行政院國家科學委員會專題研究計畫成果報告

精密輪磨加工矽晶圓表面性狀研究：(樹脂砂輪)鑽石輪磨與電解線上削銳輪磨之比較分析

A Study of the Surface Morphology and Sub-surface Characteristics of Single Crystal Silicon Generated by ELID-Grinding and (Resin-bonded) Diamond Grinding

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1.中文摘要

隨著矽晶圓之尺寸由8”(200mm)進入12”(300mm)時代其相關之規格如粗糙度、TTV、平面度(Flatness, SFQR)、金屬雜質顆粒(atoms/cm^2)等卻因製程要求反而更趨嚴格。也因此傳統製程中之研磨、拋光、腐蝕、拋光等加工方式已難以滿足這些新的規格要求(尤其在TTV、平面度)。取而代之的為更能控制形狀精度之精密輪磨配合上些許拋光以改進其表面粗糙度。這裏說些許拋光乃因拋光之加工特性雖可改進表面粗糙度卻也同時會破壞形狀精度故拋光量不可太大。但要在小量拋光中去除所有之加工變質層就必須能將前面之精密輪磨製程有極好之加工結果以控制加工變質層厚度。

精密輪磨製程中又以運用樹脂結合劑之鑽石砂輪及搭配ELID線上削銳之金屬結合劑砂輪兩大類最為常見。而這兩類精密輪磨製程又各有其利弊：ELID精密輪磨雖使超微粒磨料磨輪之輪磨加工成為可行，如果ELID削銳之各項參數選取控制得當其加工所得之結果為奈米級表面粗糙度之光學等級表面但如果ELID削銳之各項參數選取控制不當則其加工所得之結果常為表面粗糙度及形狀精度不盡理想且磨輪損耗過快。此外ELID輪磨對加工參數太過敏感亦為其缺憾。反觀樹脂結合劑之鑽石砂輪因無電壓電流等ELID輪磨中多出之電解參數故加工結果對加工參數相對較為穩定但因採自削銳故不能使用太高號數(小磨粒)之磨輪(一般鮮少使用#4000以上之樹脂磨輪，因磨輪極易於加工中造成填塞)這也影響了可得之加工表面性狀。

本研究計畫之目的既為應用樹脂結合劑之鑽石砂輪及搭配 ELID 線上削銳之金屬結合劑砂輪對矽晶圓進行精密輪磨加工並針對各項參數對加工表面/次表面造成之影響及磨輪特性對加工表面/次表面造成之影響進行比較分析以期能建立各加工法所得表面之性狀特質及此法較適用之範疇。。

關鍵詞：超精密加工，鑽石輪磨，ELID 線上削銳

Abstract

Both metal-bonded (ELID) and resin-bonded diamond wheels were used in this study to grind silicon (100) wafers and efforts were made to investigate the characteristics of obtained surface integrity. The results showed that, depending on the wheel and machining conditions, amorphous layer, nanocrystals, polycrystals, dislocations and micro-cracks were observed in both cases. It was found that the ELID ground surfaces were very sensitive to the ELID parameters and the optimized conditions were difficult to obtain and be maintained. In the case of resin bond wheel, except when feedrate is very low (say 2μm/min) or wheel is loaded, the amorphous layer generated were normally thinner than those generated by ELID grinding under the same grinding conditions.

Keywords: precision machining, diamond grinding, ELID grinding

2. Introduction(緣由與目的)

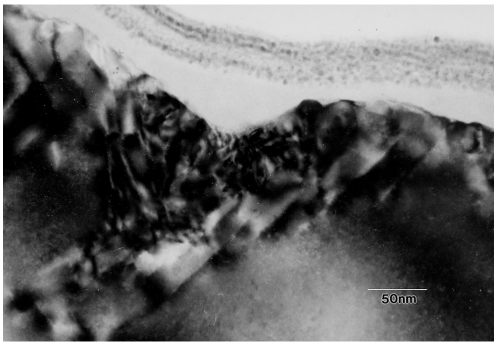
Single crystal silicon, having many advanced physical and mechanical properties, is now widely used in the semiconductor industry (account for more than 90% of the semiconductor devices). Owing to the increasing demands on brittle materials such as advanced ceramics, glasses and single crystal silicon, researches on ductile-mode grinding and related cutting theories, material removal mechanism have attracted many researchers' attention (Bifano et al 1988; Blake and Scattergood 1988; Chao et al 1989, 1997, 1999, 2000; Puttick et al 1989, 1990; Itoh et al 1998; Schinker and Doll 1983, 1987, Abe 2000). As a results, the traditional lapping, etching, polishing routine of making wafers is suggested by many researchers to be replaced by precision grinding and polishing if the requirements of flatness, TTV and roughness are to be fulfilled when producing 12"~16" wafers. In order to minimize the polishing works and the resulted deterioration of form accuracy, it is important to reduce the grinding induced surface/subsurface damage. It is well known that the grit size of abrasive on the grinding wheel has profound effect on the obtained surface roughness. Generally speaking, the smaller the grit size, the better surface finish and the less damaged layer could be achieved. However, when abrasive gets smaller the wheel has bigger chance to be loaded by swarf (chips). As a result, the wheel constantly needs to be redressed and the process becomes impractical to be employed in the real production. The ELID (electrolytic in-process dressing) technique, developed by Ohmori[1992, 1994,1995, 1999], offers a way of in-process monitoring/dressing the grinding wheel which enables the wheel of ultra-fine abrasives to be used. However, ELID grinding has its own difficulties. Problems like peak voltage/peak current to be used, gaps to be maintained, on/off duration of dressing, type of electrolyte, shape of electrode, wear of wheel and correlations between ELID parameters and grinding conditions are somehow making ELID grinding complicated to implement. That is apparently one of the reasons some people choose to remain in using resin-bonded wheel for their fine grinding works.

3. Experimental Setup

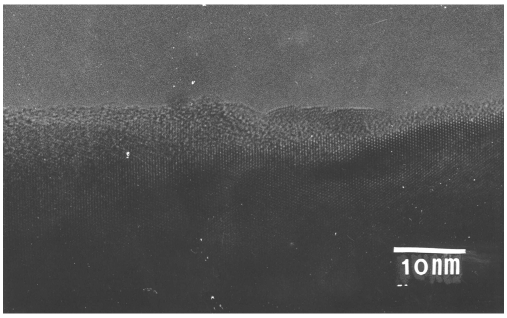
In order to clarify the underlying differences between ELID grinding and grinding by resin-bonded wheel, both ELID and resin-bonded wheel grinding were conducted in this study. A Nachi RGS20N ELID grinding machine was used in this study for carrying out grinding experiments. The power supply and CIFB(cast iron fiber bonded) diamond wheels were made by Fuji (ELIDer 630) and Noritake respectively. The (100) silicon wafer was placed on the work spindle which was set to rotate at a relatively low speed (100~400rpm). The grinding head was set to operate at the speed of 1000 to 3000rpm. The feed rates, peak voltages and peak currents ranged respectively from 2μm/min to 8μm/min, from 30V to 60V and from 2A to 10A. A pulse duration (Ton/off) of 2μSec and gap of 0.4mm were used in the study. An Okamoto Grind X VG-40 precision grinding system was used to carry out the grinding tests of resin bonded wheel. Apart from the parameters for ELID, the grinding conditions (speed, feed, total stock removed..) were kept as close as possible to those used in CIFB/ELID grinding.

4. Results and Discussions

Specimens ground under various wheels/conditions and grinding parameters were subsequently observed using SEM(scanning electron microscope), AFM(atomic force microscope) and HRTEM(high resolution transmission electron microscope) to analyze its surface and subsurface. The results showed that the obtained surfaces, depending on the wheel and machining conditions, were characterized by amorphous layer, poly-crystalline layer, occasionally micro-cracks/ distributed dislocation loops (~300nm into the substrate) and substrate of perfect single crystal (*Figure 1* and *Figure 2*).

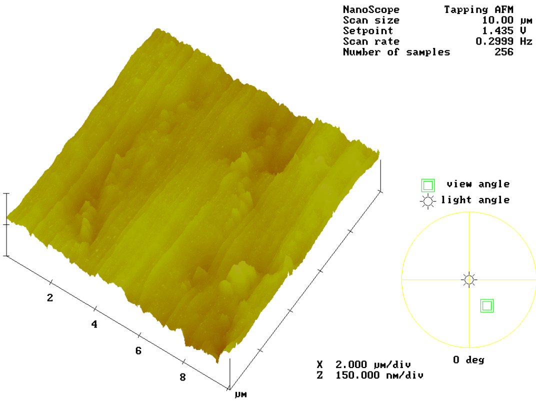


(a)

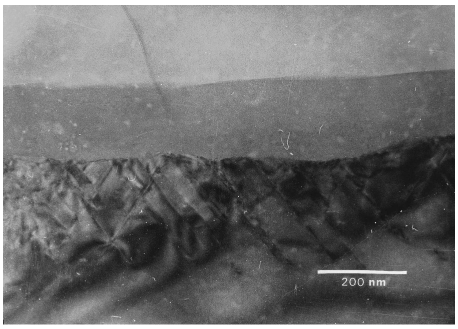


(b)

Figure 1 HRTEM micrographs of the ELID ground silicon surfaces using #6000 diamond wheel and (a) 60V, 10A, 3000/100rpm, 2µm/min (b) 60V, 10A, 3000/ 100rpm, 8µm/min, zone axis ∴[110]



(a)



(b)

Figure 2 (a)AFM (b)HRTEM micrographs of the ELID ground silicon surfaces (#6000, 30V, 2A, 2000rpm, 400rpm, 2µm/min) zone axis ∴[110]

Generally speaking, the obtained surface integrity relied heavily on the conditions of abrasives. Apart from the machining conditions such as speed and feedrate, ways of dressing and types of wheels also played important roles in the conditions of abrasives. Having the relatively greater abrasives retaining force, metal bond wheels are good in achieving form accuracy but extra efforts have to be made in dressing if good surface roughness is to be persuited. In the case of ELID grinding, ELID parameters heavily involved not only in preventing wheel from loading but also in maintaining the cutting capability of abrasives. However, when grinding with a resin bond wheel the ability to self-sharpen became the major factor of keeping the new sharp abrasives to emerge to the surface.

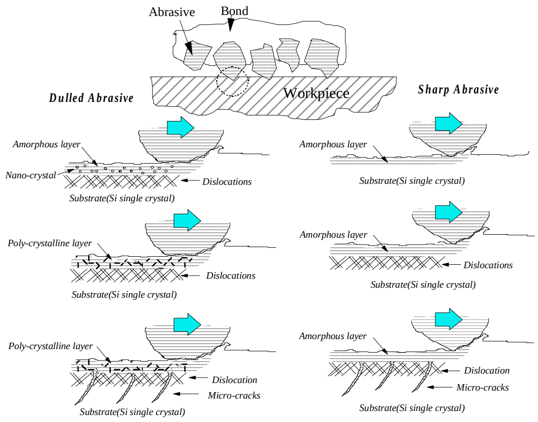
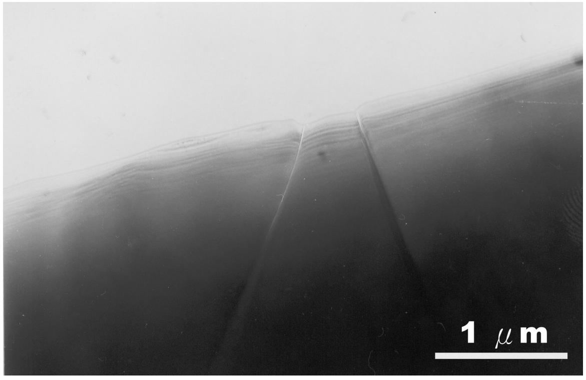
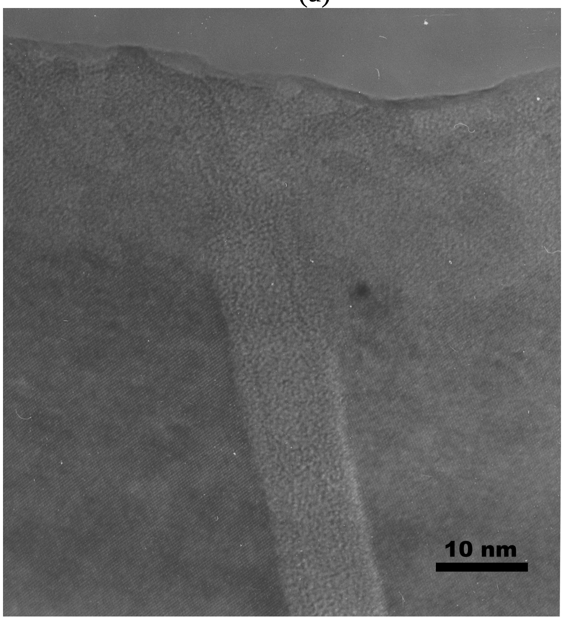


Figure 3 Schematical representation of the surfaces generated by dulled and sharp abrasives at various depth of cut (from top to bottom, shallow to deep cut)

Shown in *figure 3* are the schematical representations of the surfaces generated by dulled and sharp abrasives at various depth of cut (from top to bottom, shallow to deep cut). A dulled abrasive tends to generate relatively more heat during the cutting process than sharp ones. As a result, relatively thicker amorphous layer, scattered nanocrystalline silicon or polycrystalline silicon are normally the consequences. In the case of ELID grinding, thick oxide layer and high feedrate favors wheel to produce sharp new protruding grains so that a stable cutting condition can be reached. When thick oxide layer and low feedrate is used, there is still chances for some protruding grains getting excess attritious wear before it is pulled out. The worn grains will dull the wheel and generate much friction heat and subsurface damage.



(a)



(b)

Figure 4 HRTEM micrographs of the silicon surfaces ground by resin bond wheel showing the (a) amorphous layer and microcracks (b)detailed view of the crack on the right-hand side (#2000, 2400rpm, 100rpm, 5μm/min) zone axis ∴[110]

In the case of resin bond wheel, abrasives refresh in a relatively higher rate due to its low abrasive retaining force. This means that, except when feedrate is very low (say 2μm/min) or wheel is loaded, the wheel tends to cut with relatively sharp abrasives. This also reflected in the HRTEM observations that the amorphous layer generated by grinding with resin bond wheel were normally thinner than those generated in ELID grinding under the same grinding conditions.

5. Conclusions

1. Depending on the wheel and machining conditions, amorphous layer, nanocrystals, polycrystals, dislocations and micro-cracks were observed both on ELID ground and resin-bond wheel ground surfaces
2. It was found that the ELID ground surfaces were very sensitive to the ELID parameters and the optimized conditions were difficult to obtain and be maintained. In the case of grinding with resin bond wheel, the surface integrity was relatively insensitive to the machining conditions in comparison to ELID grinding.
3. In the case of ELID grinding, thick oxide layer and high feedrate favors wheel to produce sharp new protruding grains so that a stable cutting condition can be reached. When thick oxide layer and low feedrate is used, there is still chances for some protruding grains getting excess attritious wear before it is pulled out. The worn grains will dull the wheel and generate much friction heat and subsurface damage.
4. In the case of resin bond wheel, except when feedrate is very low (say 2μm/min) or wheel is loaded, the wheel tends to cut with relatively sharp abrasives and the amorphous layer generated were normally thinner than those generated by ELID grinding under the same grinding conditions.

6. 計畫成果與自評

1. 瞭解以樹脂結合之鑽石砂輪及配合線上電解削銳之金屬結合鑽石砂輪對矽單晶等硬脆材料進行延性模式精密輪磨加工時砂輪於加工進行時之動態特性。
2. 探討各項加工參數對加工表面造成之影響。
3. 分析精密輪磨加工硬脆材料時其主要之材料去除機制。
4. 瞭解加工表面與次表面之顯微組織變化及其與加工參數間之關係。
5. 分析精密輪磨加工硬脆材料時加工表面特性與其次表面特性間可能存在之相關性。
6. 參與本計畫之研究人員可獲得樹脂結合鑽石砂輪及電解削銳精密輪磨加工技術對矽單晶等硬脆材料時之微變形機構、表面及次表面之顯微

組織變化及電 解 削銳、精密輪磨各項參數對其之影響等相關技術之訓練與分析能力之建立。

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