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Propagating Exothermic Reactions in in Al/Pt Multilayers of Varied Composition

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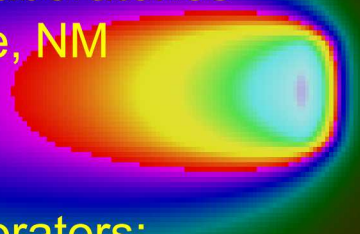

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M. Abere, C. Sobczak, R. Reeves

ICMCTF (San Diego)
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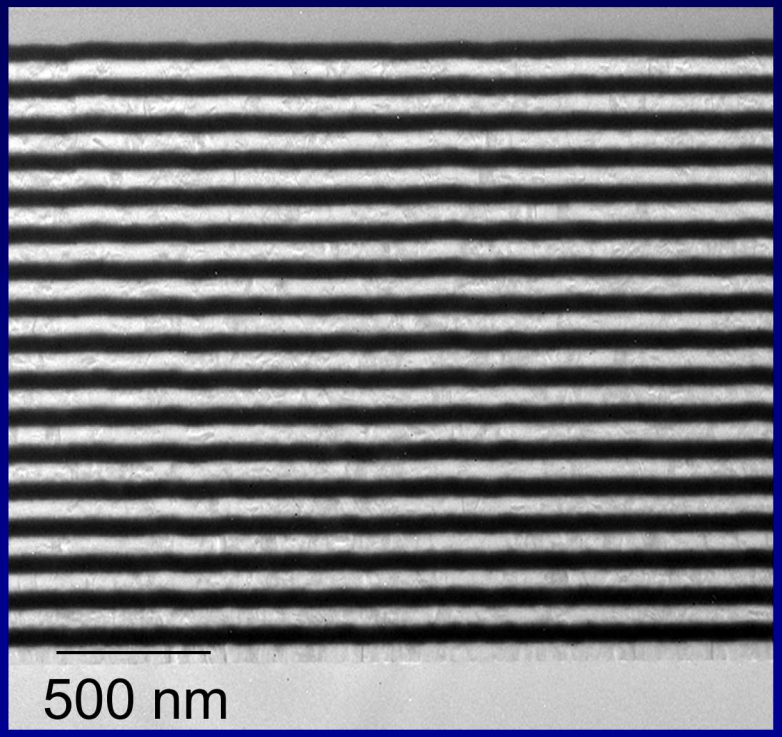
Sputtering is used to produce reactive multilayers.

- Design includes two reactants

- Single, out-of-plane periodicity for each multilayer

- Heats of reaction, ΔH_o, for reactive pairs
  - Ti/2B : - 102 kJ/mol at
  - Al/Pt : - 100 kJ/mol at
  - Ni/Al : - 60 kJ/mol at
  - Co/Al : - 58 kJ/mol at
  - Ni/Ti : - 34 kJ/mol at

- Reference review articles
  - Rogachev
  - Weihs
  - Rossi
  - Adams



Al/Pt multilayer in Cross Section by TEM

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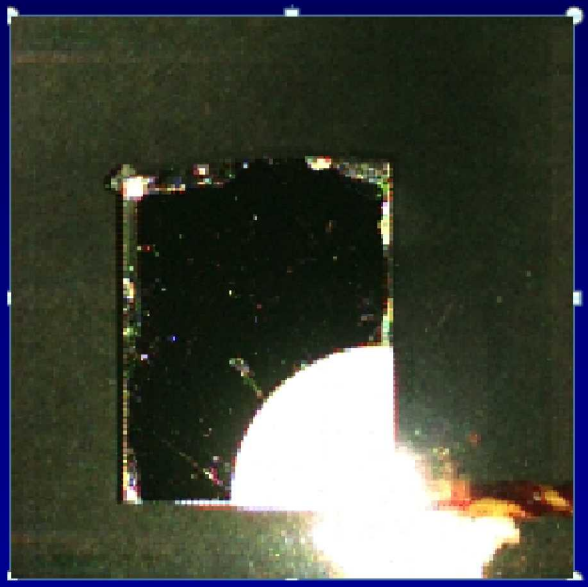


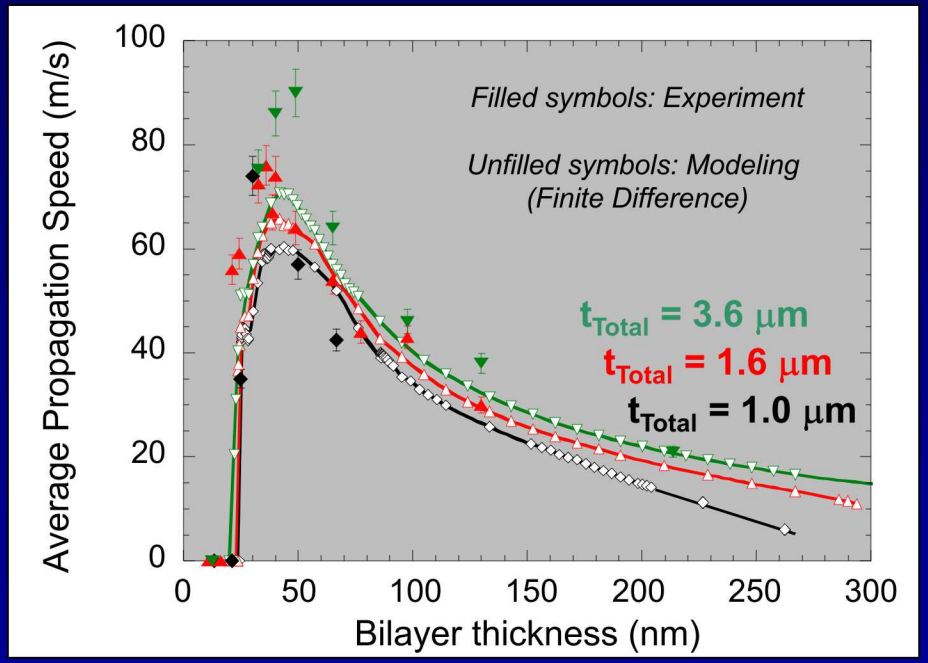
1 cm

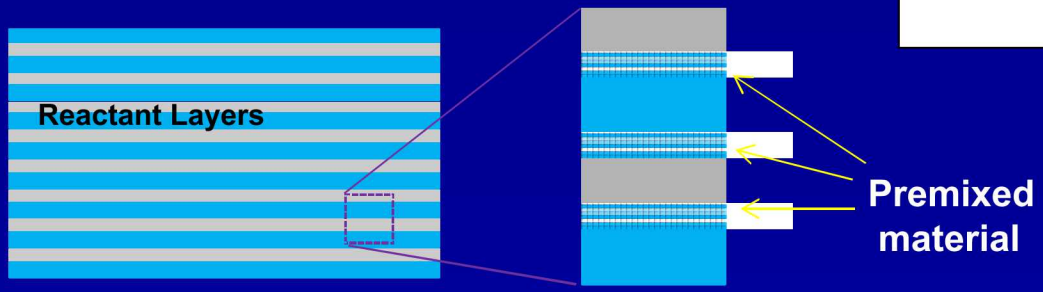
Equiatomic Al/Pt mulitlayers react at high rates; the rate of reaction varies with bilayer thickness.

- Large range of bilayer thickness over which a decreased dimension gives rise to increased average speed.
- Peak speed at small bilayer thickness.
- Decreased speed for ultra-thin bilayers is due to the presence of relatively large amounts of premixed material.

first explanation: Wickersham, 1988

Ex. Equiatomic Aluminum/Platinum on SiO_2





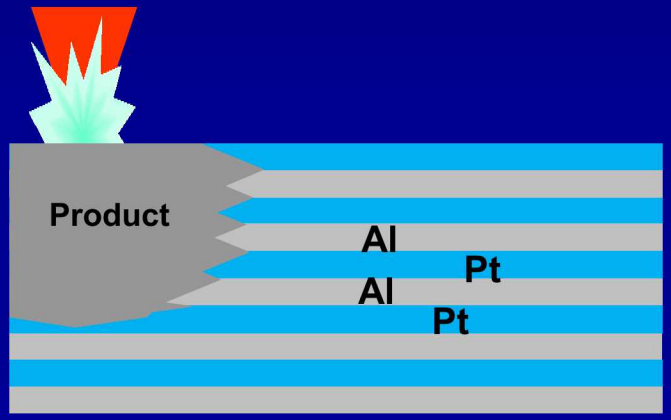
M. Hobbs, D.P. Adams, et al. 8th World Congress Comp. Mech. (2008).

Goals and approach of current study

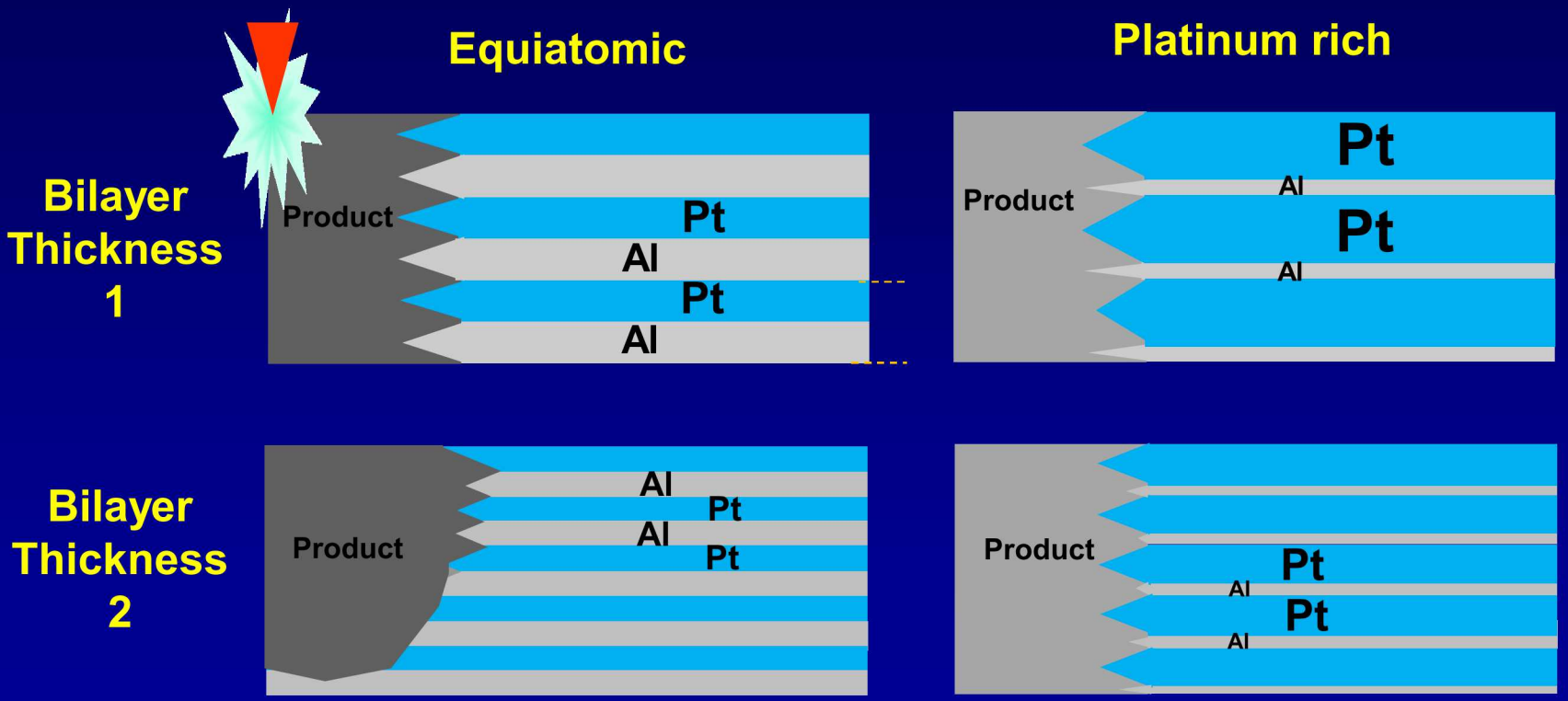
i) Determine the compositional range of Al-Pt multilayers which exhibit self-sustained, formation reactions when ignited at a point

ii) Investigate these behaviors in the context of stored chemical energy of multilayers determined by calorimetry (including effects of design, bilayer thickness)

Depiction in cross section

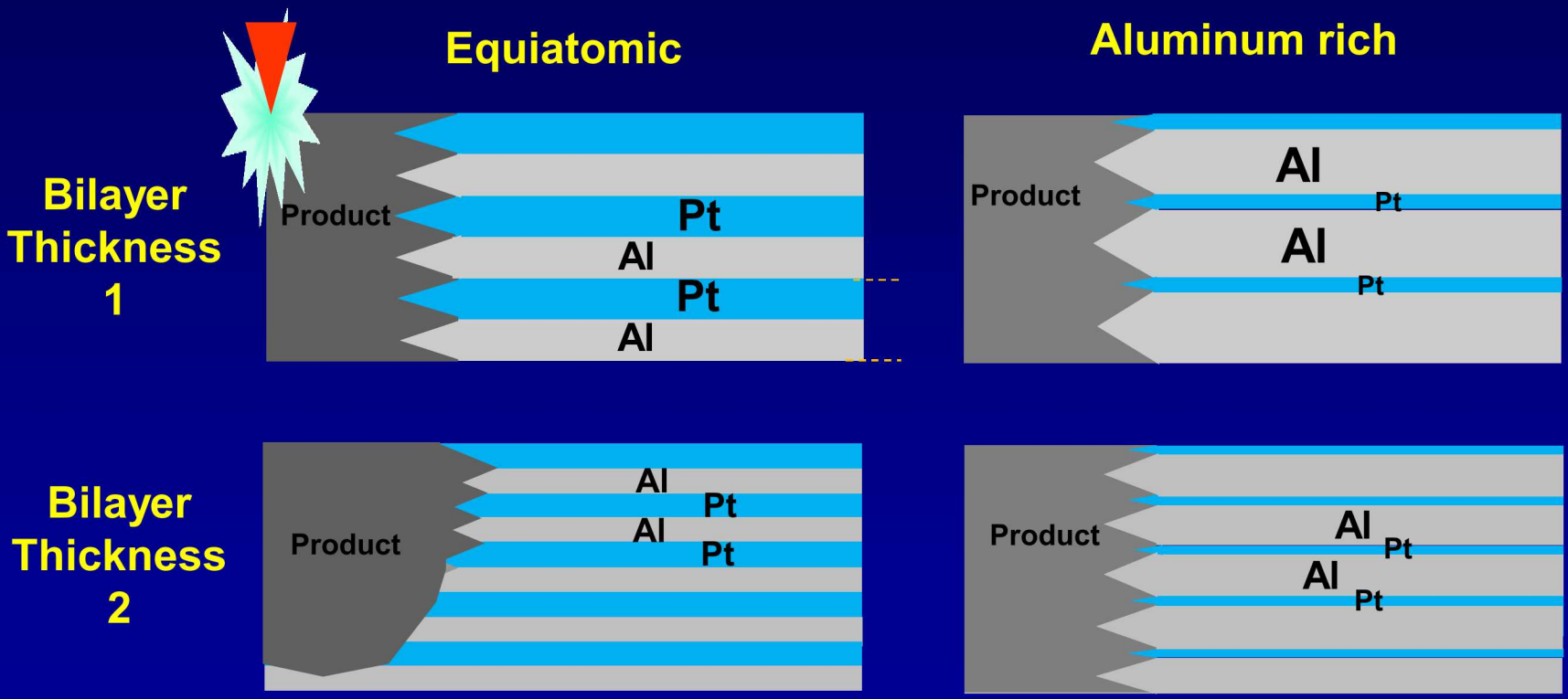


Design of experiments that vary net composition and bilayer thickness.



Investigate various Al-rich and Pt-rich compositions.

Design of experiments that vary net composition and bilayer thickness.



Investigate various Al-rich and Pt-rich compositions.

Details of Experiments

Compositions investigated:

AlPt,

Al_3Pt_2, Al_2Pt, Al_3Pt, Al_4Pt, Al_9Pt_1,

Al_2Pt_3, $AlPt_2$, $AlPt_3$, $AlPt_4$, Al_1Pt_9,

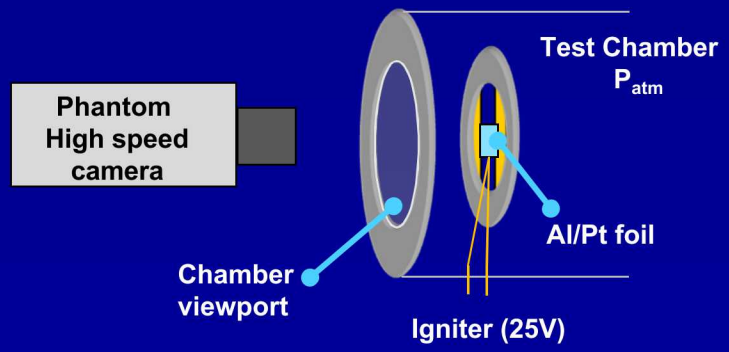
Point ignition in air

Tested as freestanding foils

No preheat above room temperature

High speed photo: Go/no go; steady-state speed

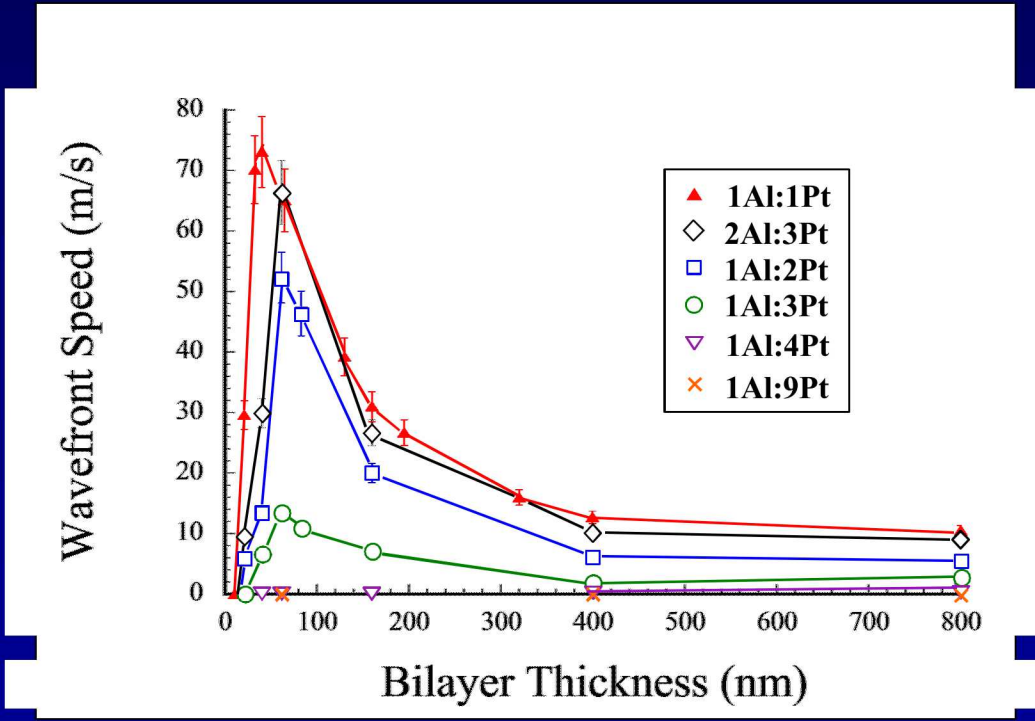
Phase analysis: X-ray diffraction



Equiatomic Al/Pt, bilayer thickness: 50 nm

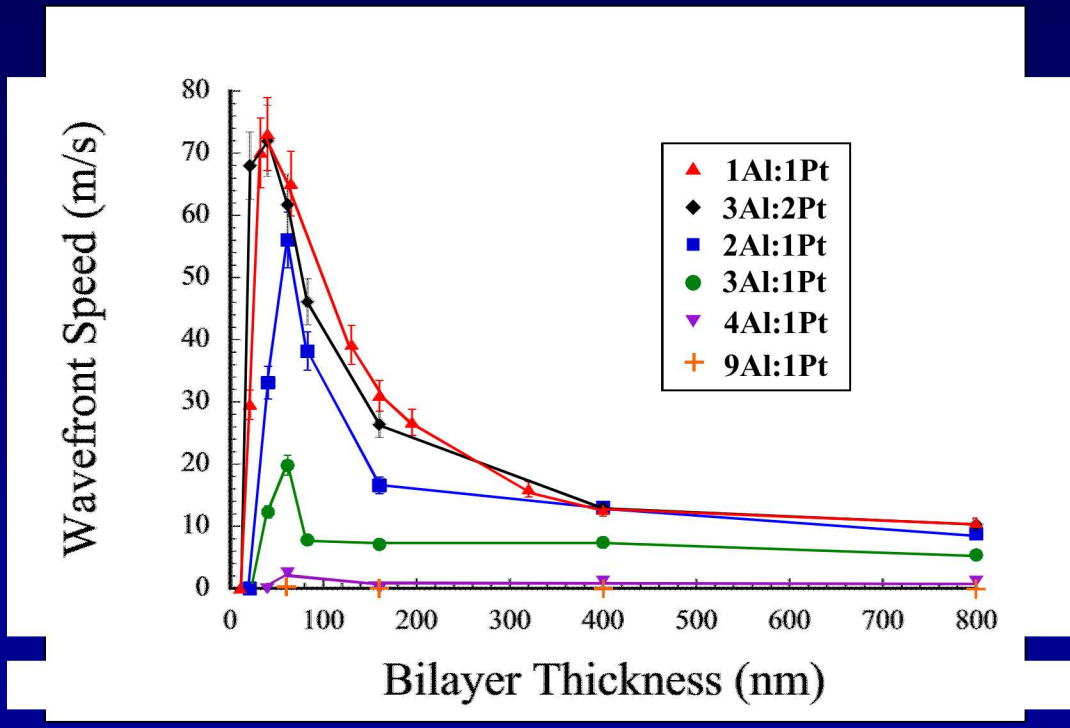
Multilayers having Pt - rich compositions exhibit self–propagating reactions.

- Equiatomic AlPt exhibits largest reaction rate.
- Pt-rich multilayers exhibit decreased propagation speeds as %Pt increased.
- Traditional bilayer thickness dependence is observed for several compositions.

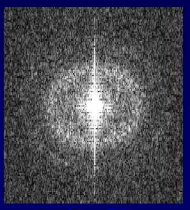


Multilayers having Al - rich compositions exhibit self–propagating reactions.

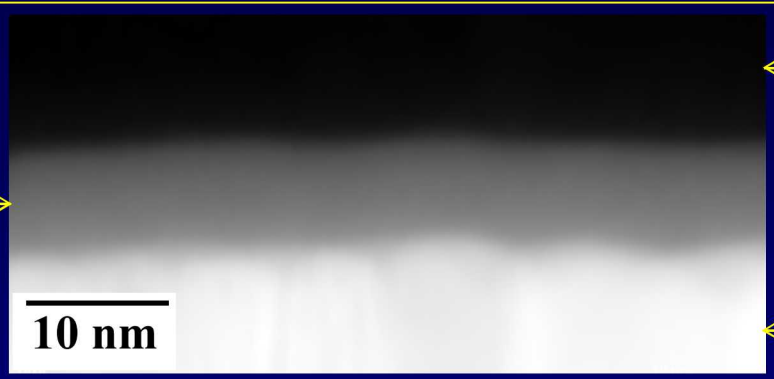
- Equiatomic AlPt exhibits largest reaction rate.
- Al-rich multilayers exhibit decreased propagation speeds as %Al increased
- Many designs of 4Al/Pt do not exhibit self-sustained reactions.

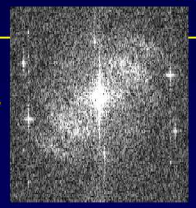


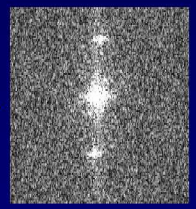
A closer look at interfaces of Al_x/Pt_y multilayers

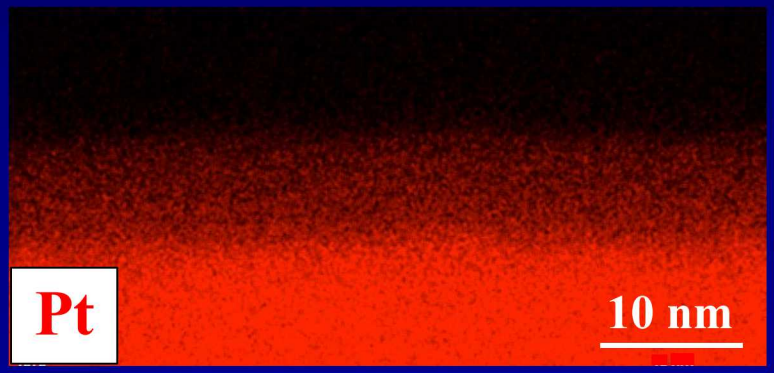


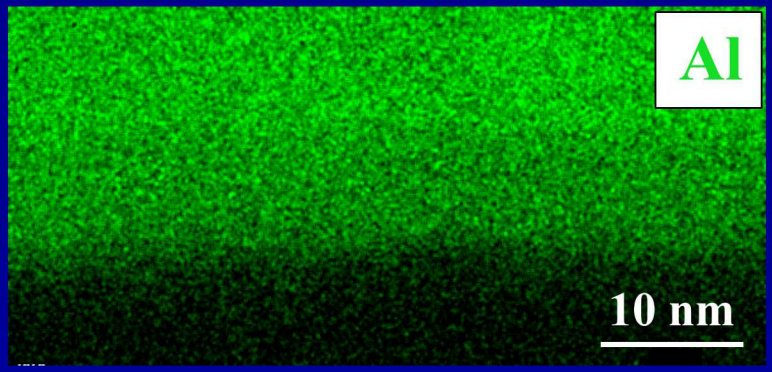
Al-Pt

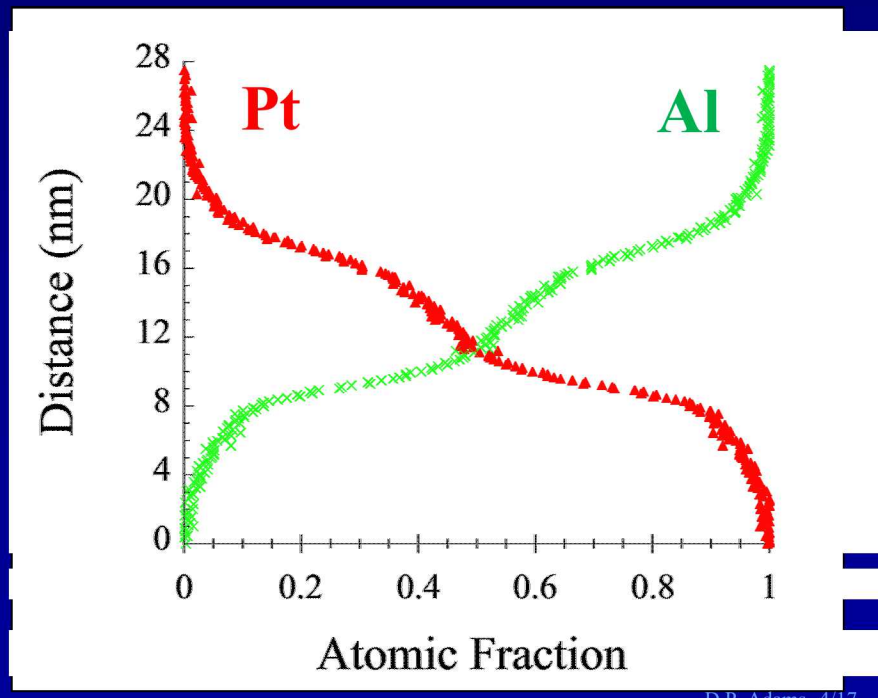






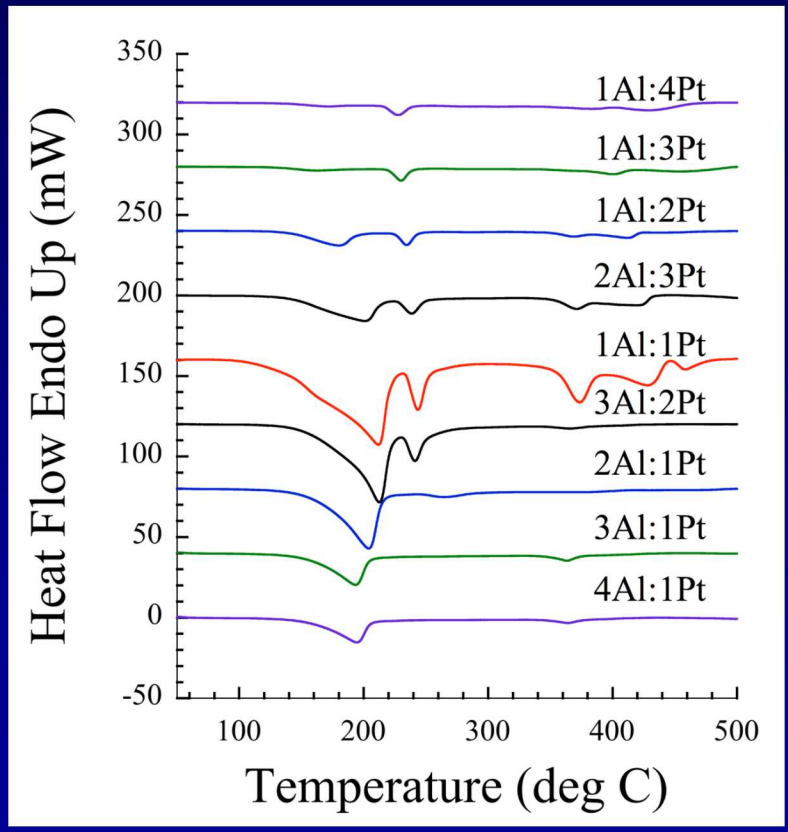






Differential Scanning Calorimetry is used to measure heats of reaction for Al_xPt_y.

- All Al_xPt_y compositions studied here are characterized by exothermic rxns.
- Equiatomic AlPt exhibits maximum ΔH_o.
- Al- and Pt-rich multilayers have reduced stored chemical energy.



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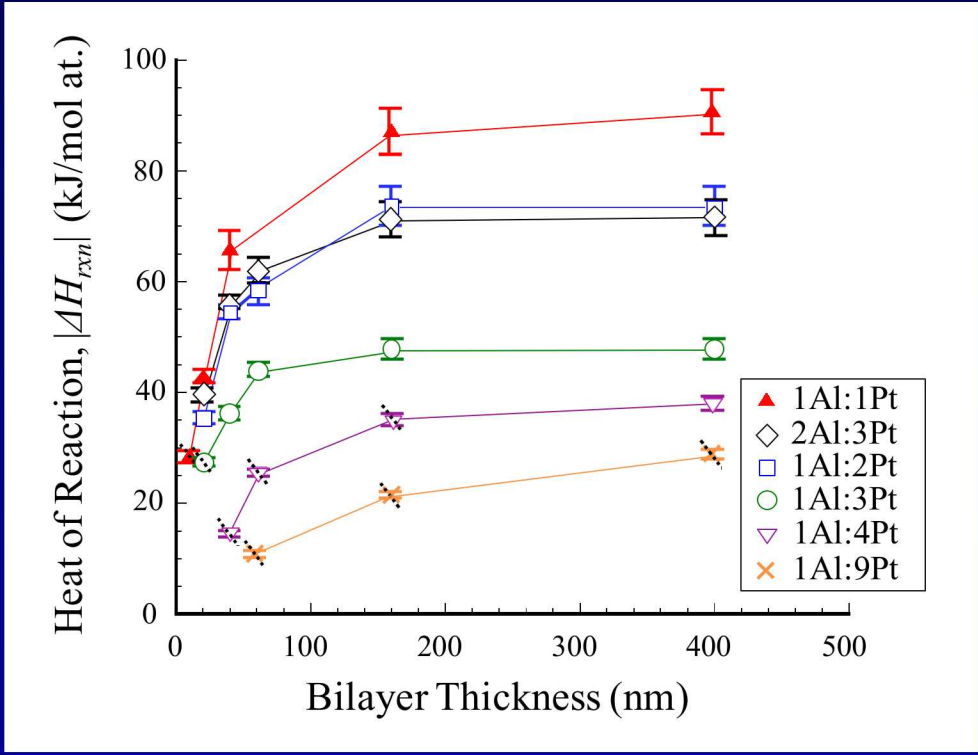

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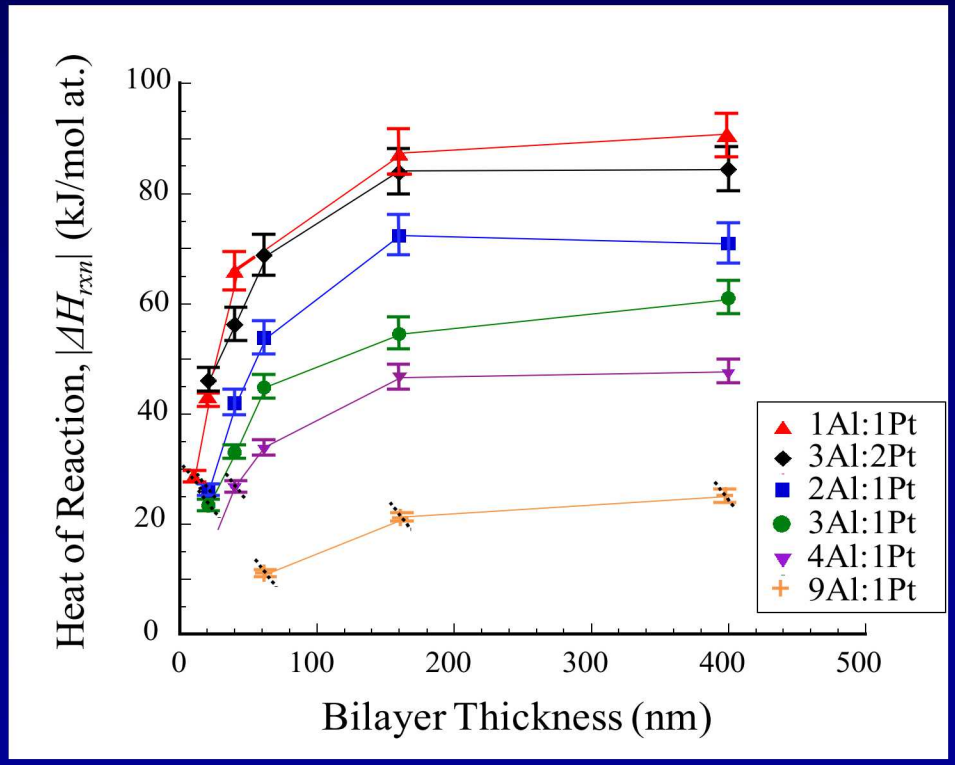
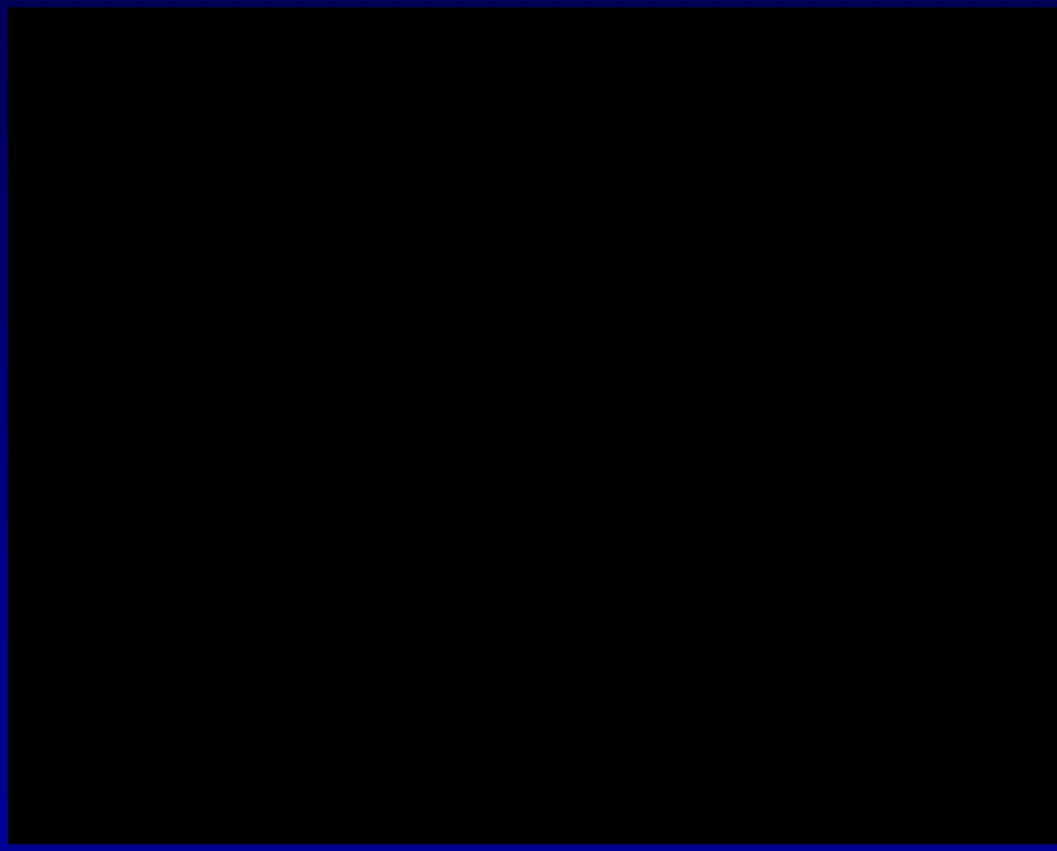


Differential Scanning Calorimetry data is used to determine heats of formation for Al_xPt_y.

- All Al_xPt_y compositions studied here are characterized by exothermic reactions.
- Equiatomic AlPt exhibits maximum ΔH_o.
- Al- and Pt-rich multilayers have reduced stored chemical energy.
- Reasonable matching to literature.



Summary

- Sputter-deposition provides the control needed for detailed studies of structure-composition-property relationships.

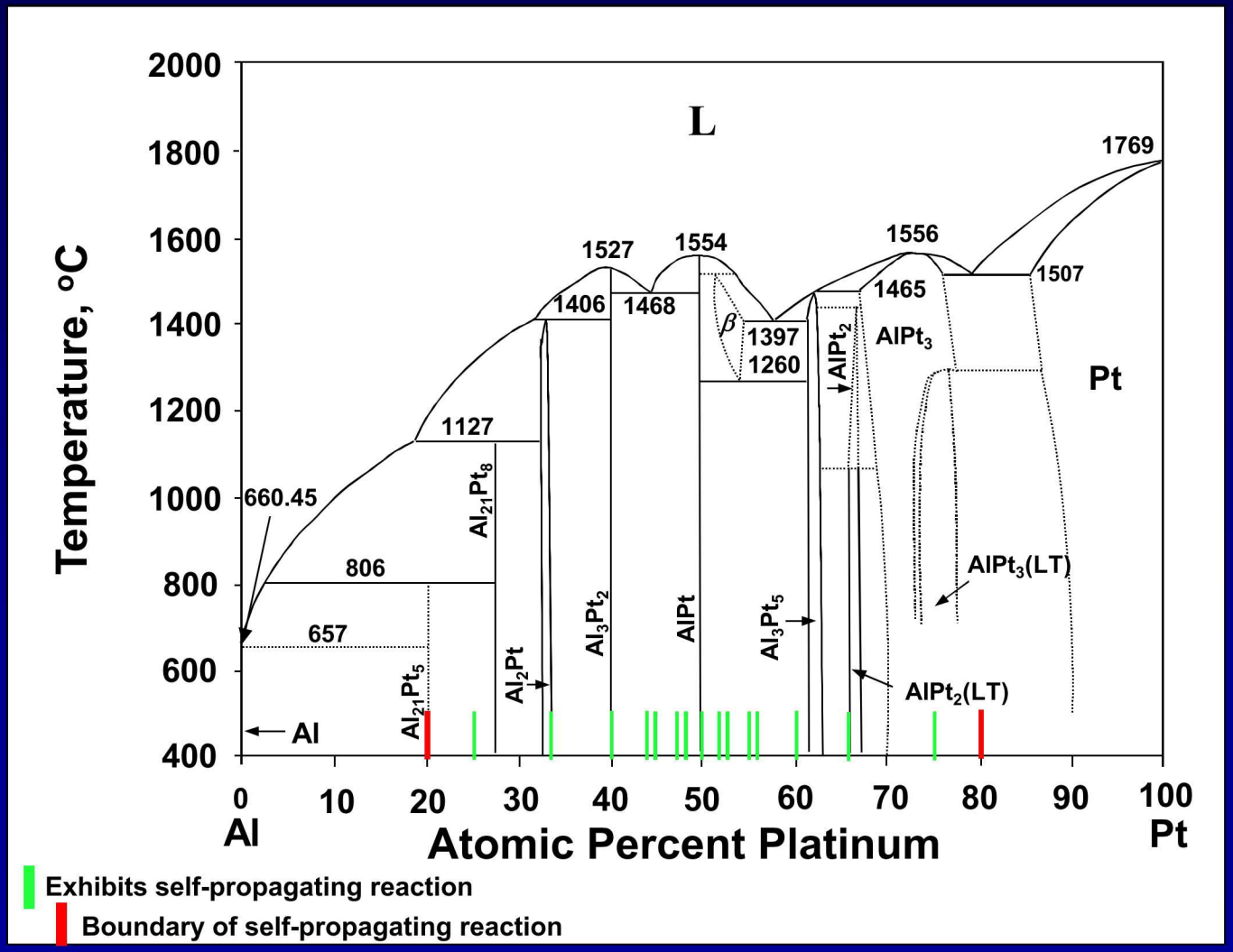
- Equiatomic Al/Pt multilayers exhibit the most rapid reactions (when comparing multilayers of a particular bilayer thicknesses) and have the largest stored chemical energy density.

- Non-equiatomic (Al_xPt_y) multilayers exhibit self-sustained reactions when $0.125 \leq x/y \leq 8$.

- Al/Pt multilayer foils with less than ~30-35 kJ/mol at. are not sufficiently energetic to self-propagate when ignition is attempted at a point.

EXTRA SLIDES

Summary of compositions tested.



Phase Diagram redrawn from McAlister and Kahan, ASM 1986

Exothermic multilayers are deposited at Sandia using magnetron DC sputter methods.

Multiple deposition systems

10^{-9} - 10^{-8} Torr base pressure
Ar sputter gas
In-situ quartz crystal monitors

Capabilities:

> 99 % uniformity across 8” area
Sample at 45°C during deposition
Precision of layer thickness:10-15 Å

Other:

Adjust film thicknesses to
compensate for densities

Generally, multilayer is peeled off to ‘create’ a foil for testing.