# Rapid Cure of Polyimide Coatings for Packaging Applications using Variable Frequency Microwave Irradiation

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Are polyimides more like pizza or popcorn?

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# VFM has been widely studied for cure of polyimides and PBOs

**VFM cure method has been demonstrated to have no harmful effects on any electronic devices or circuitry.**

**Variable Frequency irradiation produces spatial uniformity (no "hot spots") and eliminates arcing associated with single frequency microwave heating**

**VFM has been shown to cure polyimides and PBO's at much lower temperatures than oven or furnace cures**

- Lower thermal budget reduces yield loss in devices
- Lower stress from CTE mismatch

# Does rapid microwave cure give the same results as a slow oven cure?

## Rapid microwave cooking

- Microwave popcorn tastes great
- Microwave pizza is hot, but the outer crust is tough and the middle gets soggy

## How about rapid cure of polyimide?

- Does rapid VFM cure deliver the same key properties as oven/furnace cure?
- Can we define a VFM cure that reproduces the results of a specific oven cure?
- If the results are equivalent, are there cost advantages to rapid VFM cure?

# Phase 1: Compare key properties of PI's with Rapid VFM or Standard Oven Cure

**Selected two polyimides for initial testing**

- Both are used extensively for stress buffer and RDL
- PI-5878G non-photosensitive polyimide
  - Coat & soft-bake
- HD4004 photosensitive polyimide
  - Coat, soft-bake & blanket expose
- Films coated over cured PI-2611 for easy release after cure

**VFM cure in Microcure 3100-2000 single wafer**

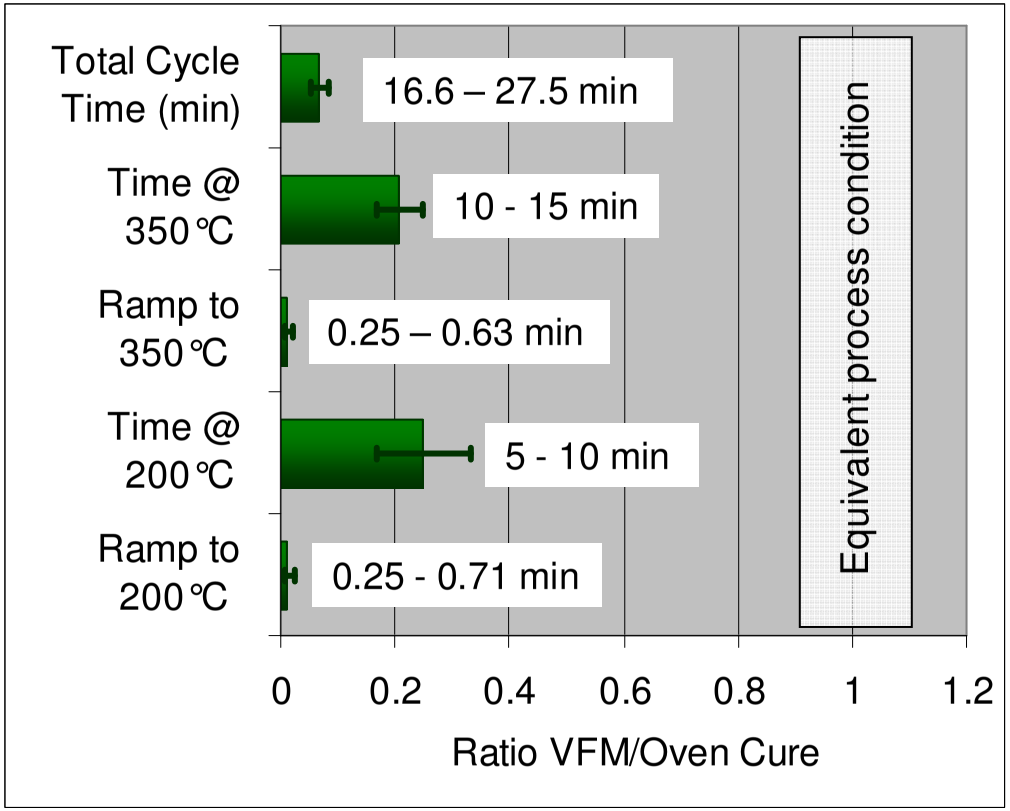
**Oven cure in Koyo CLH-21CD-S Oven**

- 60 min hold @ 350℃
- 5 hr cycle time

# Phase 1: A designed experiment looks at four process variables in VFM cure

**All process times are very far from standard oven cure**

**O2 level kept below 50 ppm**

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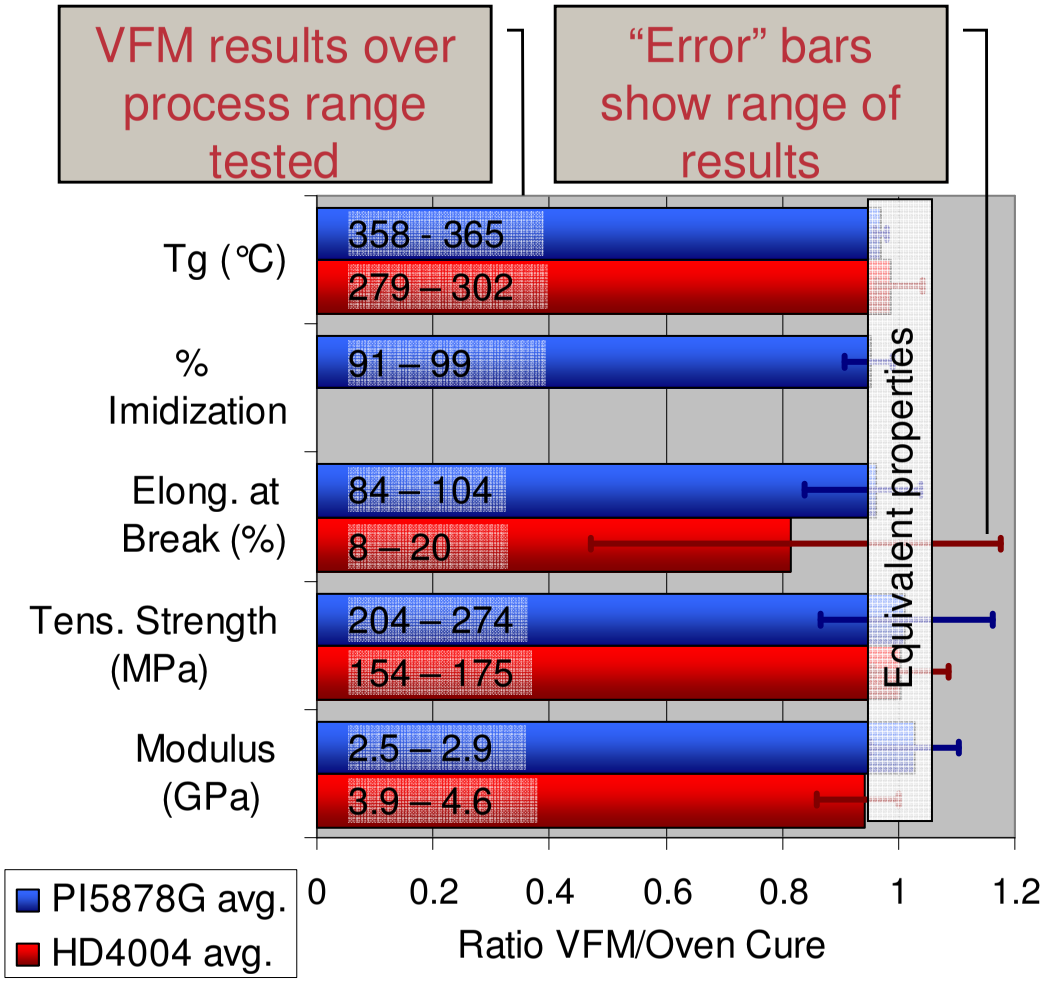
# Phase 1: VFM cure results similar to oven cure

**Both PI5878G and HD-4000 appear well cured by rapid VFM process**

**Properties show small dependence on the VFM process variables tested**

- Spread in elongation results due to experimental method
- Ramp rate to 200℃ has least effect

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# Phase 2: Focus on HD4110 & find VFM cure that replicates oven cure at 350℃

**Factors: three VFM cure process variables**

- Hold @ 200℃, Ramp to 350℃ and Hold at 350℃

**Test more properties**

- Tensile modulus, strength, elongation – photo-imaged tensile strips
- Film stress – wafer bow before and after cure
- Tg – DSC
- Decomposition temperature - TGA
- Adhesion – stud pull testing
- Via shape: height, slope and crowning – SEM, Tencor on 30µm channels
- Chemical resistance (CR) – % dimension change after exposure
  - CR1 - NMP, RT 30 min
  - CR2 - 10% H2SO4, 3 hr, RT
  - CR3 - NH4OH/H2O2/H2O 1:1:5 80℃, 30 min
  - CR4 - TMAH/H2O/DMSO 1/3/96 80℃, 30 min

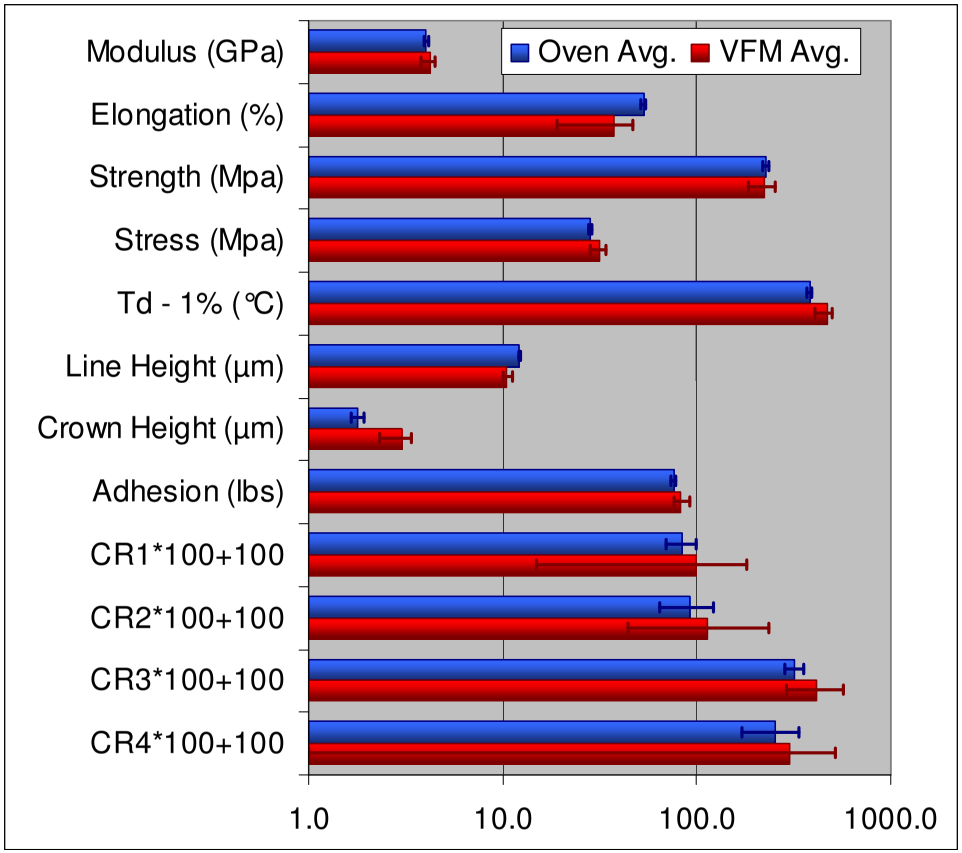
# Phase 2: VFM cure at 350°C meets or exceeds oven cure

**Range of results for VFM cure overlaps oven cure for most properties**

**Responses are significantly different for:**

- Decomposition temperature
- Thickness
- Crowning

**Differences are consistent with higher cure by VFM**




Note: "Error" bars for Oven cure results show standard deviation in data. "Error" bars for VFM cure show range of responses

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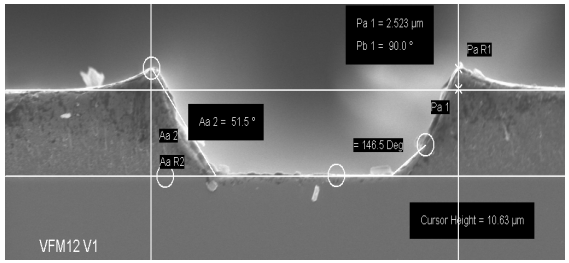
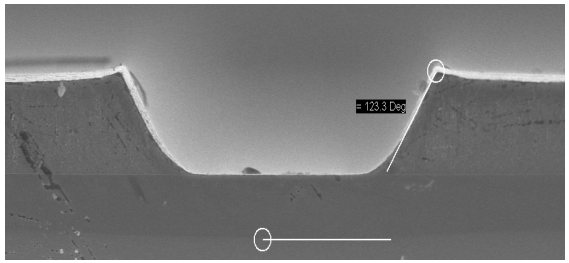
# Crowning and film thickness are sensitive to cure

| | VFM cure – 7 min 350°C | Oven cure - 60 min 350°C |
|---|---|---|
| |  |  |
| Line Thickness (µm) | 10.2 | 12.2 |
| Crown Height (µm) | 3.0 | 1.8 |
| Via Slope (°) | 128 | 123 |



**Oven cured sample was re-baked at 400°C:**

- Line thickness reduced to 10.7 µm
- Crown height increased to 2.4 µm

**Conclude: Difference in line thickness & crown height reflects higher cure level in VFM cured samples**

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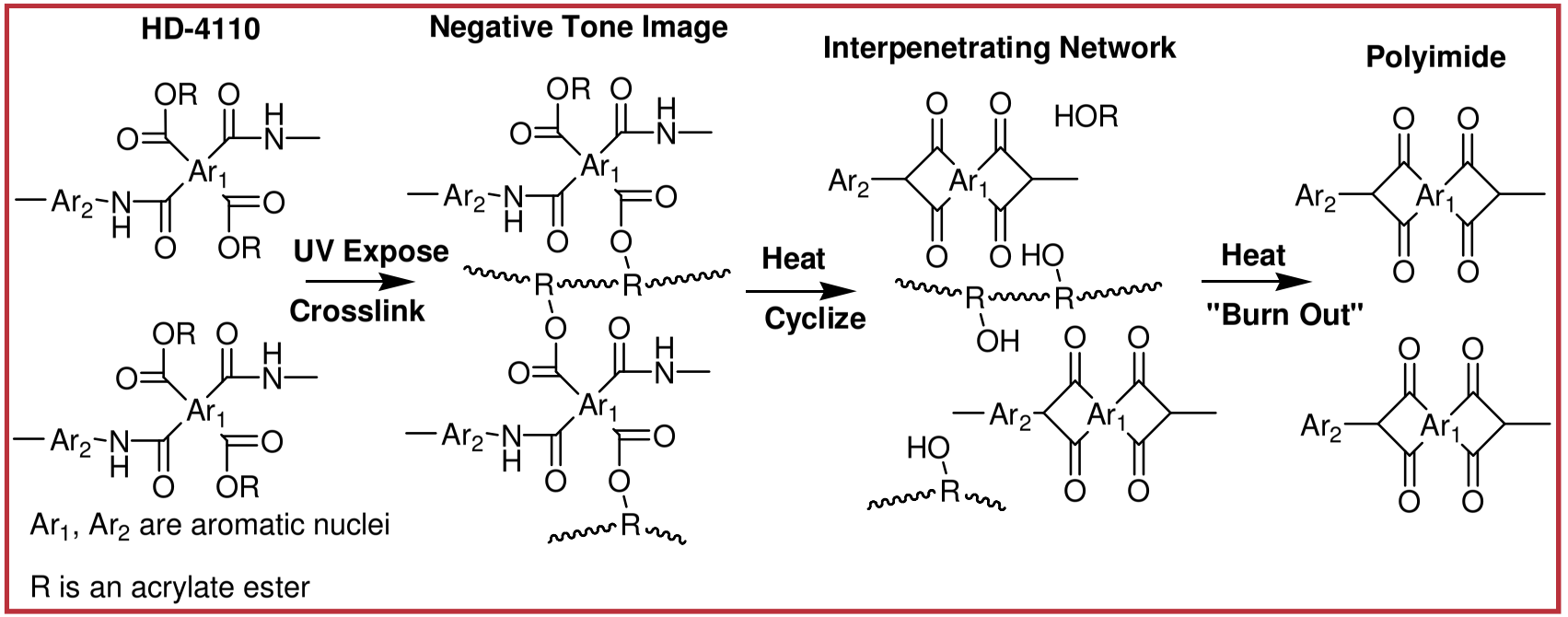
# Cure of HD4110 involves cyclization and “photopackage” burnout

## HD4110 process chemistry

- Photo-exposure yields crosslinked network
- Imidization forms linear polyimide, burn-out removes crosslinker

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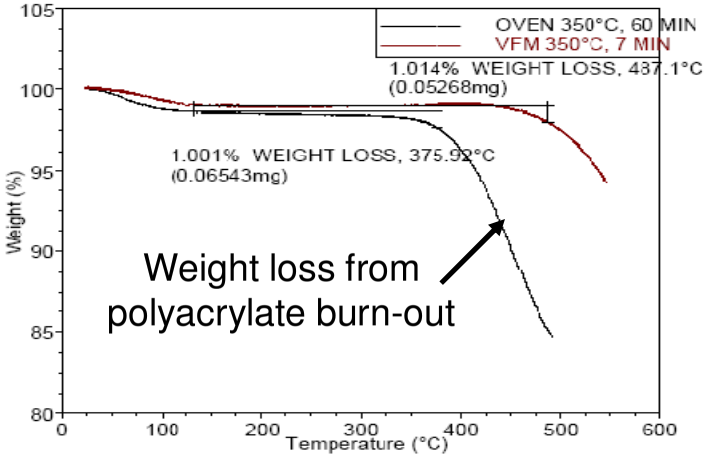
# 350℃ cure: oven cure leaves residual IPN, VFM cure does not

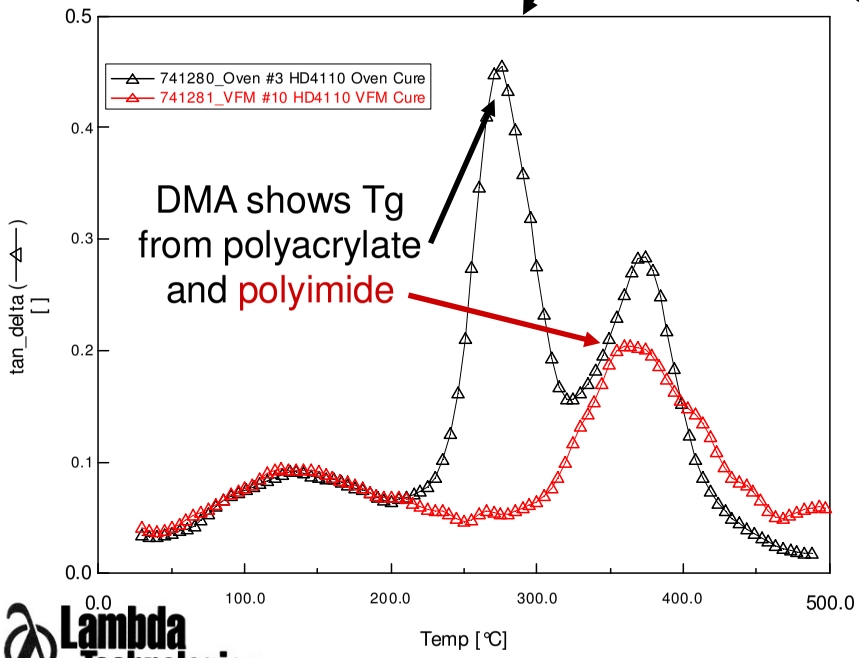
## Residual polyacrylate indicated by

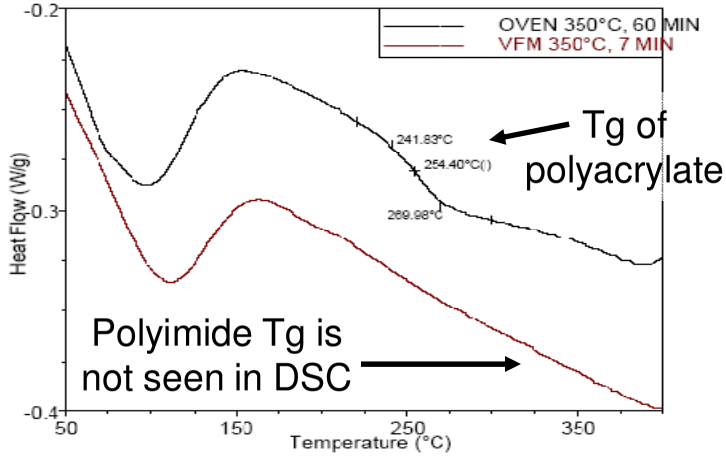
TGA

DMA

DSC

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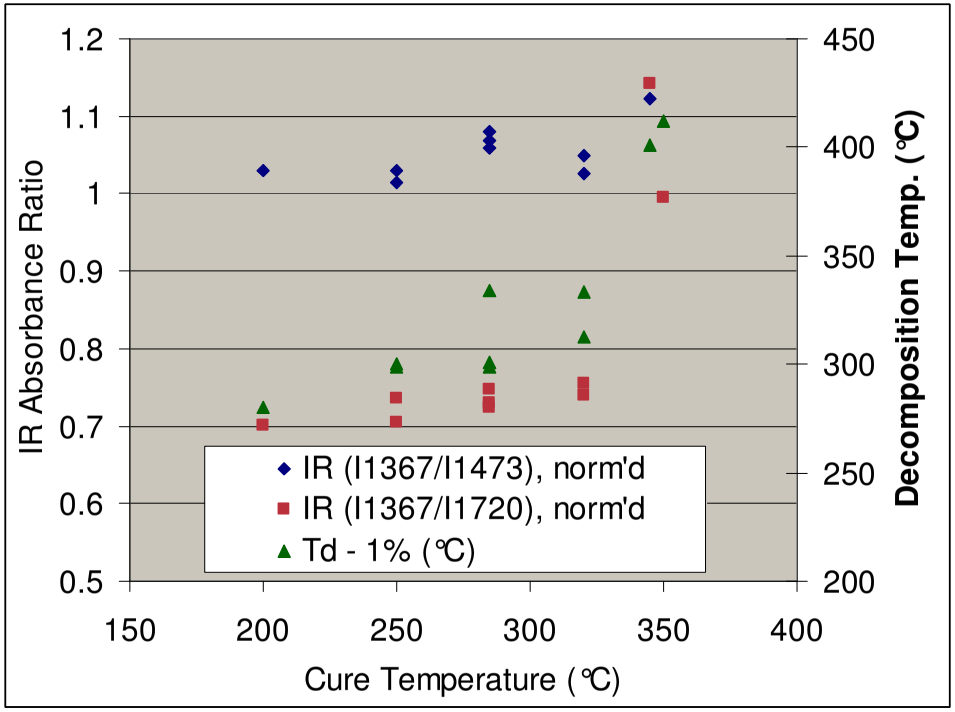
# IR method to monitor “cure” in HD4110

## TGA is a sensitive monitor of cure in HD4110

- Use Td-1%, Td-5% or weight loss at 400℃
- But TGA is a destructive test

## IR method commonly used for polyimide cure

- $I_{1367}/I_{1473}$ monitors imide content
- $I_{1720}$ monitors total C=O content, reduced by acrylate burn-out




## $I_{1367}/I_{1720}$ correlates with TGA result, captures both imide formation and burn-out

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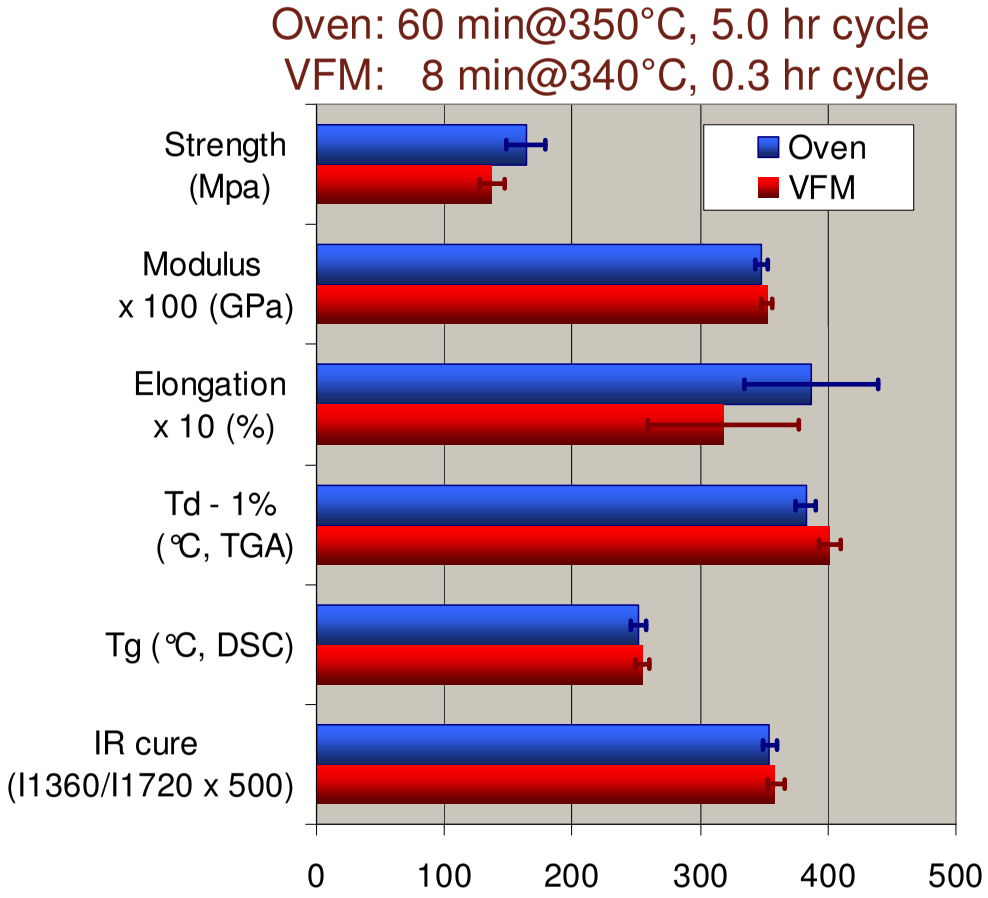
# VFM cure of HD4110 at 340°C close to oven cure at 350°C

## Mechanical and thermal properties very similar

- Results averaged for 8 VFM cured films, 9 oven cured films
- Comparable standard deviations found

**Conclude: VFM process capable of same cure as oven with 94% reduction in cycle time**

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# VFM shown to lower manufacturing and energy costs

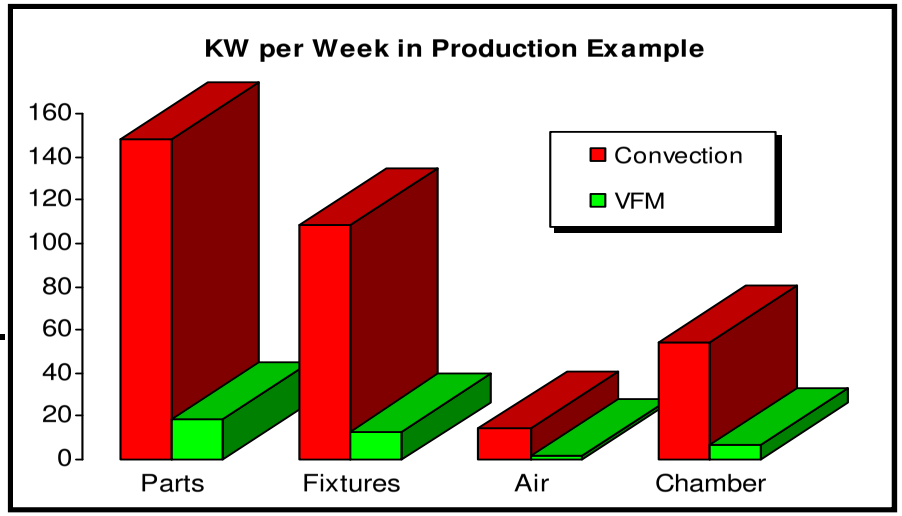
## Time reduction

- Cycle time reduced from >4 hrs to <20 minutes
- Major benefit for process development or mixed lot production
- Prototype batch VFM (300 mm wafers) shows excellent uniformity

## Energy reduction

- Energy transferred efficiently to the wafers – no energy wasted heating the oven
- No energy required to cool the oven after cure

Example of energy savings in a non-IC application

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# Conclusions

**Does rapid VFM cure deliver the same key properties as oven/furnace cure?**

Yes, and at a somewhat lower temperature.

**Can we define a VFM cure that reproduces the results of a specific oven cure?**

Yes – Defined key tests to monitor cure: TGA, IR method ($I_{1630}/I_{1720}$)

- Temperature is most significant VFM process variable. Ramp rates and hold times appear to have small impact on final properties.

**Are there cost advantages to rapid VFM cure?**

$ Significant cycle time reduction is demonstrated

- Need to demonstrate energy cost reductions for cure of 300 mm wafers

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# Acknowledgments

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