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AMORPHOUS METALLIC FILMS IN SILICON METALLIZATION SYSTEMS

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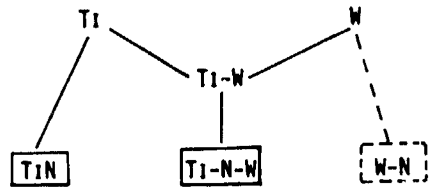
Previous Findings

Amorphous Binary Metallic Alloys (e.g. Ni-W, W-Zr):

- Crystallization temperature T_C = 650°C (Ni-W), 900°C (W-Zr).
- React with Si substrate and metal overlayers (e.g. Al, Ag, Au) below T_C.
- Useful as diffusion barriers up to ~ 500°C with Al overlayer.
- Adding N suppresses reaction with Al up to ~ 550°C.

Amorphous W-N

Motivation:



- Sputtered $Ti_{10}W_{90}$ commonly used diffusion barrier.
- Adding N improves barrier for Si/Ti-N-W/Au.
- Sputtered TiN well studied, successful.
- Study W-N.

Experimental Procedures

- Substrate: Si <100>, high resistivity (900 Ω-cm), and SiO_2.
- Barrier layer W-N: R.F. sputtering; 400W; 10mTorr ($Ar + N_2$); N_2 concentration: 0, 5, 10, 20, 40, 80%; $\sim$ 900 Å.
- Metal overlayer M: R.F. sputtered Al, Ag, Au without breaking vacuum; 1000 - 4000 Å.
- Vacuum annealing: $\leq 7 \times 10^{-7}$ Torr; 400-900°C, 30 min.
- Characterization: RBS, X-ray diffraction; sheet resistance, SEM, AES.

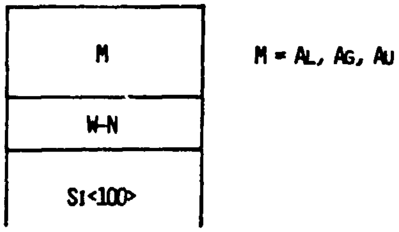


Figure 1

Sketch of W-N Phase Diagram Including Metastable Forms

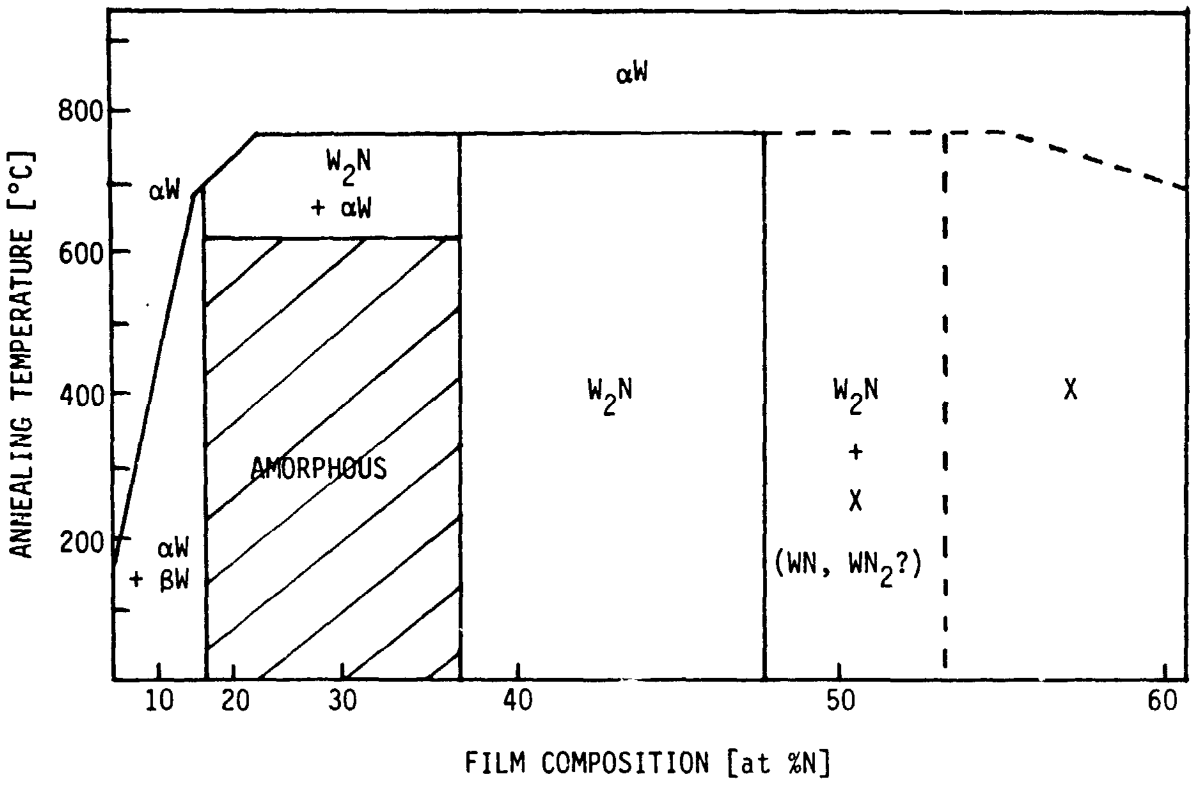
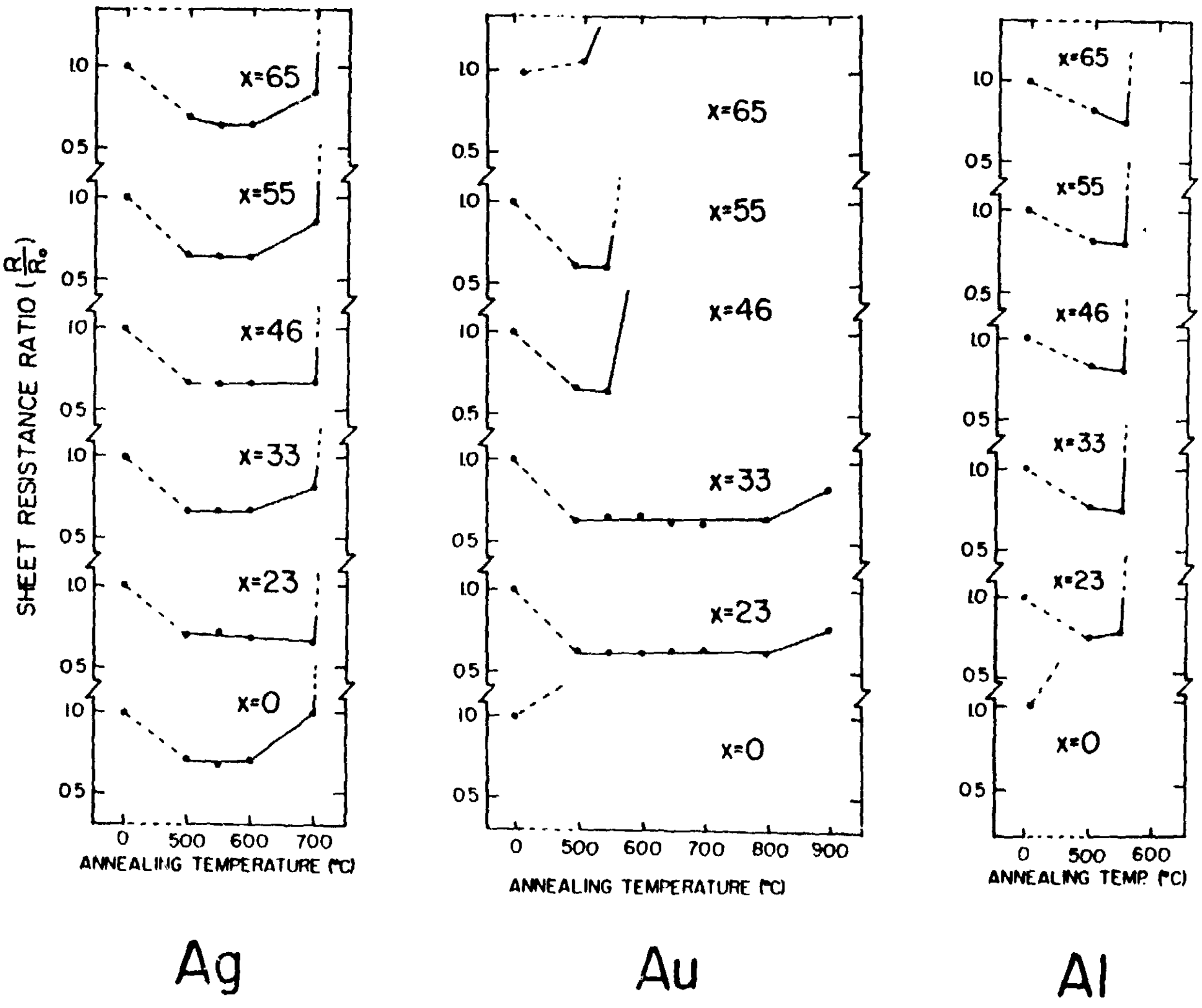


Figure 2

Normalized Sheet Resistances of Si/$W_{100-x}N_x$/Metal



NORMALIZED SHEET RESISTANCES OF Si/$W_{100-x}N_x$/M (M = AL, AG, AU) SAMPLES AS A FUNCTION OF ANNEALING TEMPERATURE (30 MIN).

Observations on Figure 2

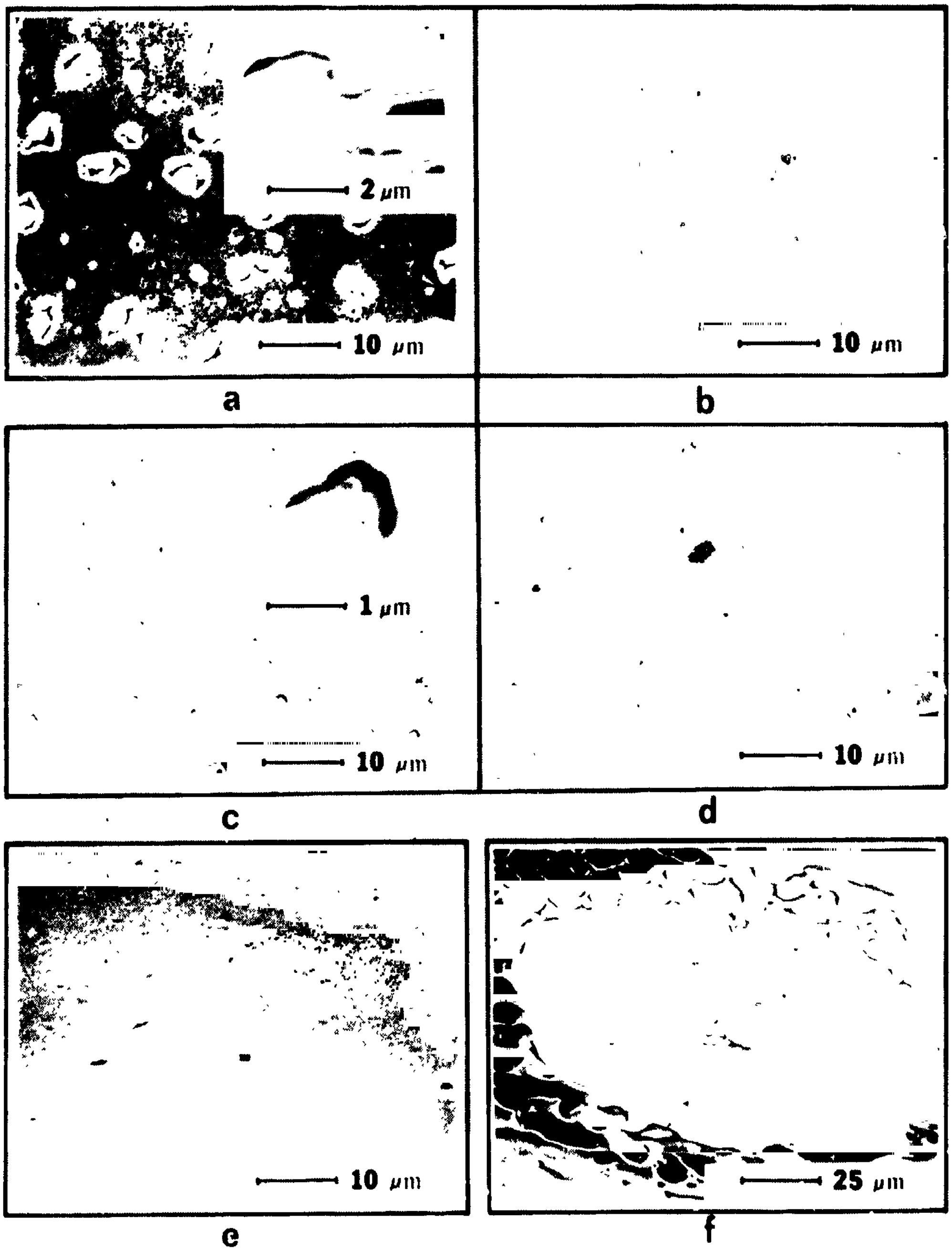
- Pure W ($x = 0$) fails below 500°C, 30 min for Au, Al.
- For Ag and Al: Amorphous and polycrystalline W-N equally good.
- For Au: Only amorphous W-N is good.
- Failure mode: Delamination → localized chemical interaction → large scale intermixing.

Conclusions

- Good barrier between Si <100> and

  Ag: $\sim 20 < x < \sim 70$ up to 700°C, 30 min.
  Au: $\sim 20 < x < \sim 40$ up to 800°C, 30 min.
  Al: $\sim 20 < x < \sim 70$ up to 550°C, 30 min.

Figure 3



SEM micrographs of annealed Si/W-N/metal samples before and after chemical etching of the metal overlayer. (A) Blistering and fracturing is seen in the $Si/W_{45}N_{55}/Ag$ sample after annealing at 700°C. (B) Etching of Ag removes the characters. (C) Blistering is seen in the $Si/W_{77}N_{23}/Au$ sample after annealing at 600°C. (D) Etching of Au removes the characters. The few characters of the $Si/W_{67}N_{33}/Al$ sample annealed at 55°C (E) are also removed by etching Al (not shown). (F) A typical localized failure point observed in Si/W-N/Au (and Si/W-N/Al) samples annealed above the eutectic temperature of the overlayer with silicon.

Amorphous Bilayers

Al metallization scheme; at 550°C

Si/W-N/Al	Stable
Si/W-Zr/Al	Not stable
Si/W-Zr/W-N/Al	Not stable
Si/Ti/W-N/Al	Not stable
Si/TiN/W-N/Al	Stable

Possible explanation:

- Ti (or Zr) deprives W-N of N upon annealing.

Need AES for N profiling.

Outlook

Questions:

- For $\sim 20 < x < \sim 40$: roles of N and microstructure in inhibiting Si/W-N/Au interdiffusion.
- Role of substrate bias and base pressure in sputtering chamber.
- Why does Ti cause thermal instability in Si/Ti/W-N/Al at 550°C?

Future work:

- Test amorphous barriers on shallow junctions.
- TEM study of W-N films.
- Amorphous bilayers.