Seed Layer 없는 반도체 소자의 구리배선을 위한 도금에 관한 연구

ut Copper seed layer in Semiconductor Device)

금오공과대학교 금속공학전공 김인수
TU Calusthal 대학교 재료공학과 김인기

Kumoh national Institute of Technology

○ 정보 통신 산업의 핵심기술 : 반도체 소자

○ 반도체 소자 : 집적도 향상(Giga시대)
배선 분야의 중요성 요구

○ 배선관련기술 : 확산 방지막 기술 - TiN, WN, TaN
Hole 매립기술
Line 형성기술

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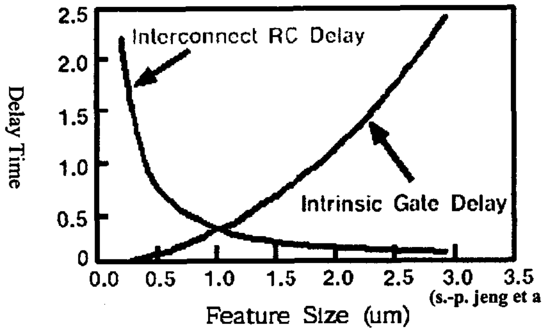
- International Technology Roadmap for semiconductors : 2001

Year of production	2001	2002	2003	2004	2005	2006	2007
Feature size(nm)	130	115	100	90	80	70	65
Minimum global wiring pitch(nm)	670	565	475	460	360	320	290
Total interconnect length(m/㎠)	4086	4843	5788	6879	9068	10022	11167
I_{max} (mA) via (at 105℃)	0.32	0.29	0.27	0.24	0.22	0.20	0.18
J_{max} (MA/㎠). wire(at 105℃)	0.96	1.1	1.3	1.5	1.7	1.9	2.1

- As ULSI(Ultra Large Scale Integration) technology progresses, the feature size decrease while the cheap size increases.

- The total lengths of interconnects increases, which leads to higher resistances

- $RC = 2\rho\varepsilon\varepsilon_0(\frac{2L^2}{P^2} + \frac{L^2}{T^2})$ → Increased RC delay



(s.-p. jeng et al., MRS 337,1994, p.25)

- The interconnect delay becomes the performance-limiting factor over intrinsic gate delay in the submicron range

- It is very critical to reduce RC delay for high performance

○ RC delay time○

: R(metal resistance) / C(dielectric capacitance)
: The quantity RC is measured the time needed to charge
the capacitor to a fixed voltage

○ Electromigration ○

Electromigration is the diffusive transport of conductor materials as a result of the Momentum transfer by passage of extremely high electron current densities. Atoms are Regarded as being driven in the direction of the "electron wind" causing the cathode end of the wire to become depleted and ultimately resulting in the formation of voids

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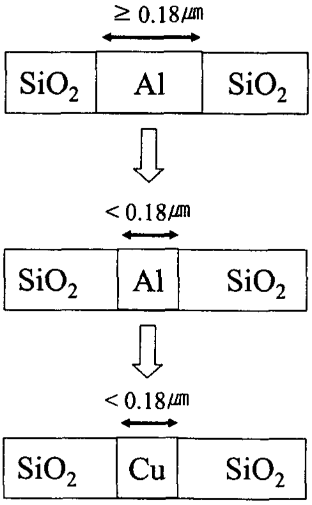
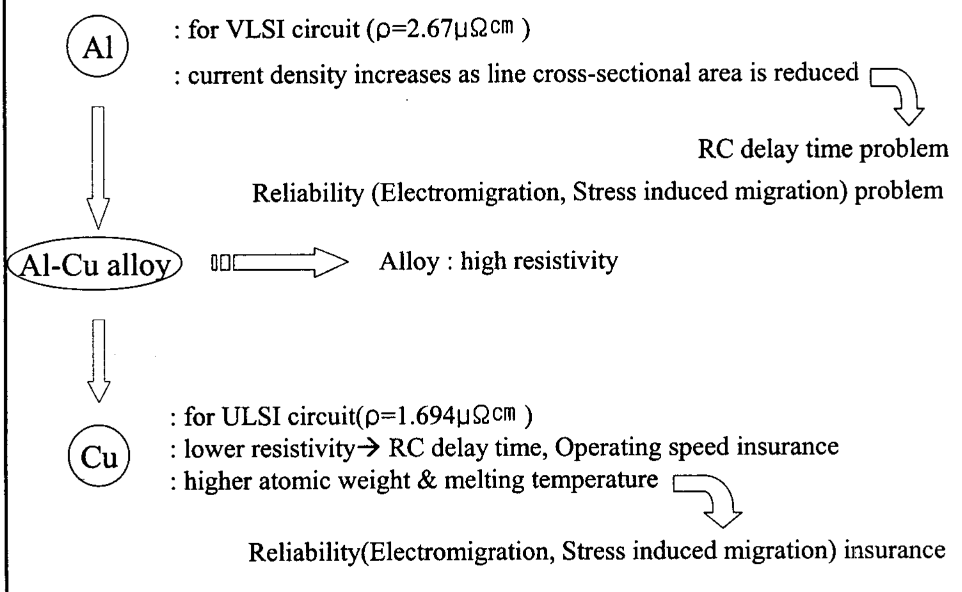


Al → Cu
- Operation speed : 1.5 ~ 2 times increase
- Reliability : 10 ~100 times increase
- Cost : 30% decrease

- 저항 증가 하고 저항 낮추기 위해
- 배선 Layer 증가→제조공정 증가

- 낮은 저항 낮아
- 배선 Layer감소

Properties	Cu	Al	Ag	Au	W
Resistivity(μΩcm)	1.67	2.66	1.59	2.35	5.65
Thermal conductivity(Wcm^{-1})	3.98	2.38	4.25	3.15	1.74
Melting point(℃)	1085	660	962	1064	3387
Corrosion resistance in air	Poor	Good	Poor	Excellent	Good
Adhesion to SiO_2	Poor	Good	Poor	Poor	Poor
Deposition					
Sputtering	OK	OK	OK	OK	OK
Evaporation	OK	OK	OK	OK	OK
CVD	OK	OK	?	?	OK
Etching					
Dry	?	OK	?	?	OK
Wet	OK	OK	OK	OK	OK



Al

: for VLSI circuit (ρ=2.67μΩcm)

: current density increases as line cross-sectional area is reduced

RC delay time problem

Reliability (Electromigration, Stress induced migration) problem

Al-Cu alloy □□ Alloy : high resistivity

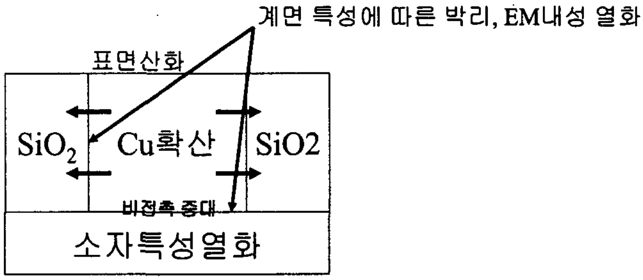
Cu

: for ULSI circuit(ρ=1.694μΩcm)

: lower resistivity→ RC delay time, Operating speed insurance

: higher atomic weight & melting temperature

Reliability(Electromigration, Stress induced migration) insurance



계면 특성에 따른 박리, EM내성 열화

표면산화

SiO_2 Cu확산 SiO2

비접촉 증대

소자특성열화

○ Cu는 상온에서 SiO_2속으로 확산이 일어난다.

○ Cu막은 SiO2를 포함한 절연막과의 접착성이 좋지 않다.

○ Cu의 산화막은 다공성으로 표면산화가 내면으로 확산한다.

○ Cu막은 표면, 계면, 입계가 불안정할 경우 Electromigration(EM)내성이 떨어진다.

❍ Advantage
- Lower Resistivity(~1.7μΩ·㎝) : Al-Alloy(~3.2), W(~ >15)
- Reduction of the Number of Metal layers
- Better Reliability than Al-Alloy : Electron migration

❍ Disadvantage
- Poor dry-etching capability of Cu
- Cu ion can drift easily through ILD under electric field
- Act as deep level acceptors in Si devices

❍ Solution and issues
- Damascene and CMP process
- Better adhesion and diffusion barriers : TiN, TaN, WN
- Needs seed layer for electrodeposition on diffusion barrier

PVD Poor step coverage

Sputtering → reflow (or) H.T. sputtering

Reliability problem

↓

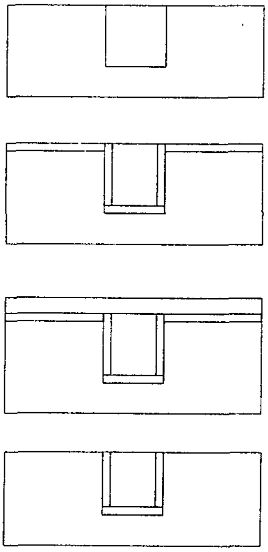
CVD High cost, low deposition rate

↓ Damascene
CMP

Electroplating ⇒

- High purity
- Simple process
- Low precess temperature
- High deposition rate
- Low cost
- Excellent via/trench filling capability
- Needs seed layer for electroplating

Process / Characteristics	CVD	PVD	Reflow	Electroless	Electrolytic
Resistivity(μΩcm)	2.0 ~ 3.0	1.75 ~ 2.2	1.9 ~ 2.2	1.75 ~ 1.9	1.75 ~ 1.95
Morphology	Smooth	Slightly Rough	-	Slightly Rough	Smooth
Impurity	C, O	Ar	-	C, O, Na, K	C, O, S
Depostion Rate(Å/min)	150 ~ 300	10 ~ 1000	-	500 ~ 1000	1500 ~ 3000
Process Temperature(℃)	150 ~ 300	25 ~ 200	Near melt	50 ~ 80	25 ~ 50
Step Coverage	Good	Fair	-	Good	Good
Filling Capability	Good	Poor	Good	Good	Good
Environment	Common	No Problem	No Problem	Need Handling	Need Handling

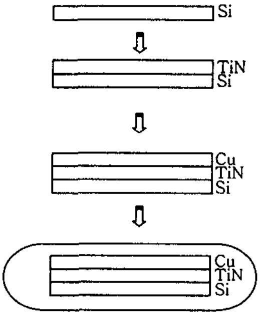


Patterning

Diffusion barrier deposition
→ TiN, TaN, WN

Copper deposition

Chemical Mechnical Polishing



Ultrasonic cleaning : Si wafer

⇩

TiN Deposition : CVD, PVD

⇩

Cu electro-deposition with and
without the use of palladium chloride

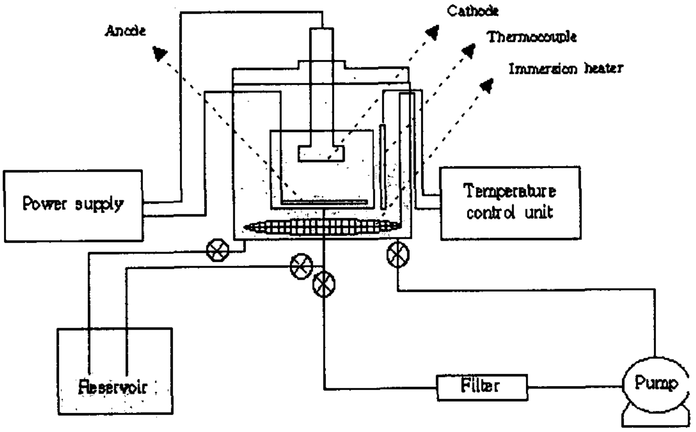
⇩

Analysis of Cu filling in trench and hole

⇩

Comparison of the characterization of Cu filling in trench and hole on TiN diffusion barrier

Schematic diagram of experimental apparatus : electrodeposition

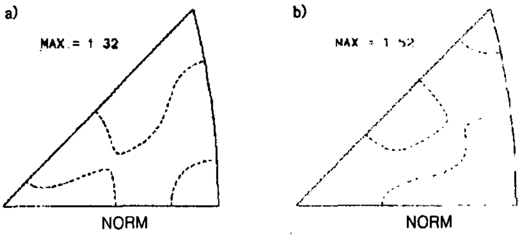


Parameters of Cu electroplating

$CuSO_4 \cdot 5H_2O$: 100 ~ 150 g/l
H_2SO_4 : 50 ~ 200 g/l
Addivives : with and without palladium chloride
Temp : 20 ~ 50 ℃
Current density : 2A ~ 12A/dm2
Diffusion barrier : TiN

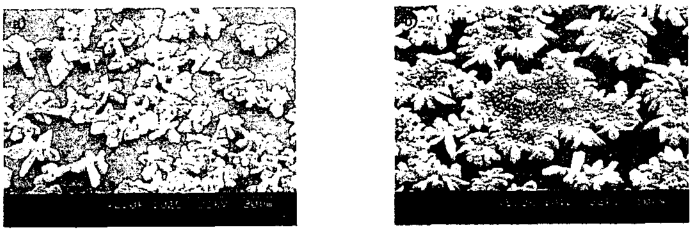
Result and Discussion

- **The inverse pole figures of copper electrodeposits on diffusion barrier TiN films under a) not using and b) using palladium chloride**



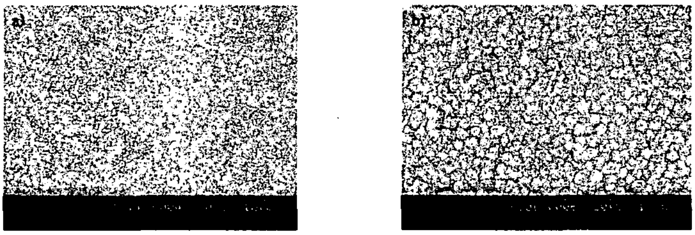
Result and Discussion

- The initial surface morphologies of copper electrodeposits on diffusion barrier TiN films when a) not using and b) using palladium chloride



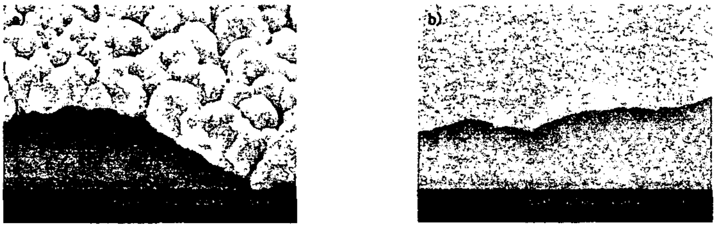
Result and Discussion

- The surface morphologies of copper electrodeposits on diffusion barrier TiN films under using palladium chloride at 2.5 A/dm^2 current density with deposition times. a) 60 sec b) 180sec



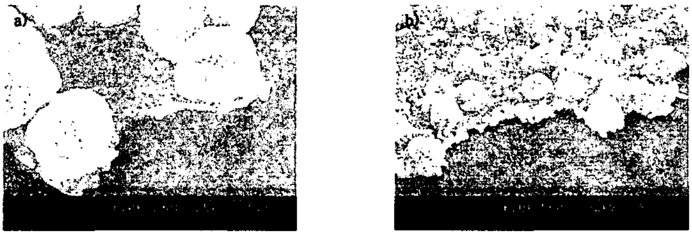
Result and Discussion

- The surface morphologies of copper electrodeposits on diffusion barrier TiN films under a) not using, and b) using palladium chloride



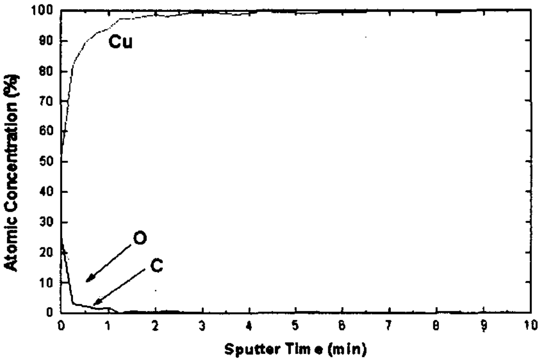
Result and Discussion

- The surface morphologies of copper electrodeposits on diffusion barrier TiN films under not using the palladium chloride.
- a) $CuSO_4 \cdot 5H_2O : H_2SO_4 = 1 : 1.5$ b) 1 : 2



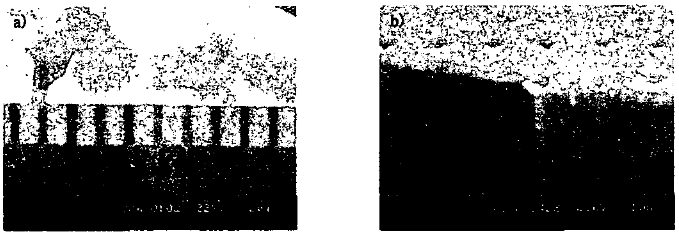
Result and Discussion

The atomic concentration depth profile of copper electrodeposits on diffusion barrier TiN films



Result and Discussion

The cross sectional microstructures of copper electrodeposits on diffusion barrier TiN films under a) not using and b) using palladium chloride



Conclusion

- 1. The number of nucleation sites of copper electrodeposits increased and size of harshness of electro- deposits decreased with the use of palladium chloride at the same condition of electrodeposition.
- 2. The size of harshness of electrodeposits decreased with the increase of the ratio of sulfuric acid.
- 3. The textures of copper electrodeposits show random texture under both not using and using palladium chloride due to the thin thickness of deposit layers.
- 4. The concentration of copper electrodeposits shows very high purity.
- 5. The hole filling of copper electrodeposits made with plalladium chloride was better than that made without it.