

Mechanical Properties of Dispersion (IrO₂) Strengthened Pt Films for Piezoelectric MEMS Applications

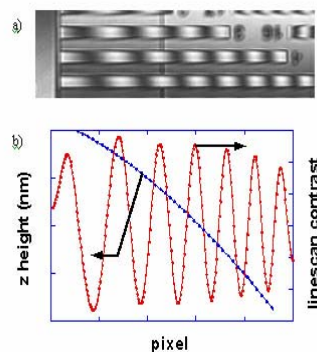
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Introduction

MEMS applications often require novel electrode materials with both robust electrical and mechanical properties. Residual stress can be a problem at room temperature whereas stress relaxation and morphological stability raise concerns especially at high temperatures. Alloying is sometimes used to address these issues, but its effectiveness in thin films may be reduced from that of bulk alloying.

Some current electrodes use a Pt/Ta or Pt/Ti metallization scheme. This typically results in a Pt layer that contains some Ta₂O₅ or TiO₂. These oxides aid in the mechanical behavior by dispersion strengthening, but are a detriment to the conductivity of the electrode. An alternative, new metallization scheme is Pt/Ir. This would result in oxide dispersion strengthening with a conductive oxide, IrO₂.

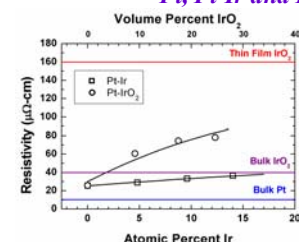
This study examines and compares the effect of **solid solution strengthening** in Pt-Ir films and **oxide dispersion strengthening** in Pt-IrO₂ films



Cantilever deflection caused by residual stress. Images courtesy of Sandia National Laboratories

Sheet Resistivity

Pt, Pt-Ir and Pt-IrO₂ Thin Films



- The Pt-IrO₂ films have lower resistivity than pure IrO₂ films and are better suited for PZT/MEMS applications.

$$\rho_{\text{alloy}} = \rho_{\text{Pt}} + A (C_{\text{Ir}}) (1 - C_{\text{Ir}})$$

where, C_{Ir} = atomic fraction of solute Ir,
A = Nordheim coefficient for Ir in Pt = 230 μΩ-cm

Samples Prepared

Films for Nanoindentation and Substrate Curvature

- Pt and Pt-Ir, 200 nm film thickness
 - 4.8, 9.6, 14 at% Ir
- Pt-IrO₂, 200 nm film thickness
 - Same deposition conditions as 4.8, 9.6 and 14 at% Pt-Ir films
 - Corresponds to 9.2, 17.5 and 24.6 vol% IrO₂
 - Pt-Ir solid solution films with large, widely spaced IrO₂ particles

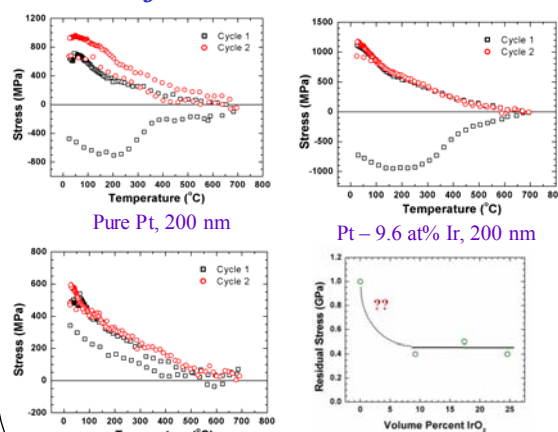
Additional Films for Nanoindentation

- Pt-Ir, 900 nm film thickness
- 1.7, 2.4, 10.2, 17 at% Ir

Film	Low	Medium	High
Pt-Ir	4.8 at%	9.6 at%	14 at%
Pt-IrO ₂	9.2 vol%	17.5 vol%	24.6 vol%

Film Stress

Wafer Curvature Results



Pt - 17.5 vol% IrO₂, 200 nm

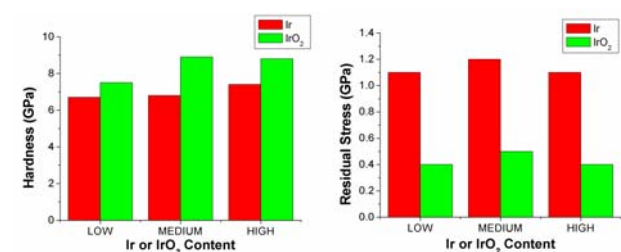
Small IrO₂ additions effective?

Thermoelastic Slope and Residual Stress

Material	M Δα (MPa/°C) Theoretical	M Δα (MPa/°C) Experimental	Room Temperature Stress (GPa)
Pt	2.22	1.59	1.0
Pt-4.8 at% Ir	2.28	1.87	1.1
Pt-9.6 at% Ir	2.34	1.94	1.2
Pt-14 at% Ir	2.39	2.10	1.1
Pt-9.2 vol% IrO ₂	1.68	0.88	0.4
Pt-17.5 vol% IrO ₂	1.53	0.86	0.5
Pt-24.6 vol% IrO ₂	1.41	0.85	0.4

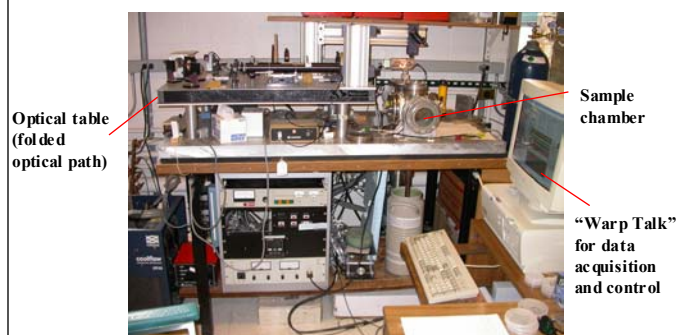
Property Comparison

Pt-Ir and Pt-IrO₂ Thin Films



Stress Measurement Tool

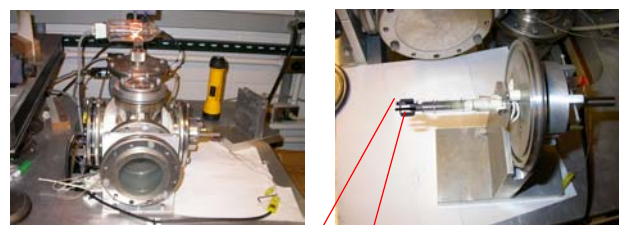
“Wafer Curvature System”



Optical table (folded optical path)

Sample chamber

“Warp Talk” for data acquisition and control



Vacuum chamber with enclosed heater

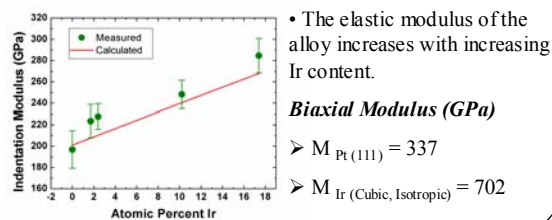
Sample insertion flange

Control sample

Actual sample 5 mm x 25mm

Indentation Modulus

900 nm Pt and Pt-Ir Thin Films



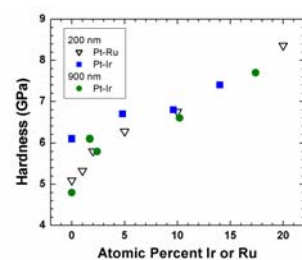
- The elastic modulus of the alloy increases with increasing Ir content.

Biaxial Modulus (GPa)

- M_{Pt(111)} = 337
- M_{Ir(Cubic, Isotropic)} = 702

Hardness

Pt-Ir and Pt-Ru Comparison

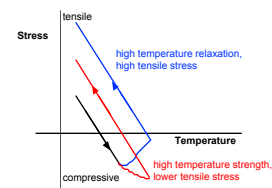


$$H_{\text{tot}} = H_{\text{int}} + H_{\text{ss}} + H_{\text{ps}}$$

- Increase in hardness with solute content observed in Pt-Ir system similar to that in Pt-Ru*.

*S. Hyun, R.P. Vinci and O. Kraft, “Mechanical Behavior of Pt and Pt-Ru Solid Solution Alloy Thin Films.”, submitted to Acta Materialia, February 2004.

Possible effect of strengthening mechanisms



- Sufficient delay in onset of high temperature plasticity can reduce room temperature residual stress.
- If T_{max} << Transition temp then elastic only.
- If T_{max} ≈ Transition temp and transition is gradual (as pictured) then elastic-plastic, some benefit.
- If T_{max} > Transition temp then no benefit (perhaps worse).

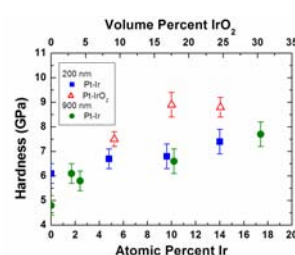
Key features

“Wafer Curvature System”

- Sample size: 5 mm x 25 mm lateral area (optimum)
- Furnace temperature Range:
 - Standard: Room Temp to 700 °C,
 - Optional: Sub zero °C to Room Temp
- Max achievable heating rate:
 - 100 °C/min till 500 °C
 - ~75 °C/min between 500 – 700 °C
- LN2 assisted cooling:
 - Max cooling rate: 100 °C/min between 700 - 400°C
- Cooling rate below 400 °C drops off because of limited forced cooling reaching 1 °C/min below 100 °C
- Scan length: User programmable up to 10 mm

Hardness

Pt-Ir and Pt-IrO₂ Thin Films



- The IrO₂ particles increase the strength above that achieved by solid-solution.

Conclusions

- Solid solution strengthening of Pt with Ir *is not effective* in reducing residual stress by delaying the onset of high temperature plasticity.
- Oxide dispersion strengthening of Pt with IrO₂ may delay the onset of high temperature plasticity slightly from 500 °C to 550 °C.
- Oxide dispersion strengthening of Pt with IrO₂ *is effective* in reducing the residual stress by reducing the thermoelastic slope.

Acknowledgements

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