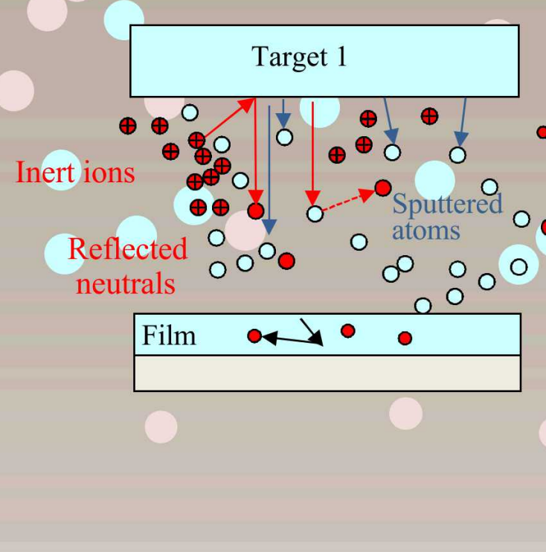
SAND2019-10640C

# Exothermic Reactions in Al/Pt Multilayers of Varied Stoichiometry

Catherine E. Sobczak, David P. Adams, Robert V. Reeves*, Michael J. Abere, Cole D. Yarrington
Sandia National Laboratories, *Lawrence Livermore National Laboratories

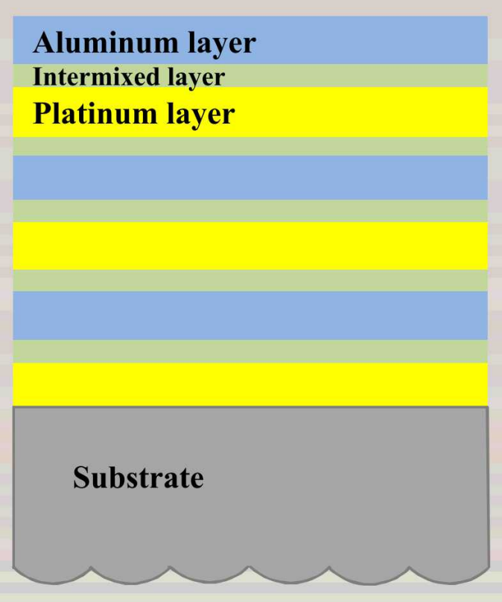
## Process Parameters and Initial Deposited Structure

### Sputter Growth of Reactive Films[1-3]



**Sputtering Process used for Al/Pt Multilayers**

- Chamber base pressure: $10^{-7}$ Torr
- Throttled chamber pressure: 10 mTorr
- Each material was sputtered at rates in the range from 200-400Å/min.
- No deliberate heating. Estimated deposition temperature ~ 50°C.

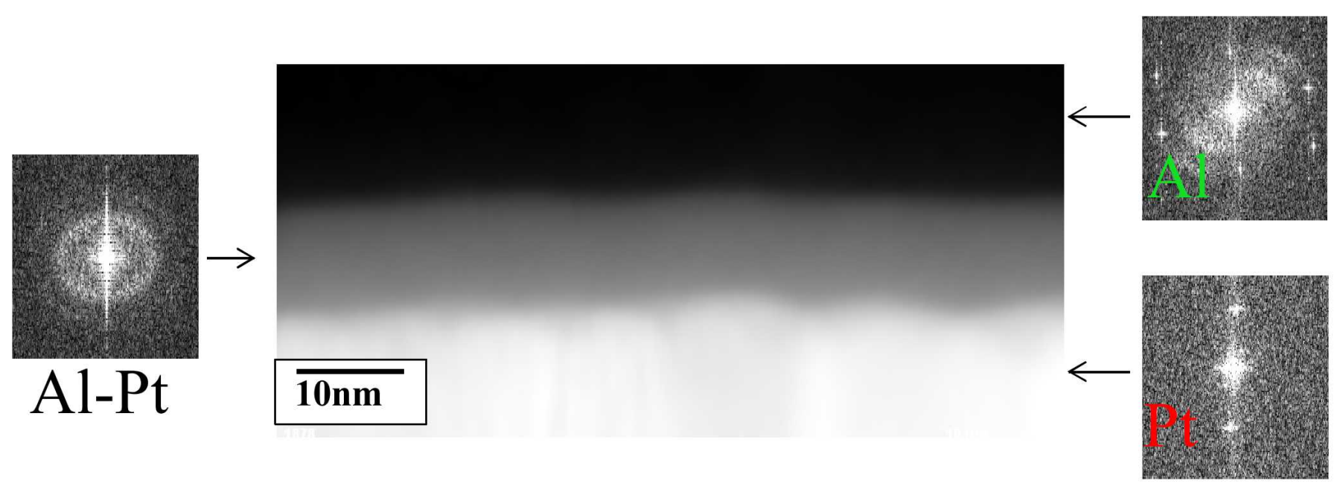


### Characteristics of Aluminum - Platinum Multilayers

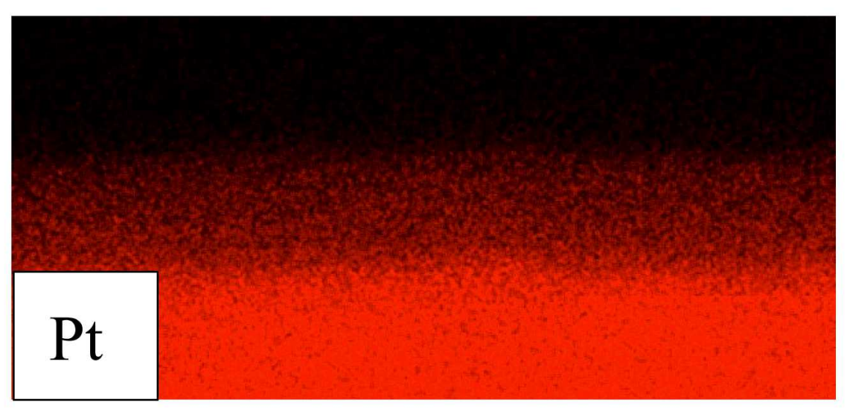
- Aluminum and platinum are grown in alternating thin film layers.
- The reactive layers undergo intermixing at the Al/Pt interface during film growth.
- The intermixed layer has been shown in prior work to have an effect on stored chemical energy and propagating reactions.

## Pt/Al Bilayer Analyzed by TEM and EDS

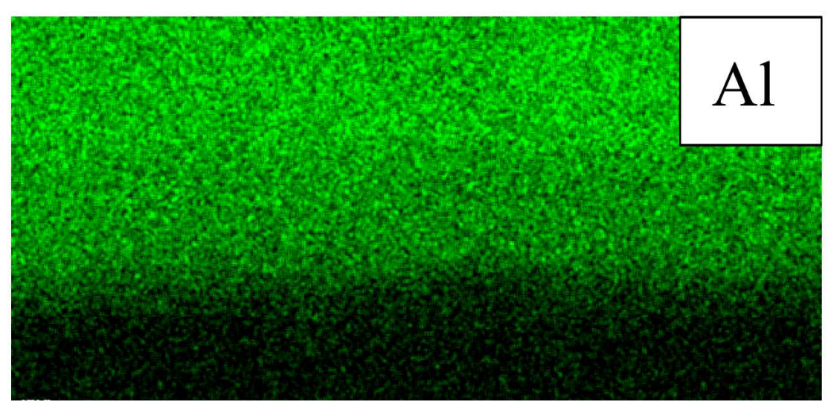
**TEM Cross Section of Pt/Al Bilayer Shows Intermixed Volumes**



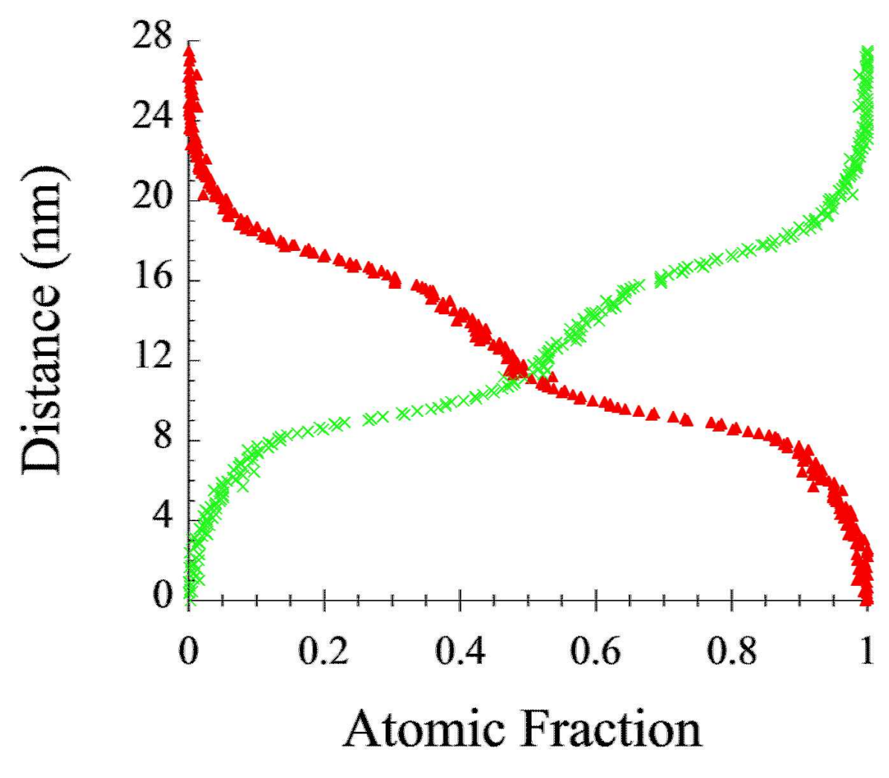
**EDS Analysis of Bilayer Cross-Section, Pt in Red**



**EDS Analysis of Bilayer Cross-Section, Al in Green**



**Plot of Atomic Fraction of Al/Pt based on EDS Results**

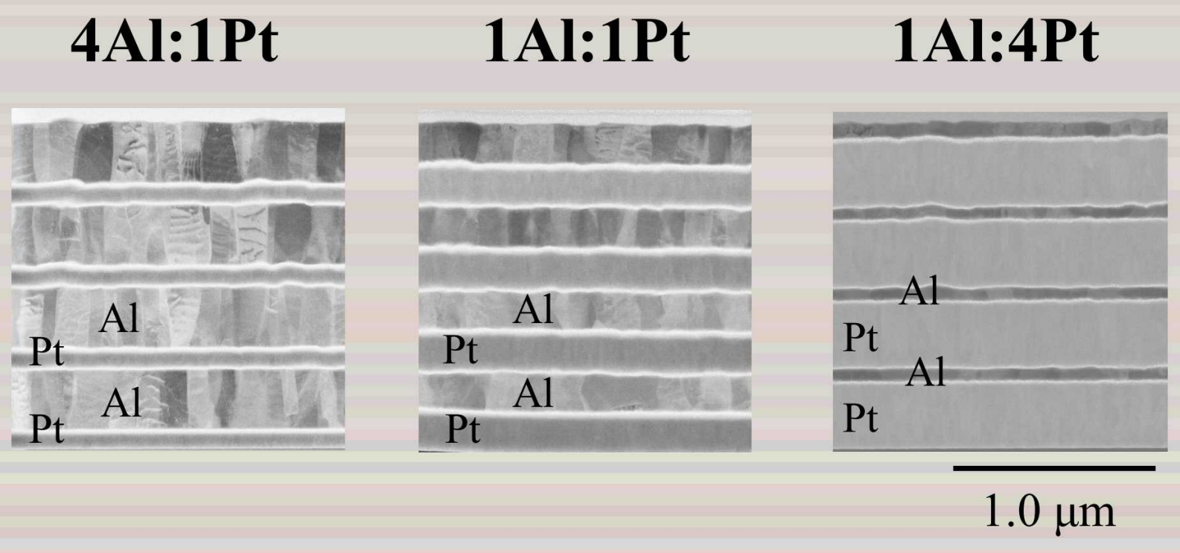


## Abstract

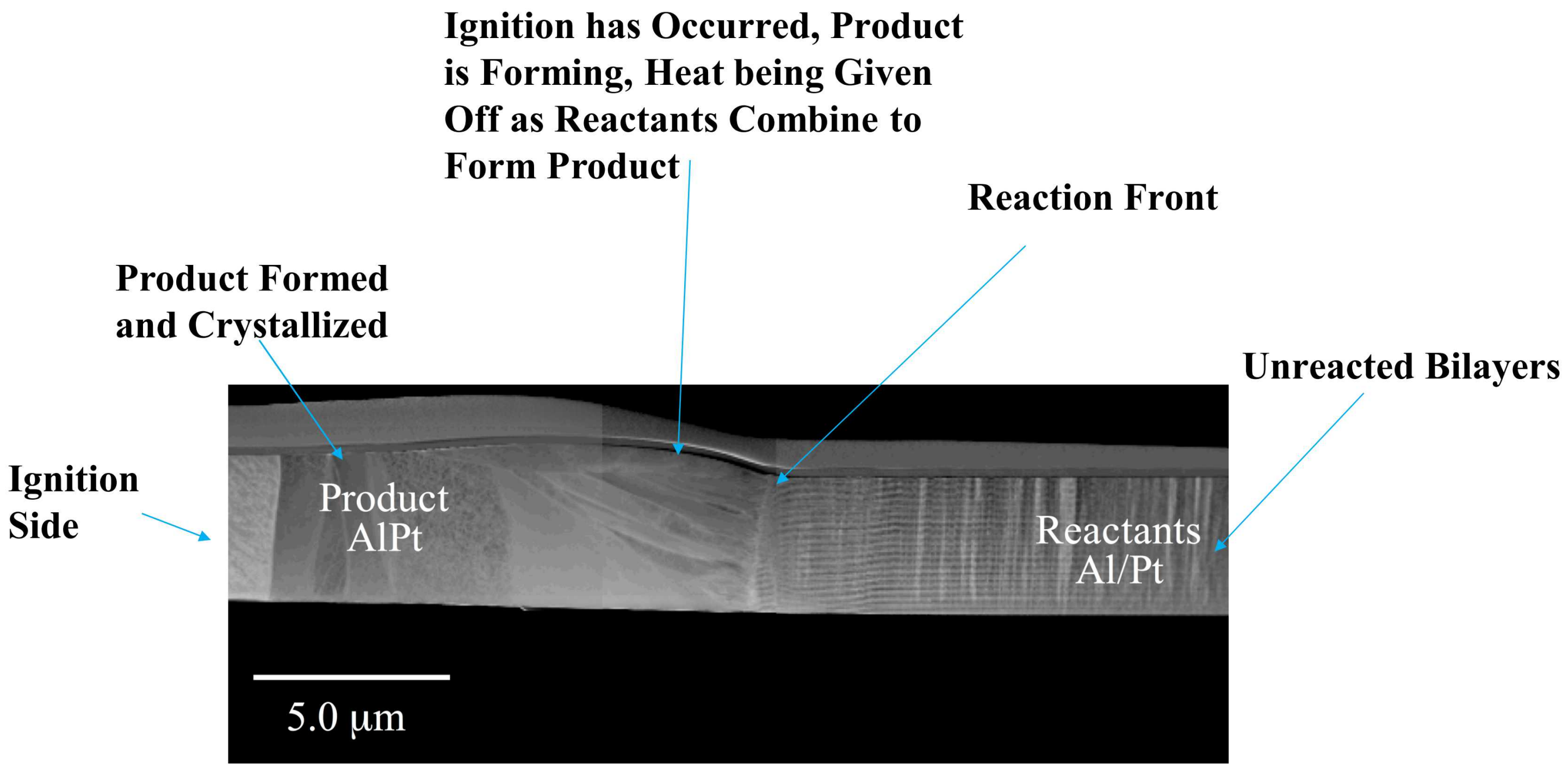
Reactive bimetallic multilayers of aluminum and platinum form an energetic material that can be ignited at a single point and undergo rapid, exothermic, self-propagating formation reactions. Reactivity has been evaluated across a broad range of stoichiometry (nAl:mPt) and layer periodicity. Experiments demonstrate self-propagating reactions in ~ 1.6 micron-thick Al/Pt multilayers when the molar ratio of reactants is in the range 4Al:1Pt to 1Al:4Pt. This rather large compositional range is characterized by different reaction rates and behaviors. High-speed photography shows that equimolar Al/Pt multilayers undergo the most rapid reactions with wavefront speeds as large as 80 m/s. Al- and Pt-rich multilayers react at reduced rates with speeds as low as 1 m/s. Ongoing work will explore how this broad range of composition can be used to benefit joining and other related applications.

## Observations prior to Reaction

### STEM of Al/Pt Films (3 compositions)

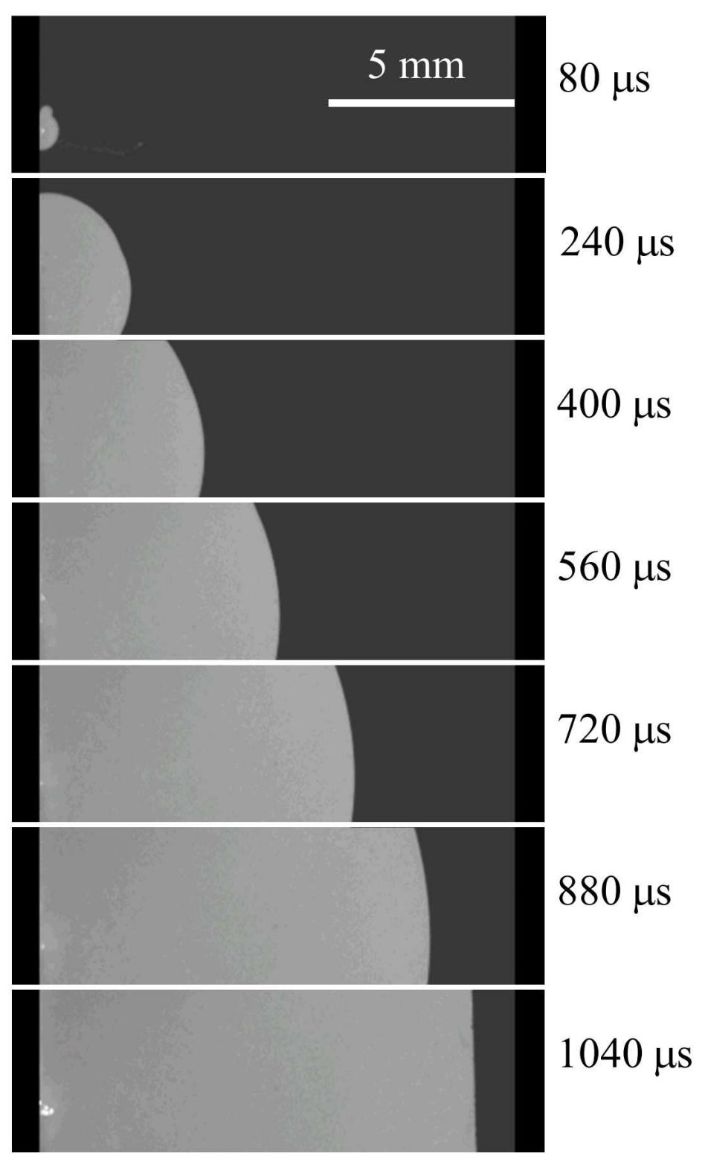


## Quenched Wavefront for Demonstrating Changes that Occur during Self-Propagating Reactions



- This image was obtained after partial reaction.
- Multilayer was ignited in a region that was detached from substrate. When the reaction front reached the silicon, the substrate acted as a heat sink and stopped the reaction.
- The Al/Pt undergoes a volumetric expansion as a result of the formation reaction as seen to the left of the reaction front.
- Unreacted material is visible to the right of the reaction front in this image.

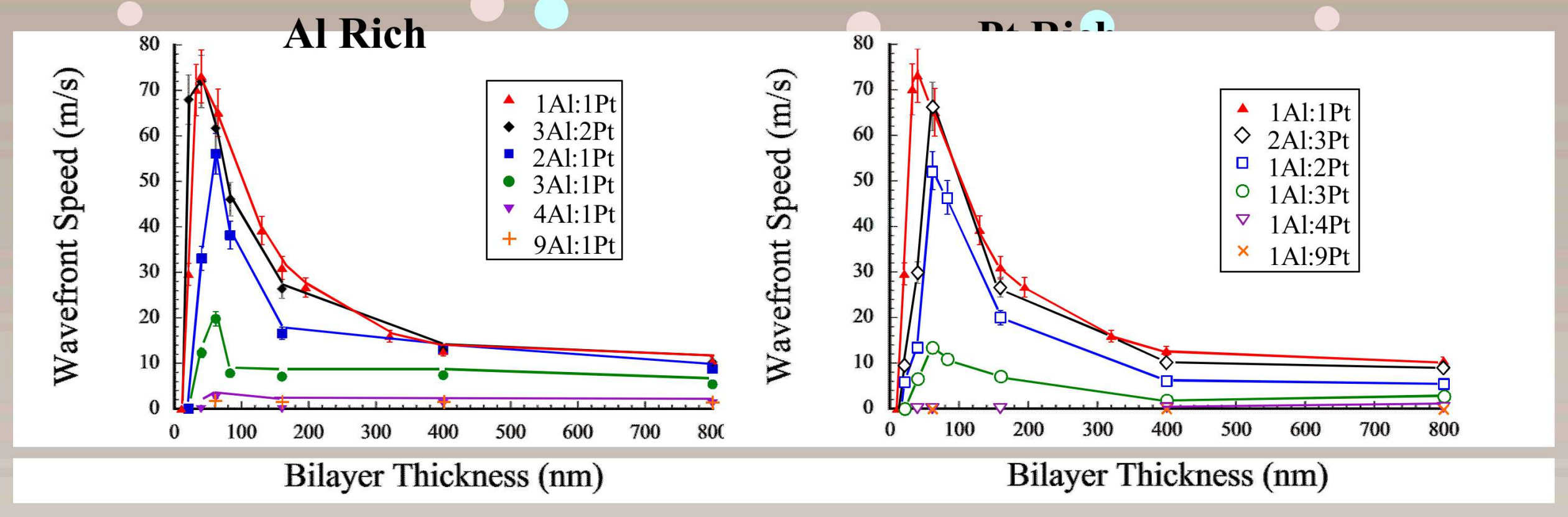
## Images of Reaction Captured by Plan View High-Speed Photography



- Steady propagation is characterized by a uniform, single velocity (per multilayer).
- There is no evidence of instabilities.

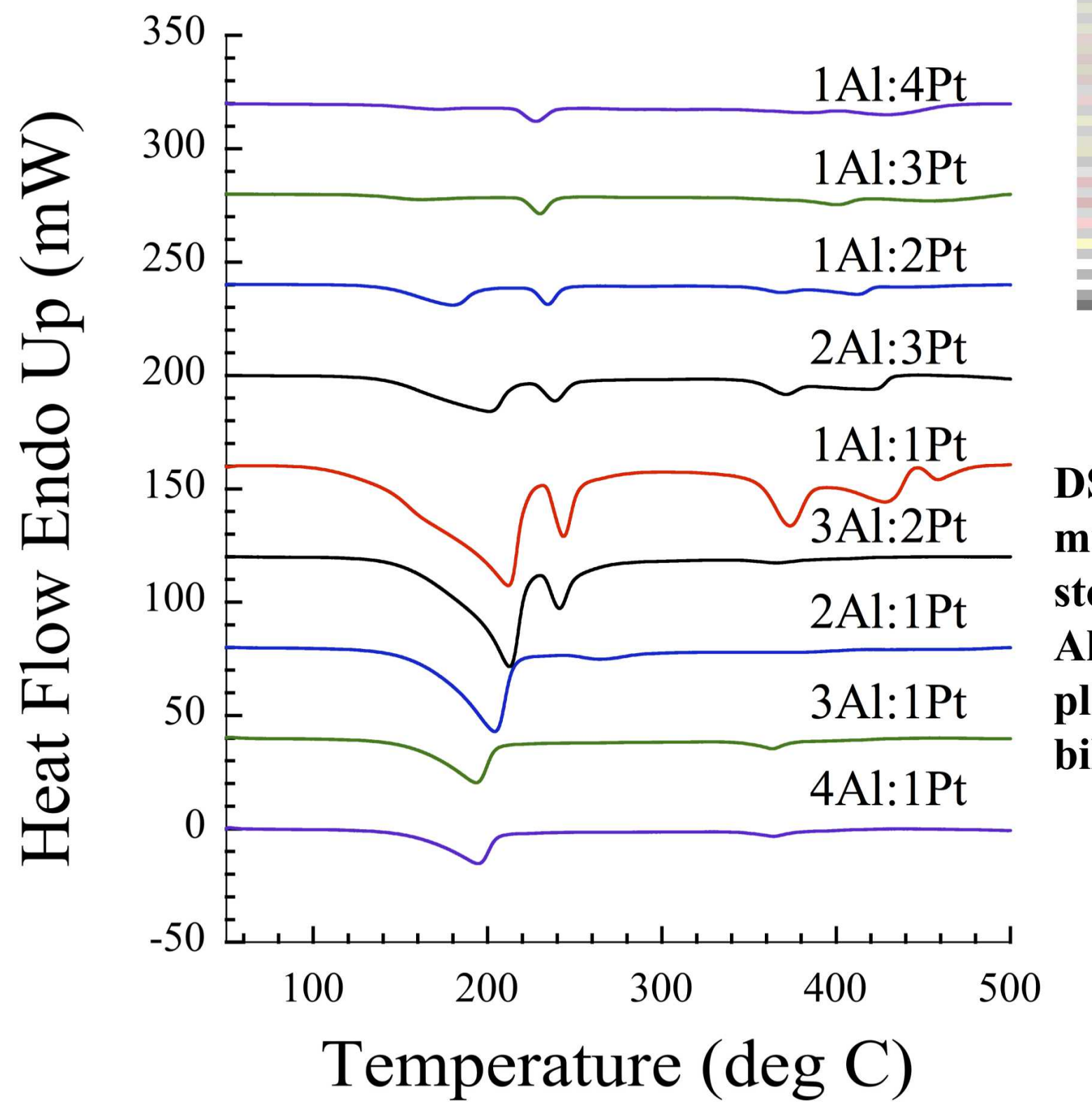
## Reaction Speed as a Function of Composition and Bilayer Thickness

### Composition and Reaction Speed



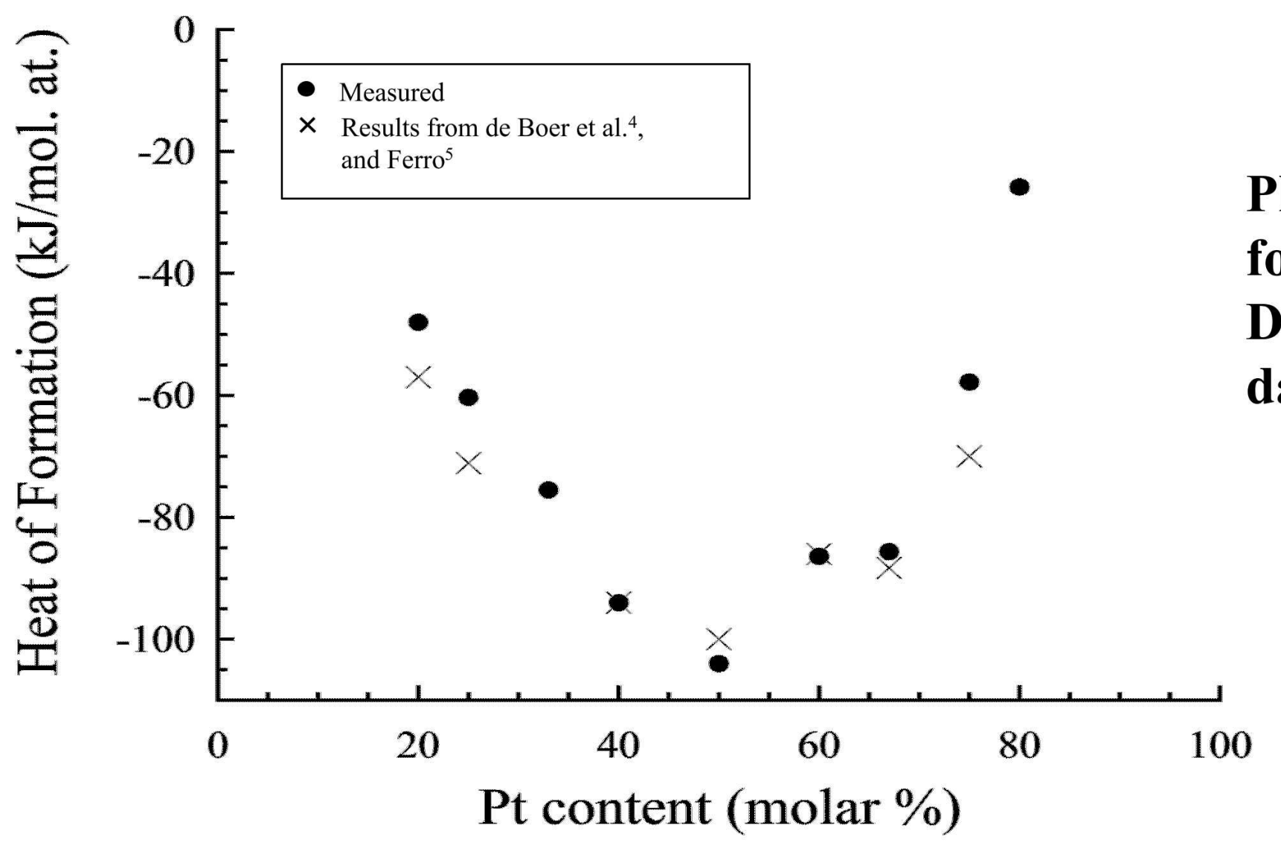
## Differential Scanning Calorimetry of Various Al:Pt Stoichiometry

Samples are measured by differential scanning calorimetry (DSC)
The samples are taken through a heating profile which allows us to observe the heat profile and compare it to known standards and to observe the effects of various compositions



DSC thermograms for Al-Pt multilayers of different stoichiometry are included. All samples described in this plot were made with a bilayer thickness of 61.5 nm.

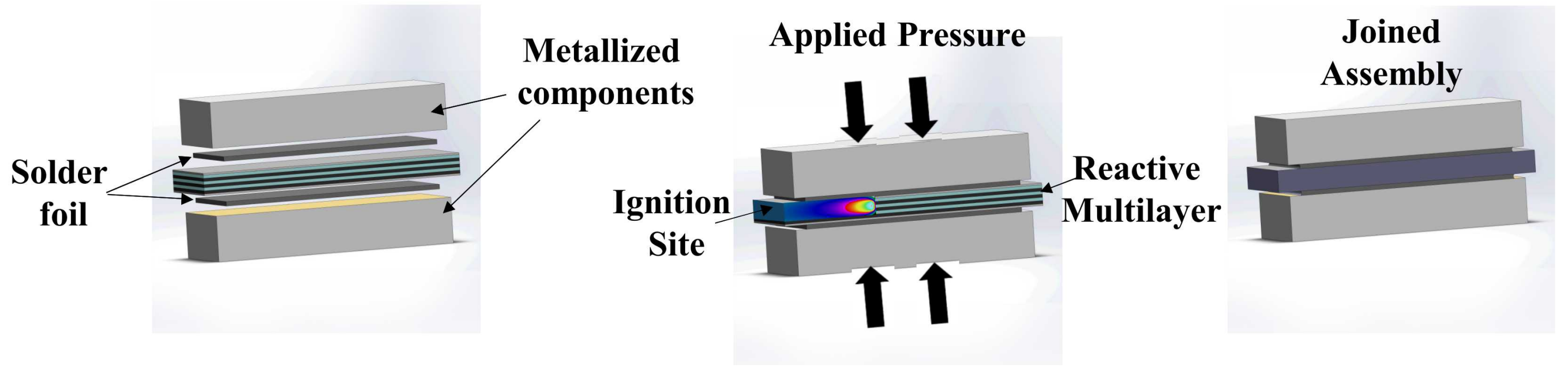
## Heat of Formation



Plot of heat of formation derived from DSC thermograms and data from literature

## Future Work: Joining with Thin Multilayers

J. Braeuer [6] demonstrated successful joining using a micron-thin Al/Pd multilayer and a Sn solder layer.



## References

1. T.P. Weihs, Fabrication and characterization of reactive multilayer films and foils. In Metallic Films for Electronic, Optical and Magnetic Applications: Structure, Processing and Properties (Edited by K. Barmak and K. Koffey; Woodhead Publishing, Cambridge, 2014) 160-243. DOI: 10.1533/9780857096296.1.1.60
2. C. Rossi, K. Zhang, D. Esteve, P. Alphonse, P. Tailhades, C. Vahlas, Nanoenergetic Materials for MEMS: a Review IEEE/ASME J. MEMS 16 (2007) 919-931. http://dx.doi.org/10.1109/JMEMS.2007.893519
3. D.P. Adams, Reactive Multilayers fabricated by vapor deposition: A critical review, Thin Solid Films 576 (2015) 98-128.
4. F.R. De Boer, R. Boom, W.C.M. Mattens, A.R. Miedema, A.K. Niessen, Cohesion in Metals: Transition Metal Alloys, North Holland, Amsterdam, 1988.
5. R. Ferro, R. Cappelli, A. Borsese, G. Centineo, Atti Accad. Naz. Lincei, Classe Sci. Fis. Mat. Nat. 45 (1968) 54-59 (in German).
6. J. Braeuer, J. Besser, E. Tomoscheit, D. Klimm, S. Anbumani, M. Wiemer, T. Gessner, ECS Trans. 50 (2012) 241.

The authors would like thank P. Kotula for TEM and M. Rye for Focused Ion Beam Sectioning. Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. S