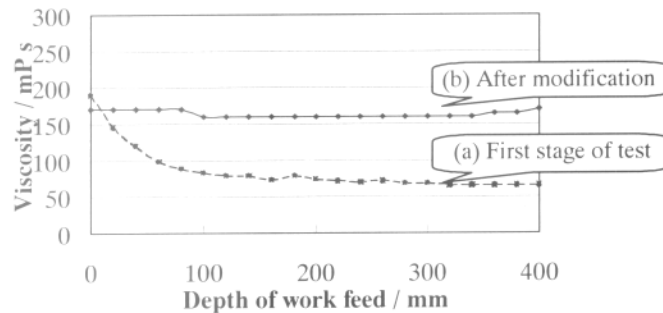
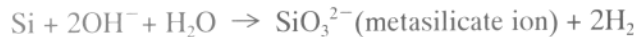


Fig.6 Example of slurry viscosity changes (measured with an axial cylinder viscometer).

7. Improvement of viscosity change

Slurry viscosity in the first stage of developmental test showed a thixotropy as shown in Fig.6(a) in which the viscosity decreased with a slicing duration. Therefore, in order to compensate it, crystalline cellulose was added which had a rheopectic nature and increased a viscosity with a slicing duration. Furthermore, synthetic mica which had constant viscosity was added to adjust a total viscosity level. Fig.7 shows viscosity changes of these 3 additives. They are added, respectively, to polypropylene base and stirred by the homogenizer (high speed) stirrer to simulate the slicing condition. Fig.6(b) shows a viscosity change of the modified slurry. By this modification, a practical wire saw slicing for 400mm-diameter silicon has become achieved through an improved abrasives suspension and an eased wire withdrawal from an ingot following slicing. However, amounts of these 3 additives are so sensitive to the coolant characteristics that a fine adjustment of these additions is needed.

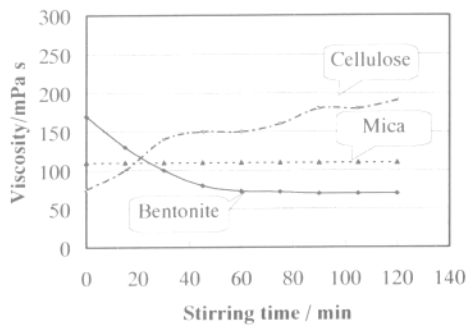


Fig.7 Viscosity characteristics of 3 additives (bentonite 0.5wt%, cellulose 0.25wt%, mica 2wt%).

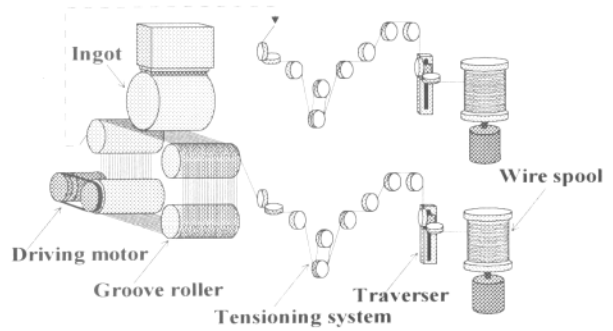


Fig.8 Schematic drawing of the wire saw.

Fig.8 shows a schematic diagram of the wire saw^[1] and Table 1 indicates major slicing conditions for 400mm silicon. Table 2 shows, in rough figures, 400mm as-sliced wafer qualities.

Table 1 Major slicing conditions for 400mm.

Ingot feed rate	Ave. 0.26mm/min
Wire (high tension steel)	0.18mm in diameter
Wire tension	2.5kg (25N)
Wire speed	Ave. 500 (Max. 750) m/min
Reversing cycle	30s
Slurry tank capacity	400L
Slurry flow rate, temperature	110L/min, 23.5 ± 0.1°C
Abrasive	GC#600 (50wt% in slurry)

Table 2 400mm as-sliced wafer qualities

Item	Quality level
Center thickness variation (TH)	x-bar 1,020 μm, σ 4 μm
Total thickness variation (TTV)	x-bar 40 μm, σ 5 μm
Surface roughness (Pt)	x-bar 15 μm, σ 2 μm

8. Summary

A new water-soluble coolant for multi-wire saw slicing of 400mm-diameter silicon was developed. It has non-Bingham rheology, and consists of polypropylene base and 3 additives; hydrophilic bentonite to improve abrasives suspension, crystalline cellulose to compensate a thixotropy of bentonite, and synthetic mica to adjust total viscosity level.

Reference

- [1] H. Oishi, et al : Proc. 1998 ASPE Spring Topical Meeting, (1998) 109.