

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

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Are polyimides
more like
pizza or popcorn?



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

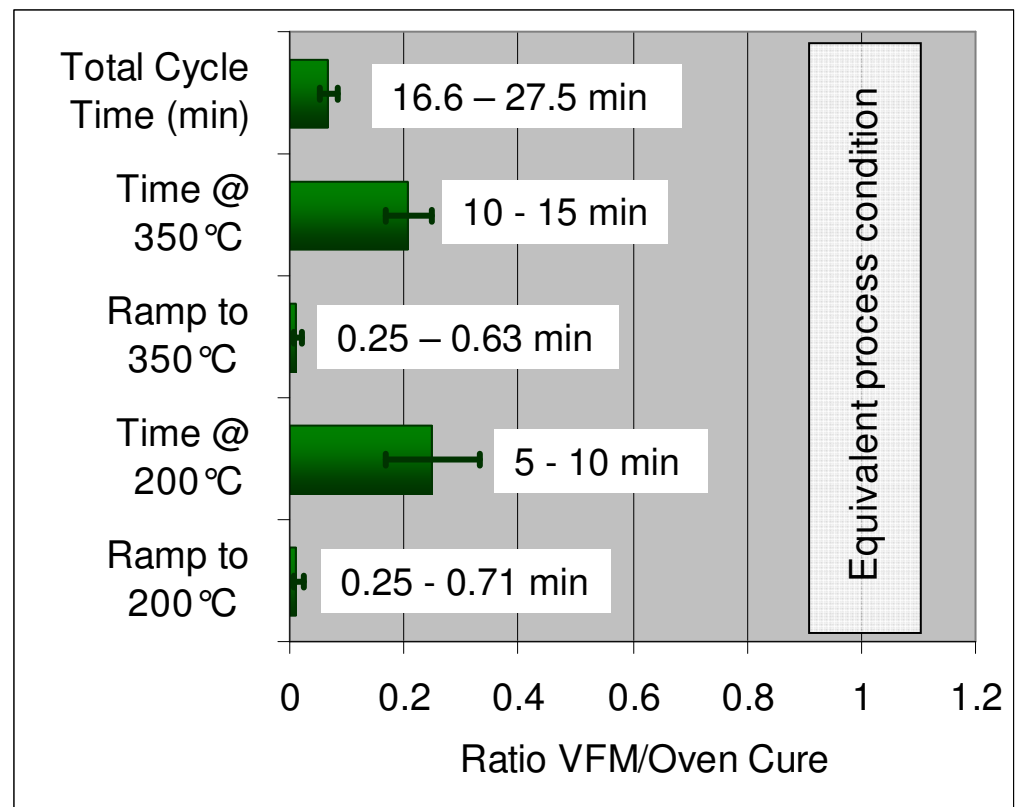
Oven cure in Koyo CLH-21CD-S Oven

- 60 min hold @ 350°C
- 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

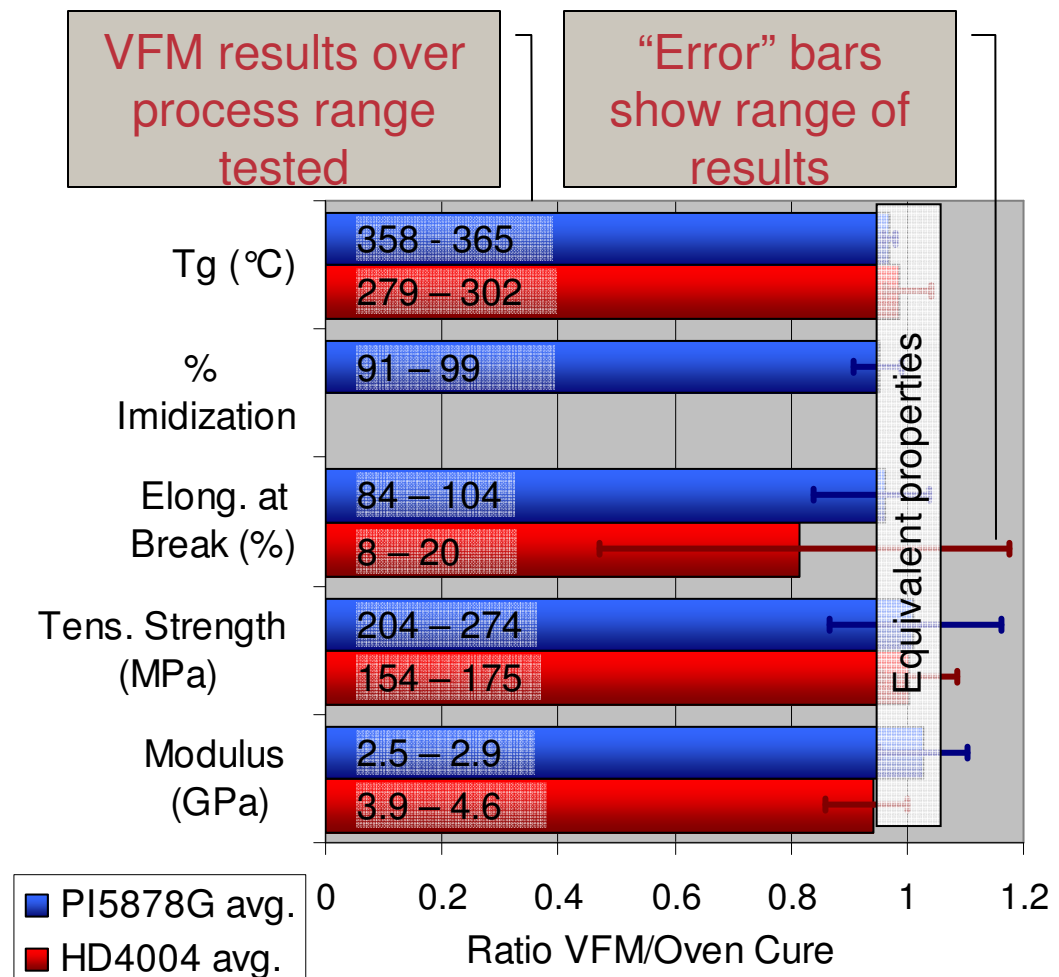


Phase 1: VFM cure results similar to oven cure

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°C has least effect



Phase 2: Focus on HD4110 & find VFM cure that replicates oven cure at 350 °C

Factors: three VFM cure process variables

- Hold @ 200 °C, Ramp to 350 °C and Hold at 350 °C

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 °C, 30 min
 - CR4 - TMAH/H₂O/DMSO 1/3/96 80 °C, 30 min

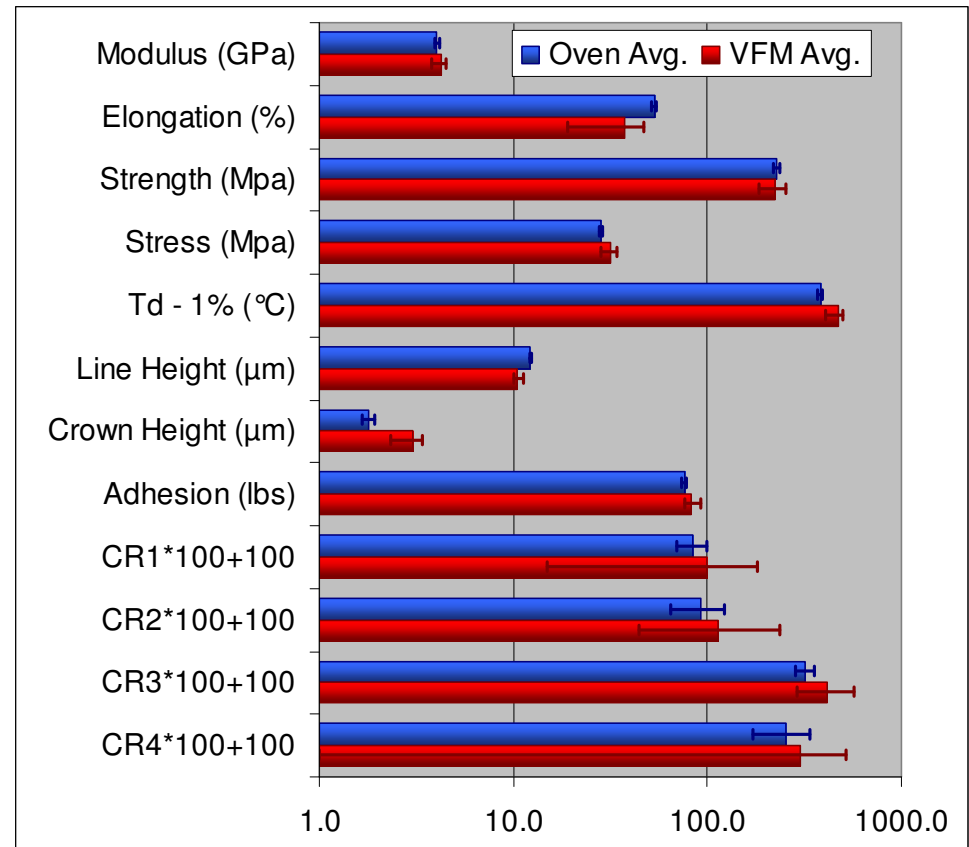
Phase 2: VFM cure at 350 °C meets or exceeds oven cure

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

Responses are significantly different for:

- Decomposition temperature
- Thickness
- Crowning

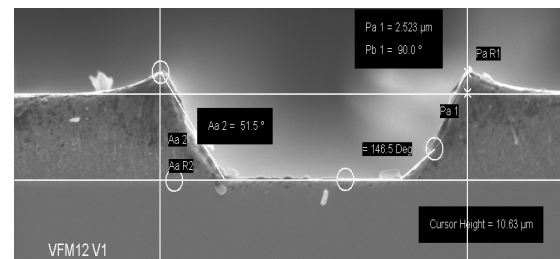
Differences are consistent with higher cure by VFM



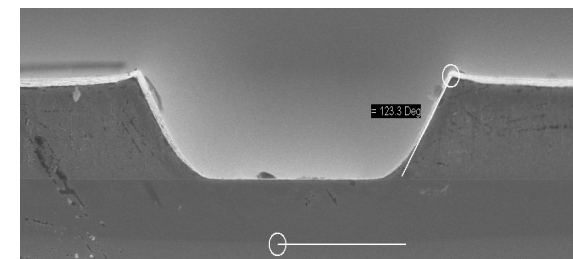
Note: "Error" bars for Oven cure results show standard deviation in data. "Error" bars for VFM cure show range of responses

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:

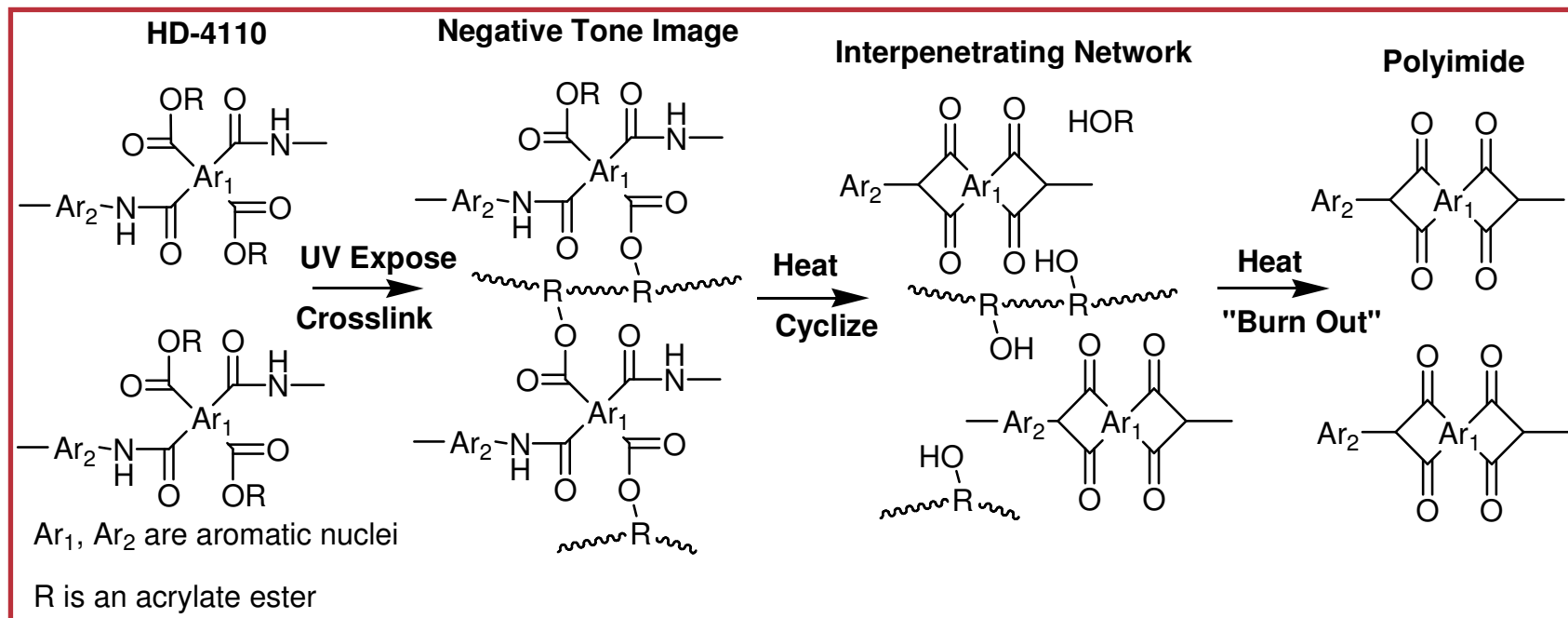
- Line thickness reduced to 10.7 µm
- Crown height increased to 2.4 µm

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

Cure of HD4110 involves cyclization and “photopackage” burnout

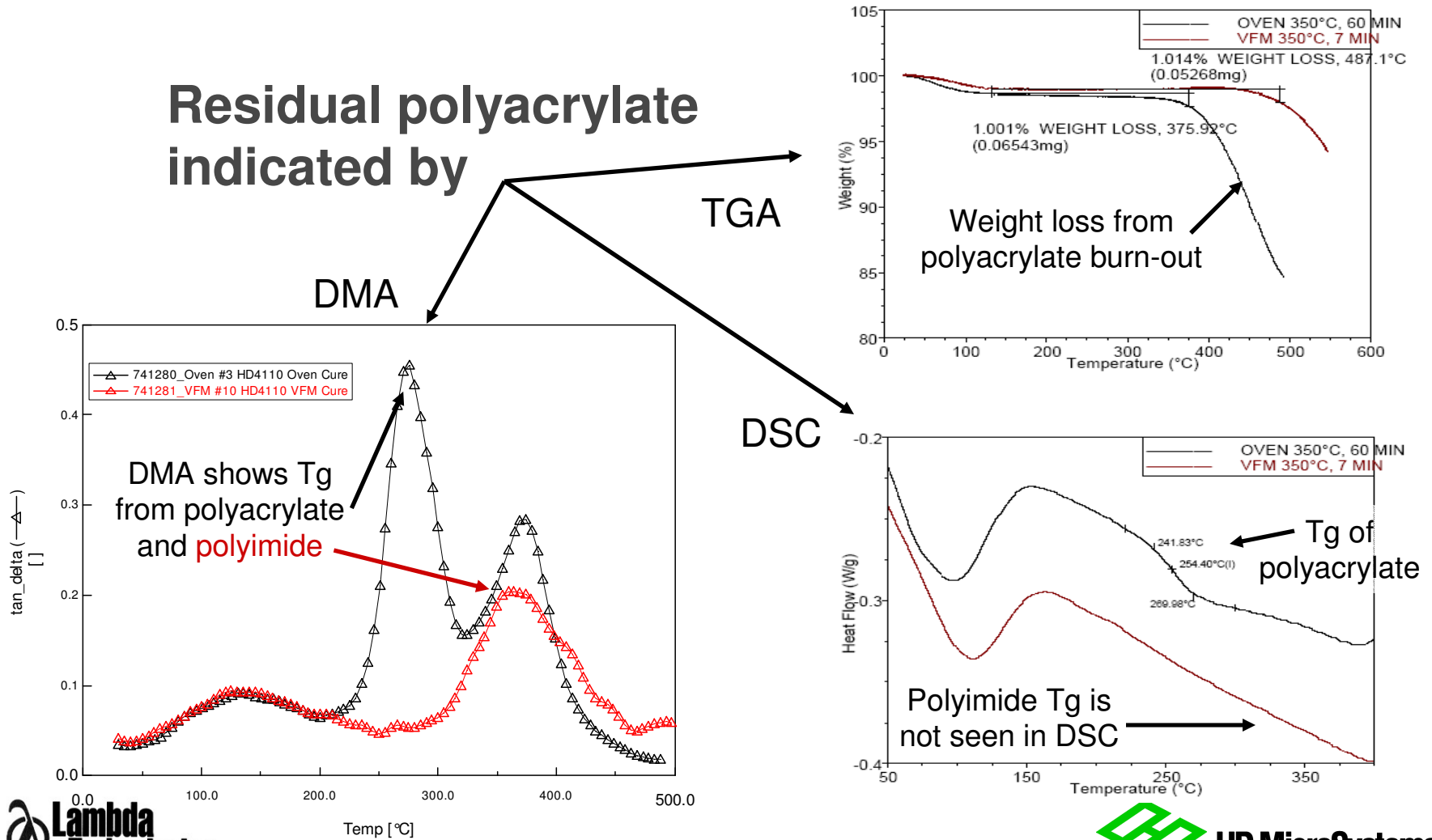
HD4110 process chemistry

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



350 °C cure: oven cure leaves residual IPN, VFM cure does not

Residual polyacrylate indicated by



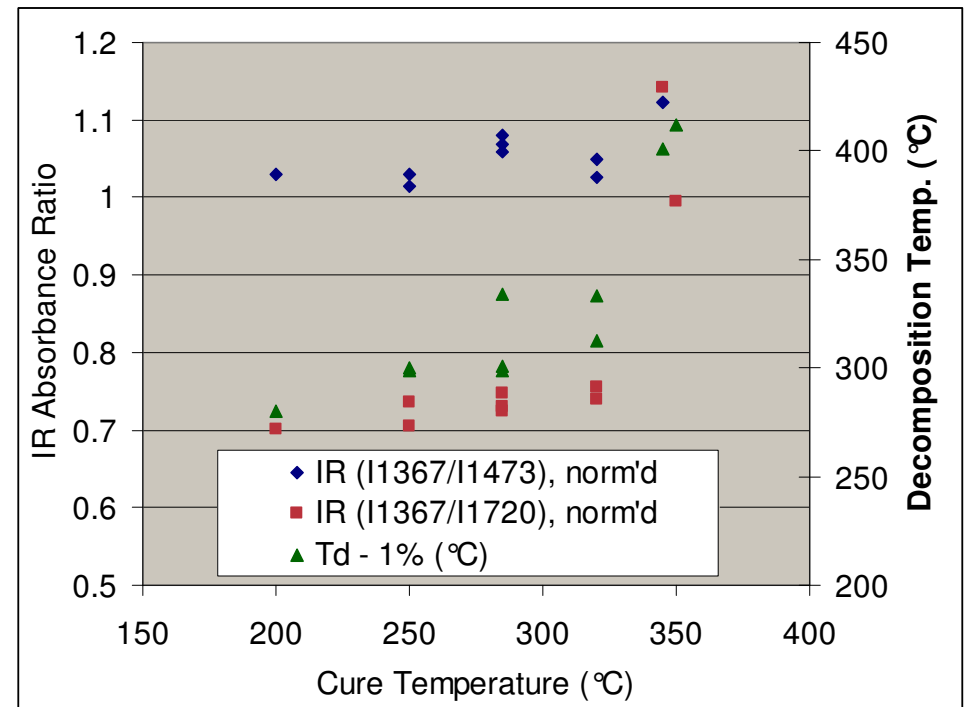
IR method to monitor “cure” in HD4110

TGA is a sensitive monitor of cure in HD4110

- Use Td-1%, Td-5% or weight loss at 400 °C
- 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

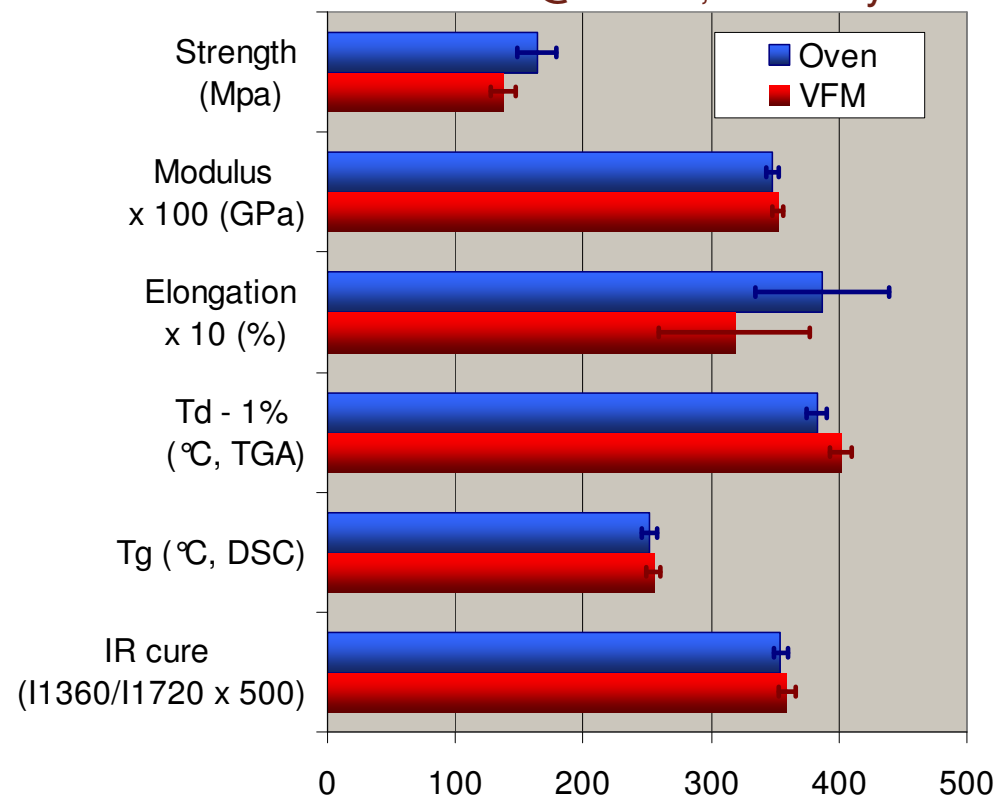
VFM cure of HD4110 at 340°C close to oven cure at 350°C

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

Oven: 60 min@350°C, 5.0 hr cycle
VFM: 8 min@340°C, 0.3 hr cycle



VFM shown to lower manufacturing and energy costs

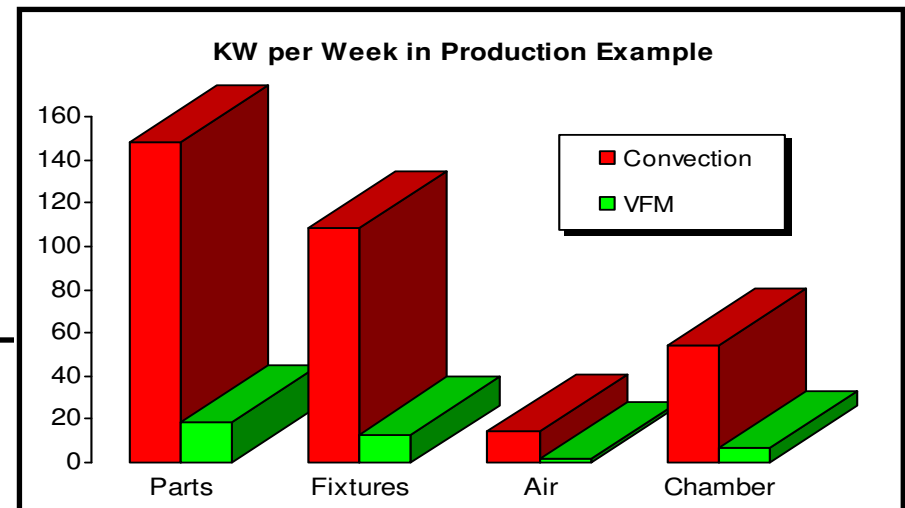
Time reduction

- 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



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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