









creating the

Pad Conditioning Effects in Chemical Mechanical Polishing

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- Background
- Pad Conditioning and Pad Surface Structure
 - Competing effects of wear and restoration

Introduction

- Conditioner design and cutting behavior
- Void-filled vs. solid pads
- Intrinsic vs. induced structure
- Contact area
- Process effects
- Pad Conditioning and Polish Rate
 - Ex situ response
 - In situ response
 - Rate maximization behavior
 - Hydrodynamic effects
- Pad Conditioning and Planarization
 - Planarization efficiency
 - Dishing
- Conclusions



- Pad conditioning is the process of "dressing" the polishing pad
 - Pad is contacted with an abrasive medium, typically a diamond abrasive disc
 - The conditioning process involves the removal of a thin layer of pad material
- Conditioning determines the intrinsic asperity structure of the pad
 - Conditioning acts to maintain surface stability through the removal of worn surface material and restoration of the intrinsic structure

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Extremes of Pad Surfaces



- Conditioning dominated surface exhibits the intrinsic structure imparted by a medium aggressive conditioner
- Wafer dominated surfaces exhibits the truncated asperity structure (red component in the distribution at lower center) induced by polishing many wafers in the absence of conditioning
 - Intrinsic contribution to distribution in blue at lower center AS Lawing NCCAVS CMPUG 5/5/2004



Pad Wear Rate

- The pad surface structure is determined by the balance between the competing effects of pad wear due to pad-wafer contact and pad surface restoration due to conditioning
 - The pad wear rate is a function of process conditions and the consumable set
 - The conditioner cut rate is a function of the conditioner design and the process conditions
 - The intrinsic structure of the pad surface is also dependent on the conditioner cutting characteristics



The effect of increasing cut rate is to reduce the amount of steadystate glazing on the pad surface

Competing Effects



In this example, pad wear rate is varied by manipulating wafer down-force

> The point at far left represents a pad surface after break-in (*i.e.* zero pad wear)

The effect of increasing wear rate is to increase the amount of steady state glazing on the pad surface



Conditioner Design



Diamond Crystal Types



- Pad surface structure is the product of many individual pad-diamond crystal interactions
 - Structure is driven by the cutting characteristics of diamond crystals
- Intrinsic pad surface structure can be manipulated through conditioner design
 - Size, shape and density of diamonds on conditioner surface drive cutting characteristics and intrinsic surface structure
 - More aggressive diamonds tend to remove more pad per unit interaction and result in more "rough" surface



- Pad surface height statistics are significantly affected by conditioning aggressiveness
 - Aggressiveness adjusted through changes in conditioning design
- In solid pad, aggressiveness affects roughness
 - Solid pad has no inherent texture
 - Intrinsic solid pad surface height distribution nearly Gaussian
- In void-filled pad aggressiveness affects near surface region
 - Roughness of void-filled pad determined by filler material
 - Conditioning superimposes additional roughness frequency

Intrinsic Structure vs. Pad Wear



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- In steady state polishing, surface structure is determined by balance between restorative effect of conditioning and destructive effect of wear due to pad-wafer contact
 - Conditioner acts to restore intrinsic structure by removing worn surface material
 - Less aggressive conditioner characterized by lower cut-rate such that more wear is evident on the steady-state surface as aggressiveness is reduced
- Asperity structure becomes more truncated (lower Diameter/height ratio) as aggressiveness is decreased
- Estimated contact area increases as aggressiveness is decreased
 - Contact area estimated at 11.3 %, 7.7 % and 2.2 % for the low, medium and high aggressive conditioner respectively



- Increased conditioning down-force results in the removal of more pad material shifting the balance between wear and restoration
 - Below a critical down-force, polish rate will drop with decreasing down-force
 - Above critical down-force rate saturates with increasing conditioner downforce
- Intrinsic structure does not change significantly with increasing conditioner down-force
 - Once intrinsic structure is restored (wear component is accounted for) additional conditioning does not change the structure of the pad surface







- Typical "logarithmic" decay of rate after conditioning is suspended
- Increase in asperity wear with time corresponds to decrease in polish rate
- Colloidal slurries induce less significant asperity wear and result in less significant rate decay
- Conditioning sets initial rate but has little influence after conditioning is suspended

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Polish Rate, Slurry and Conditioning



Steady-State Polishing with 100% In Situ Conditioning

- Less aggressive conditioners exhibit more significant deviation from maximum polish rate
- Colloidal slurries exhibit less significant deviation from maximum rate compared to fumed silica slurries
- More significant deviation from maximum rate with increased velocity as opposed to increased down-force
 - Low aggressive-fumed silica data set exhibits rate maximization with respect to velocity



- High aggressive conditioner exhibits the least surface wear and the maximum polish rate
- Low aggressive conditioner exhibits the most surface wear and the most significant polish rate deviation
- More significant wear as a result of increase in down-force compared to increase in velocity
 - Increasing down-force driving abrasive wear
 - This contradicts trend of more significant rate reduction with increase in velocity compared to increase in rate
- Colloidal slurries induce less significant asperity wear (not shown) corresponding to less significant deviation from maximum rate AS Lawing NCCAVS CMPUG 5/5/2004



- Influence of partial lubrication with increasing Sommerfeld number explains the more significant rate decrease with increasing relative velocity
 - Hydrodynamic effects become more significant at low contact pressure (high contact area) and high velocity
- Aggressively conditioned surfaces are dominated by solid contact



- Using simple elastic model, equate volumetric displacement of ideal bulk material with the pad height probability distribution function (pdf) at a given applied pressure
 - Effective spring constant used was obtained by fitting patterned wafer polish data to elastic pad model (Lawing & Merchant ECS 2000)
 - Similar length scale for pad compression
- "Asperities" are defined as the portion of the pad lying above the contact plane (dotted line in the figures above)
- Estimate of contact coincides with maximum in the component of the distribution due to abrasive wear

Polish Rate and Contact Area



- Polish rate is maximized with respect to estimated contact area
 - Increasing ex situ rate trends support this observation

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- Wear model demands that surface area increases as a function of time without conditioning
- Above a critical point rate is proportional to contact area (applied pressure)
 - Working model is that below a critical contact area rate is limited by absolute contact area and not contact pressure

Conditioning and Planarization



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- Low aggressive conditioning results in more efficient planarization
 - More truncated asperity structure results in preferential polishing on high areas and more efficient step removal



Conditioning and Dishing



Low aggressive conditioning results in less dishing

More truncated asperity structure penetrates less deeply into low lying areas



- Pad conditioning defines the intrinsic structure of the pad surface
 - Intrinsic pad structure can be adjusted through changes in conditioner design

Conclusions

- Process and consumable variables adjust the balance between pad surface restoration due to conditioning and asperity wear due to pad-wafer contact
 - Conditioner design, conditioner and wafer down-force, relative linear velocity, conditioning time and slurry type are all significant factors in defining equilibrium pad surface structure
- Pad surface structure and conditioning have a significant effect on CMP process response
 - Polish rate, planarization performance and hydrodynamic effects are heavily influenced by pad conditioning





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