Infrared Blocking of Ultrathin Aluminum Films on Freestanding Polyimide Substrates

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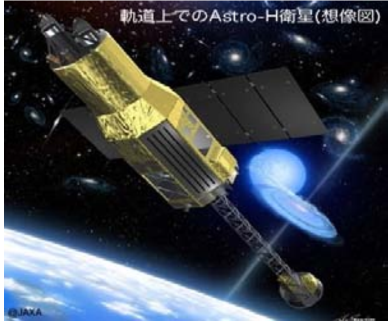
Aluminum /Polyimide Advantages

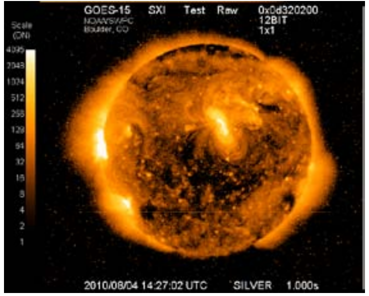
Polyimide (<200nm)/Aluminum (<100nm):

-Good Soft X-ray transparency
-Good mechanical durability
-Atomic oxygen resistance
-Vis-IR-LWIR blocking

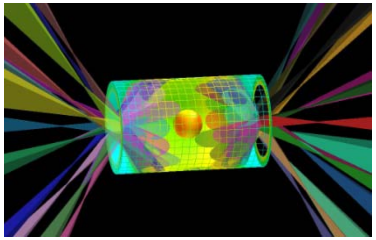
Microcalorimetry/Astronomy



Contamination Blocking Filters



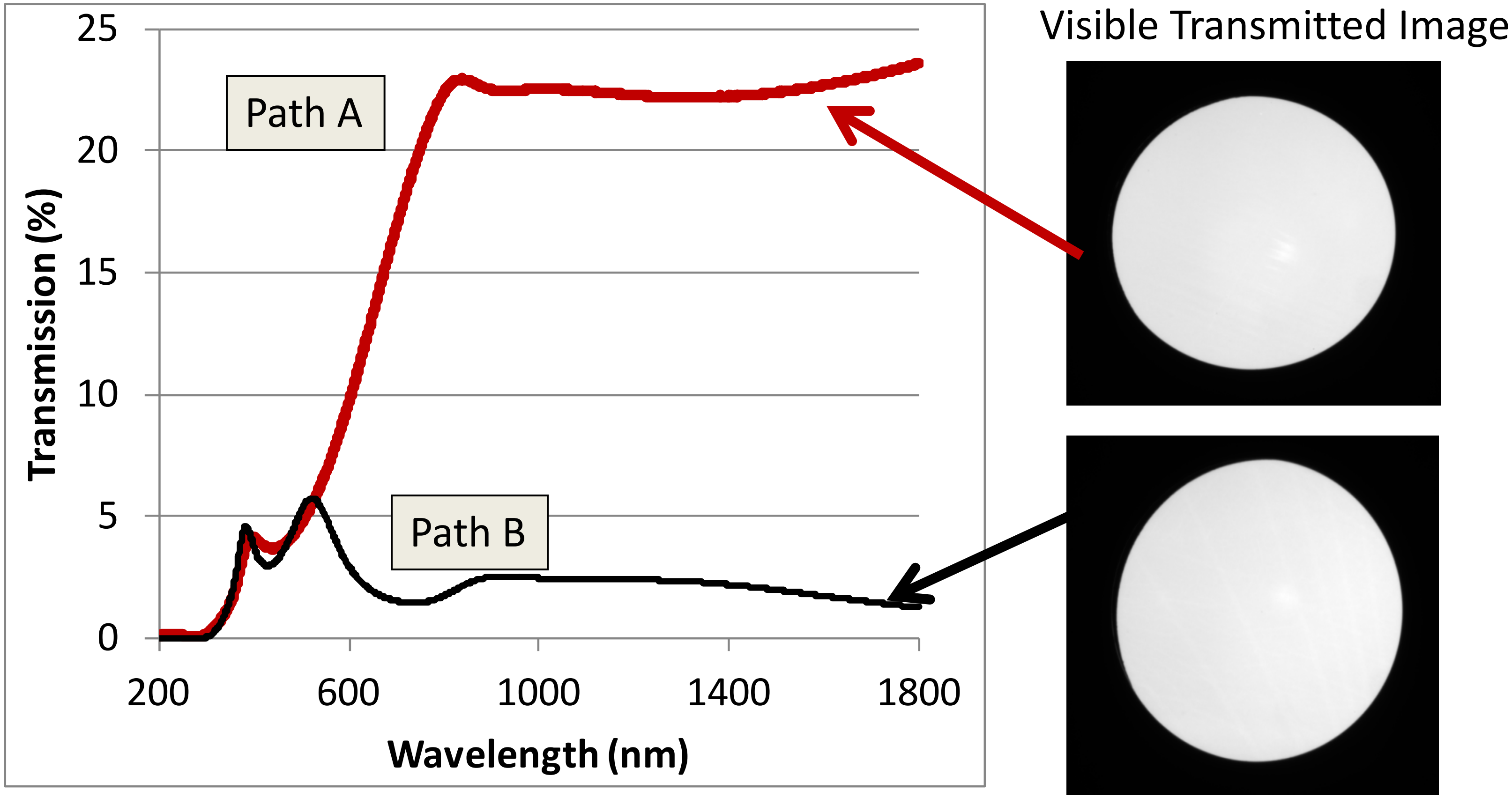
Future NIF Windows?



For these ultrathin films, it was noticed that UV-Vis-IR transmission could vary greatly depending on filter constraints

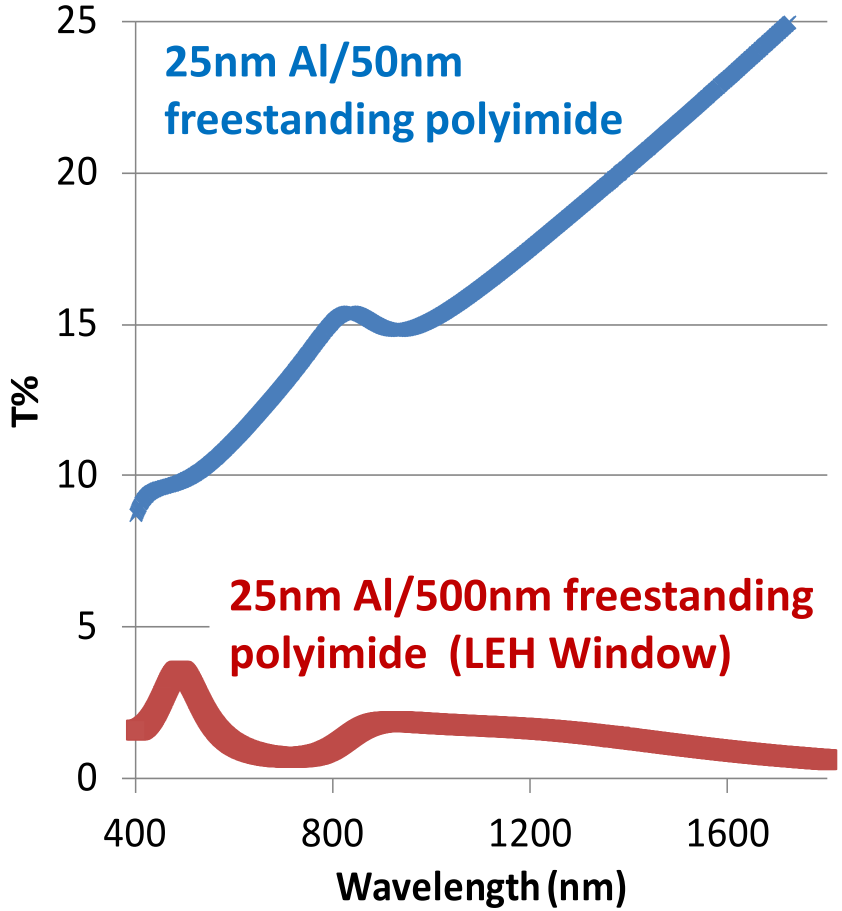
- **-Filter film tension**
- **-Filter Size**
- **-Coating method (E-beam, thermal, sputtering)**

Transmission of Two 25nm Al/200nm Polyimide Filters



- Infrared transmission depends on coating parameters
- IR transmission varies greatly, visible transmission largely unaffected
- Different IR transmission not detectable from visible spectra or images

Aluminum Optical Density Depends on Processing Parameters



Parameters:
-Sputter, e-beam, or thermal
-Rate
-Vacuum impurities
-etc. etc.

Luxel has a well-developed LEH window process with 25nm Al and 500nm polyimide

Perform DOE Screening to isolate variables and responses

Experimental Runs on 200nm thick polyimide

-Various coating methods, cleaning methods

Cleaning	**No clean**	Air Plasma	IB Clean	ArH Plasma	Air Plasma	No clean	No Clean	No Clean
Rate A/sec)	**10**	10	10	10	10	10	10	10
On/Off Substrate	**On Substrate**	Off Substrate Top	On Substrate	On Substrate	On Substrate	On Substrate	Off Substrate Bottom	Off Substrate Top
Crucible	**None**	None	None	None	None	None	None	None
Clean	**None**	1 min air	IB 5 min	ArH 20min	air 20min	None	None	None
Base Pressure	**3.00E-06**	5.00E-07	5.00E-07	5.00E-07	5.00E-07	3.00E-06	1.50E-06	1.50E-06
Method	**System 5 Ebeam**	System 6 Ebeam	System 5 Ebeam	System 6 Ebeam	System 6 Ebeam	System 6 Ebeam	System 5 Ebeam	System 5 Ebeam
Post Treat in situ	**None**	None	None	None	None	None	None	None
T1800 %	**1.57**	**20.75**	**1.85**	**1.26**	**1.81**	**1.4**	**13.4**	**16.65**
T450-650 %	**3.79**	**6.48**	**4.41**	**3.98**	**5.78**	**3.36**	**6.7**	**6.7**

-Visible Transmission (450-650nm) varies little.

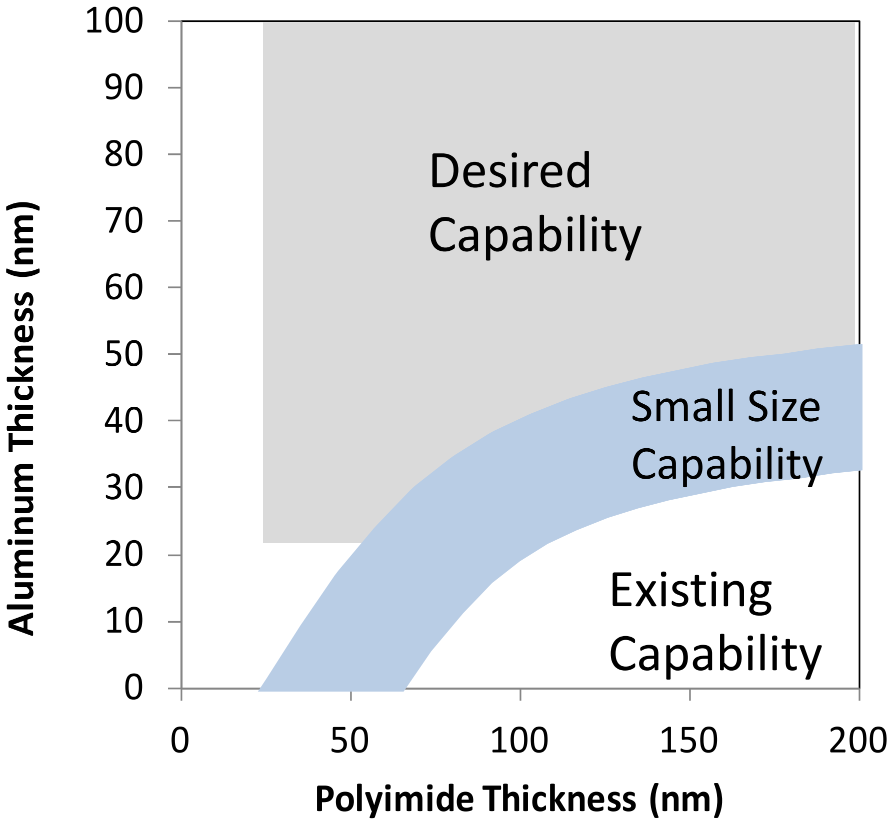
-Infrared transmission (e.g. 1800nm) varies greatly

Change in IR Optical Density for Selected Process Changes 25nm Al/200nm polyimide

Condition:	Optical Density Change (1800nm)
Off vs On Substrate System 6 Ebeam Evap	-1.17
Off vs On Substrate Thermal Evap	-0.92
Off vs On Substrate System 5 Ebeam Evap	-0.89
High Dose Air Plasma vs No Plasma Clean	-0.08
Low Dose Air Plasma vs No Plasma Clean	-0.03
Low Dose ArH plasma vs No Plasma Clean	0.02
Ion Beam Clean vs. No Clean	0.03
System 6 vs System 5	0.04
High Dose ArH plasma vs. No Plasma Clean	0.05
Front vs back side coating	0.05

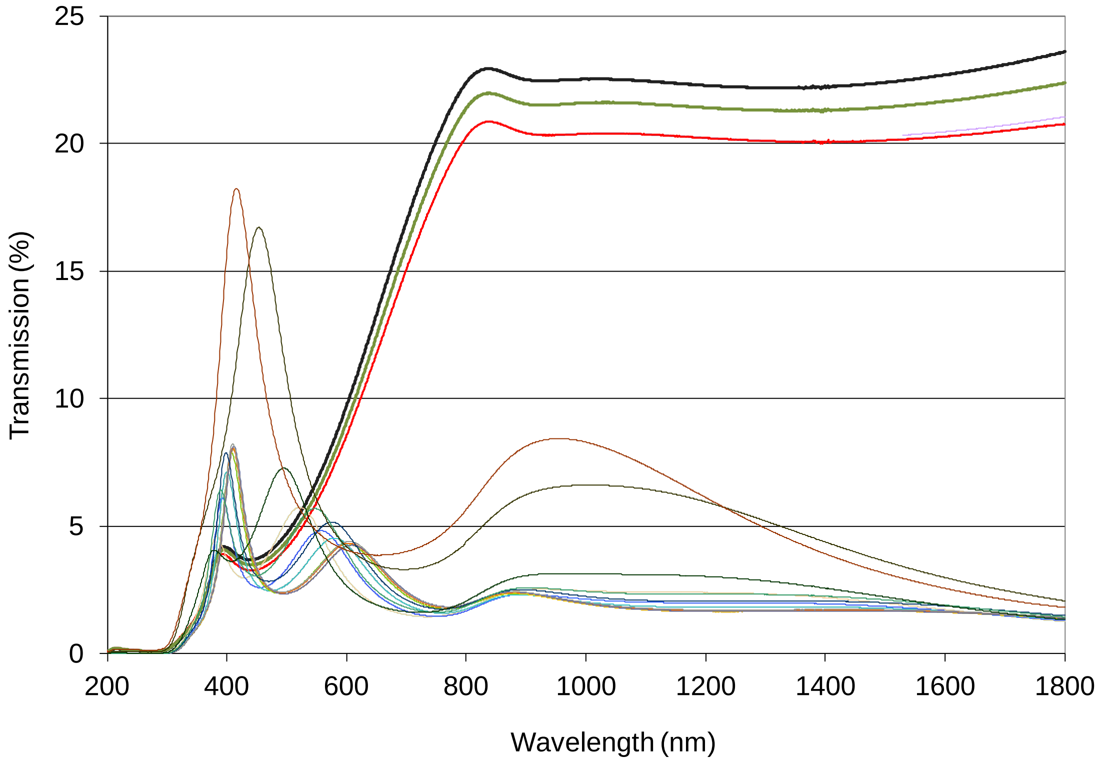
-Coating on freestanding films results in lower infrared optical density
-Plasma cleaning prior to aluminization might be mildly beneficial

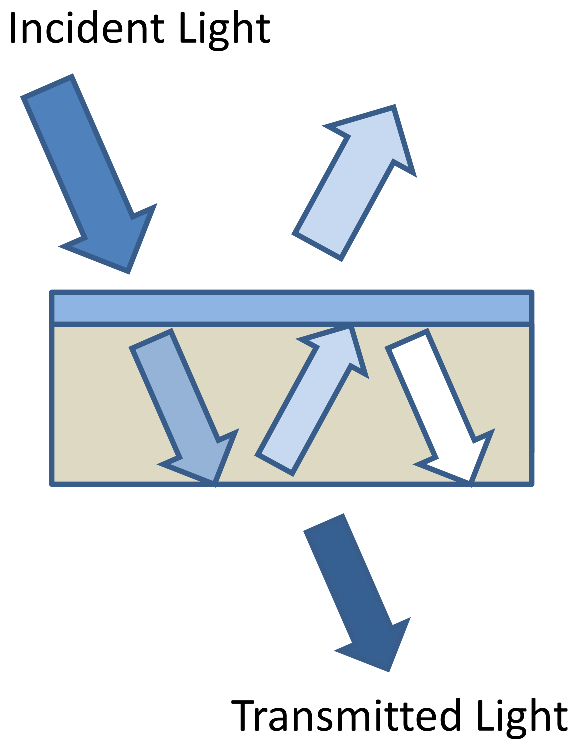
Desired thicknesses for IR-dense aluminum on polyimide



Goal: Produce IR-blocking aluminum on <200nm thick polyimide in large (~100mm) areas

Transmission of 25nm Al on 100-200nm Thick Polyimide

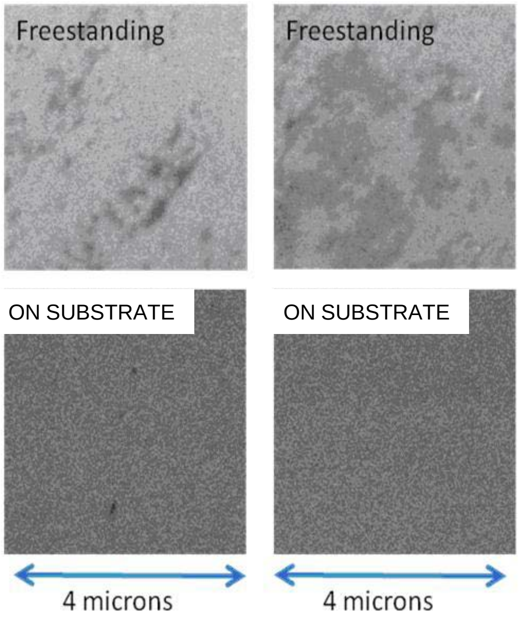




-Aluminum is Optically Coupled to the Polyimide Film

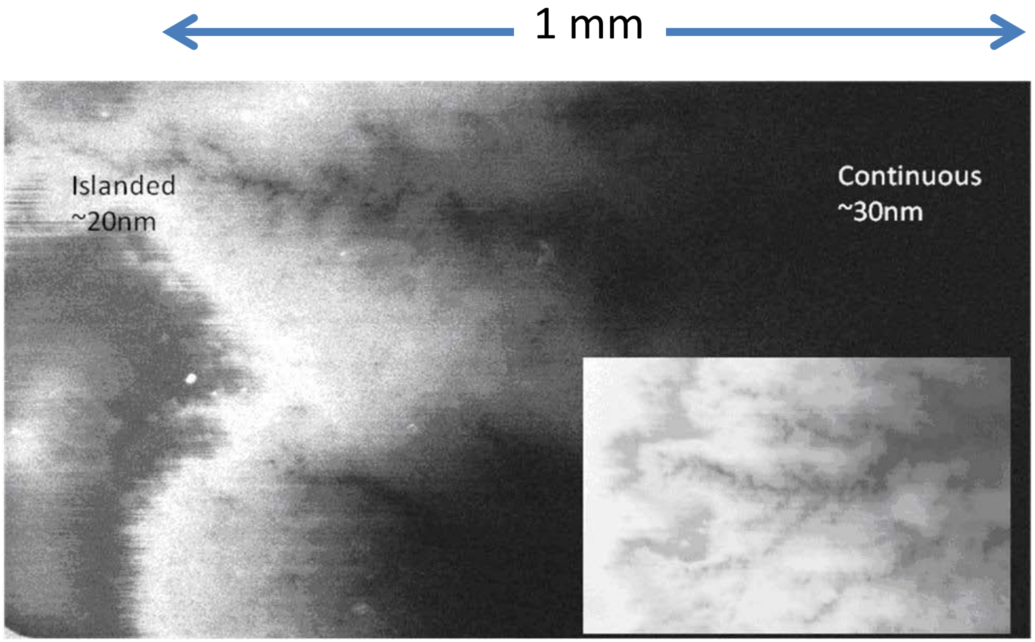
How to separate Intrinsic IR density of Aluminum from Substrate Interference?
Does the microstructure change for the different aluminum processes?

SEM Images of Aluminum on Polyimide



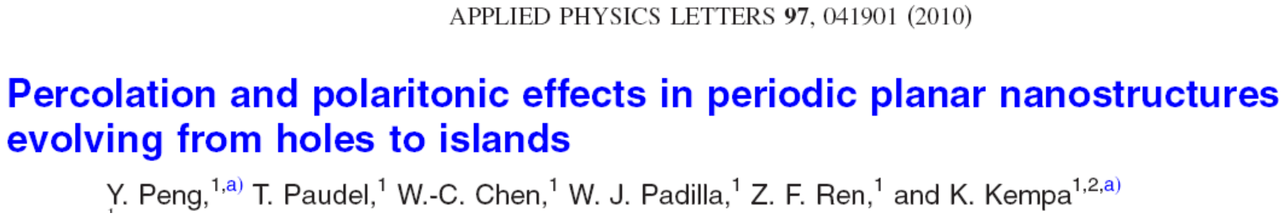
Top: Al deposited onto 200 nm freestanding polyimide.

Bottom: Al deposited onto 200 nm polyimide while still on the imidization substrate.



-Dark dendrites appear along the ground path.

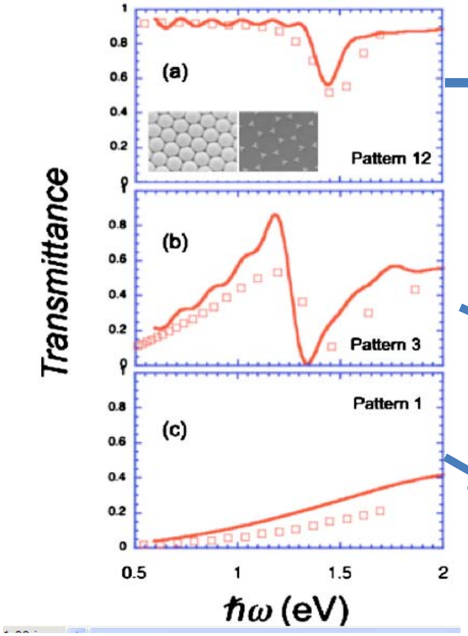
Optical Model for Discontinuous Aluminum Transmission



APPLIED PHYSICS LETTERS **97**, 041901 (2010)

Percolation and polaritonic effects in periodic planar nanostructures evolving from holes to islands

Y. Peng,[1,a)] T. Paudel,[1] W.-C. Chen,[1] W. J. Padilla,[1] Z. F. Ren,[1] and K. Kempa[1,2,a)]

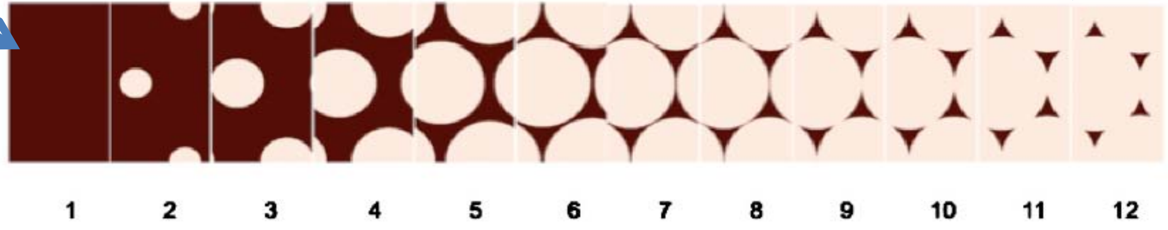


Islands

$$\varepsilon(\omega)=\varepsilon_b+\frac{\omega_{p1}^2}{\omega_1^2-\omega(\omega+i\gamma_l)}$$

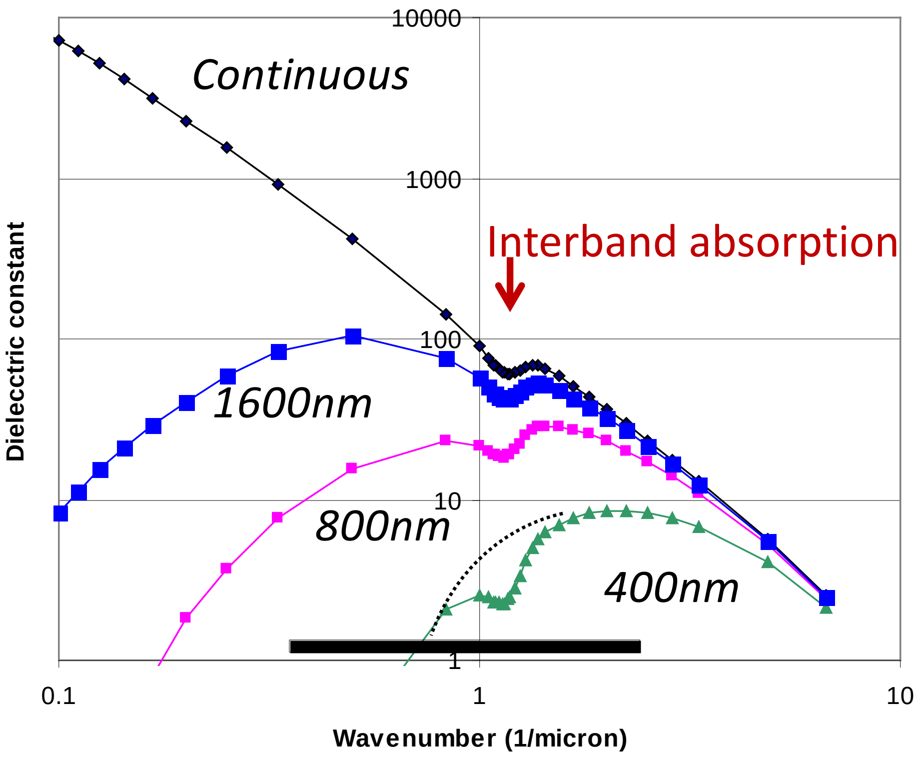
Holes (=continuous film+ “-islands”)

$$\varepsilon(\omega)=\varepsilon_b-\frac{\omega_{p0}^2}{\omega(\omega+i\gamma_l)}+\frac{\omega_{p2}^2}{\omega_2^2-\omega(\omega+i\gamma_l)}$$



- Complication: ε_b changes with island geometry (ignored)
- OK to use effective dielectric constant if scattering vector is small

Optical Model for Discontinuous Aluminum Transmission

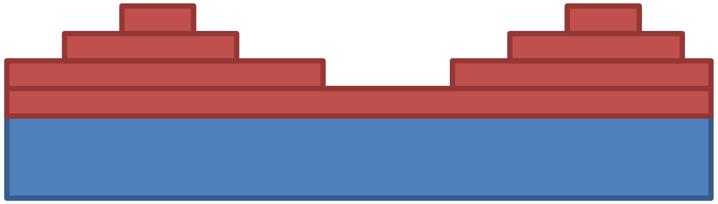


Assume 5 optical layers:

- Polyimide
- Continuous Al layer (Palik)
- Al with $\lambda_{Lorentz}$=1600nm
  - =800nm
  - =400nm

Island size:

D~$\lambda_{Lorentz}$*geometry factor



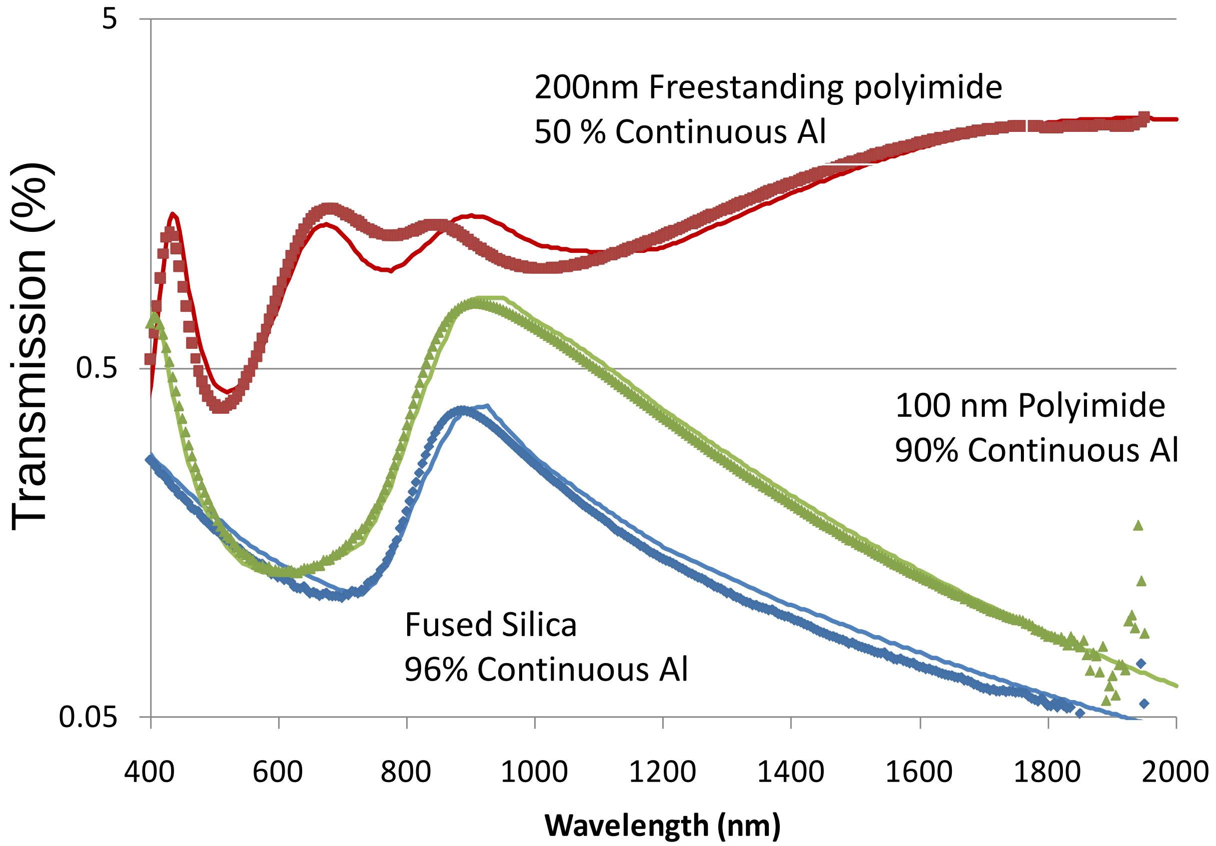
-Lorentz layers defined as Mie scattering function convolved with Bulk Aluminum*

-Define Parameter “%Continuous” = Thickness bulk Al/Total modeled Al thickness

*E. Palik, “Handbook of Optical Constants of Solids”, Academic Press, 1998

-Interband absorption at 800nm shifts and disappears for islanded Al (neglected)

Optical Model Fits for 40nm Aluminum Transmission

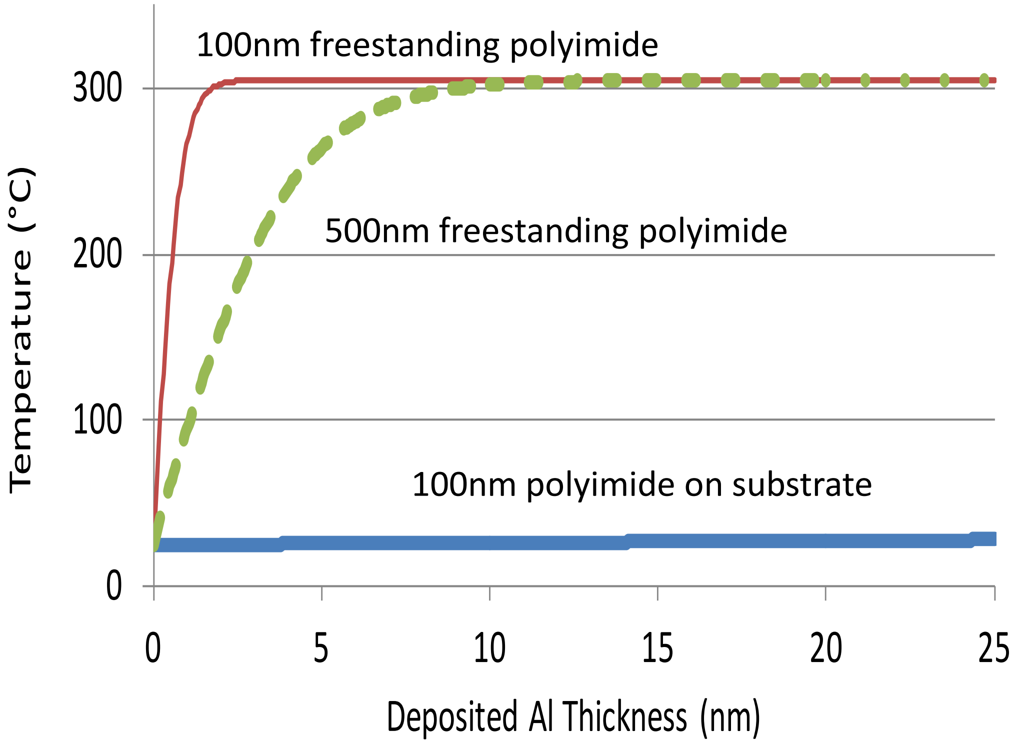


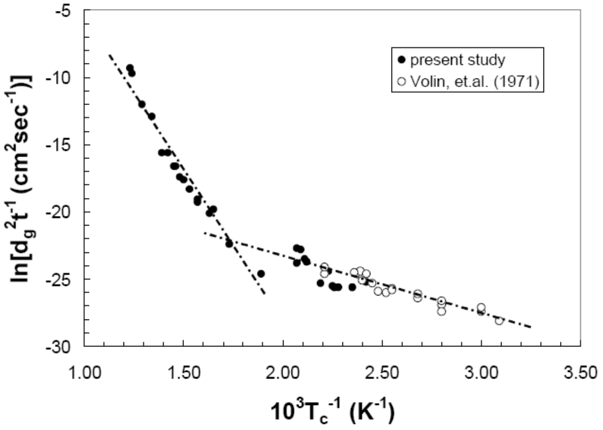
-Model describes infrared transmission increases well

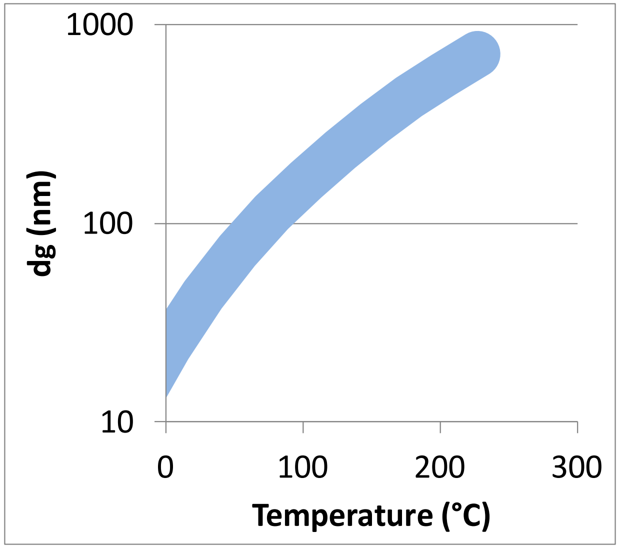
-Loss of interband absorption peak for islanded Al is not captured by the model

-IR transmission increase is due to film discontinuity

Substrate Temperature Increase During Al Deposition





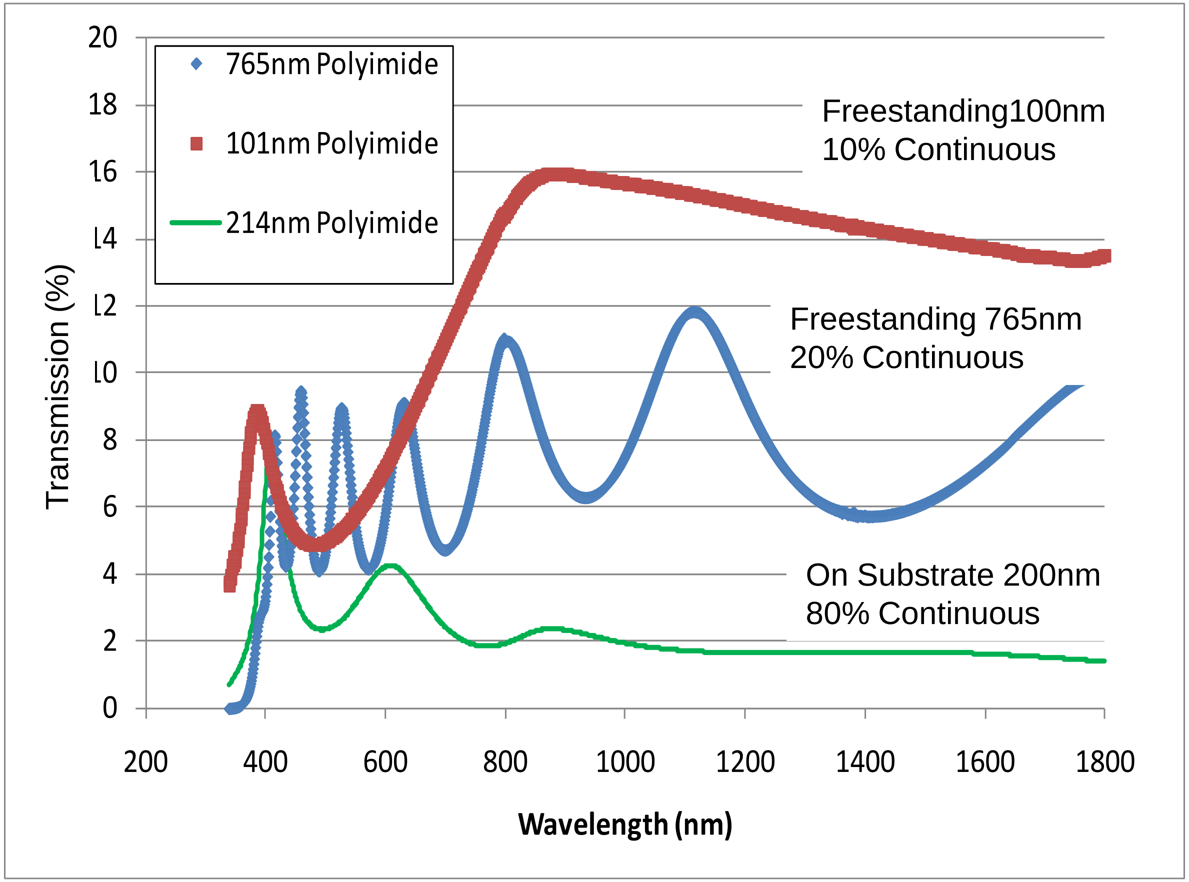


-Heating:adiabatic condensation of Al, IR from source

-Radiative cooling

Activation Energy for Grain Growth in Aluminum Coatings
A. Jankowski, J. L. Ferreira, J. P. Hayes,
Thin Solid Films 491 (*2005*) 61-65

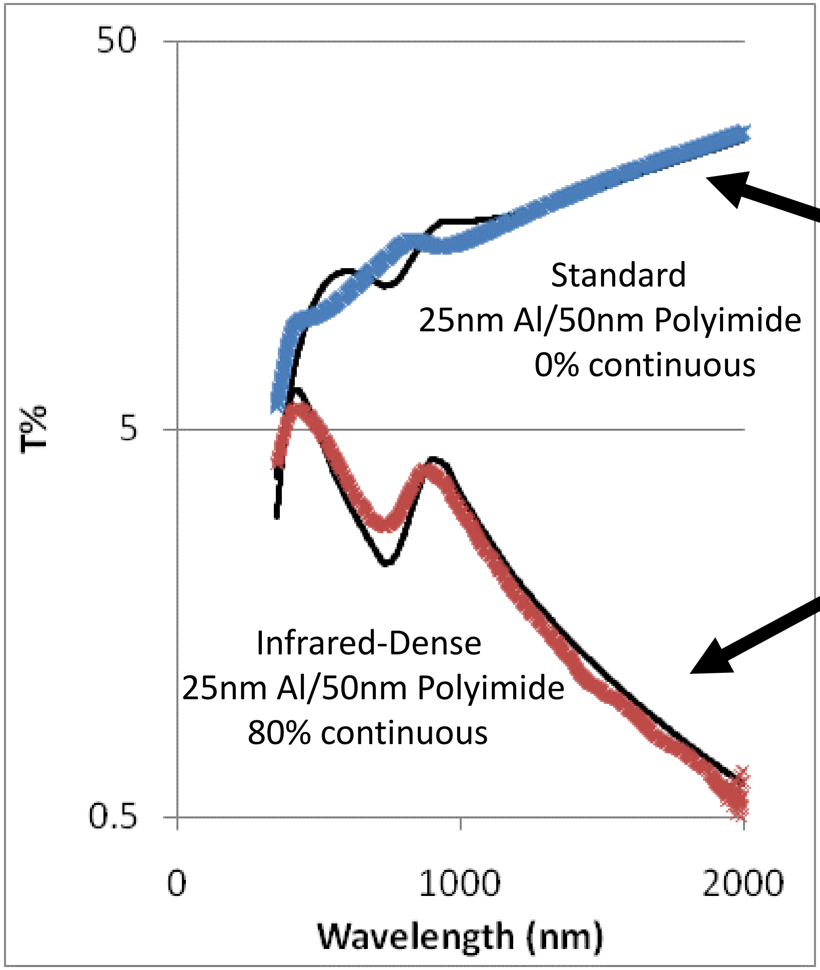
Transmission of 25nm Al (Same coating run) on Various Thickness Polyimide Substrates



Thicker freestanding polyimide yields more continuous Al films

Thermal contact with a substrate provides enough thermal reservoir to keep coating cool

Transmission of 25nm Aluminum /50nm Polyimide



Coated Freestanding

Polyimide film placed in thermal contact with a thick substrate using a heat transfer layer

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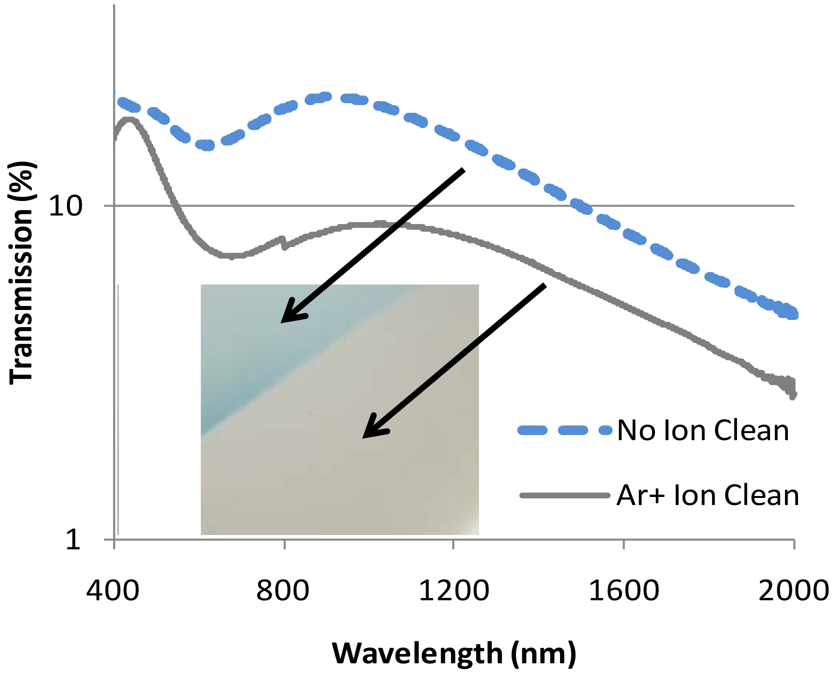
Plasma Clean of Polyimide Prior to Al Coating



-On-substrate reflected color changed from blue to silver
-Improvement of 10% in %Continuous

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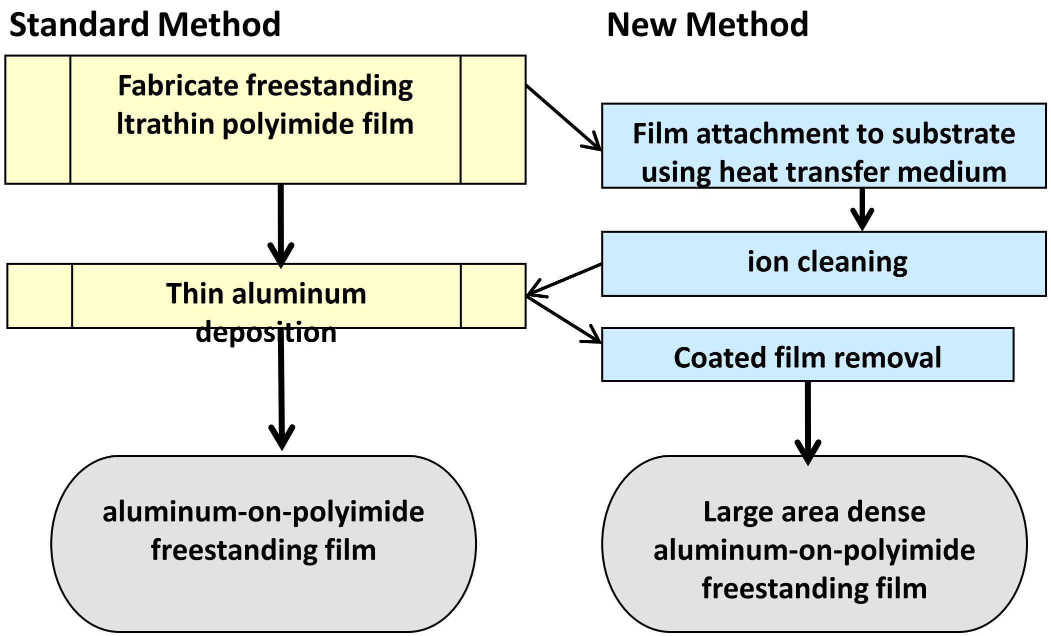
A New Process for Al/ <200nm Polyimide



Standard Method

Fabricate freestanding ltrathin polyimide film

Thin aluminum deposition

aluminum-on-polyimide freestanding film

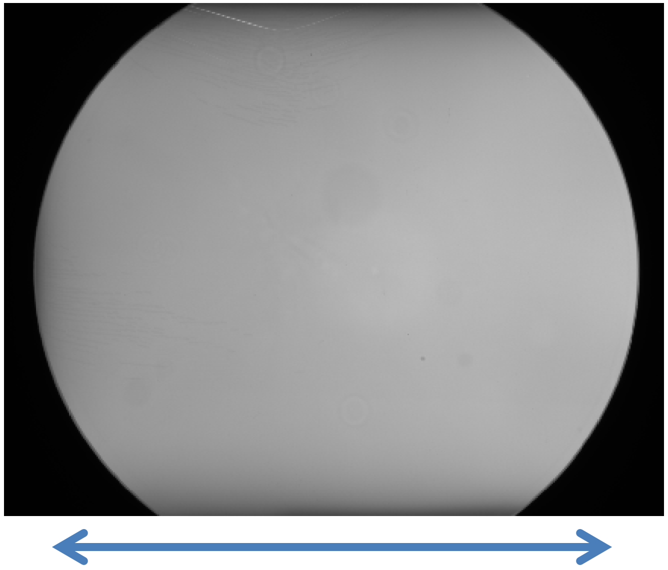
New Method

Film attachment to substrate using heat transfer medium

ion cleaning

Coated film removal

Large area dense aluminum-on-polyimide freestanding film



100mm

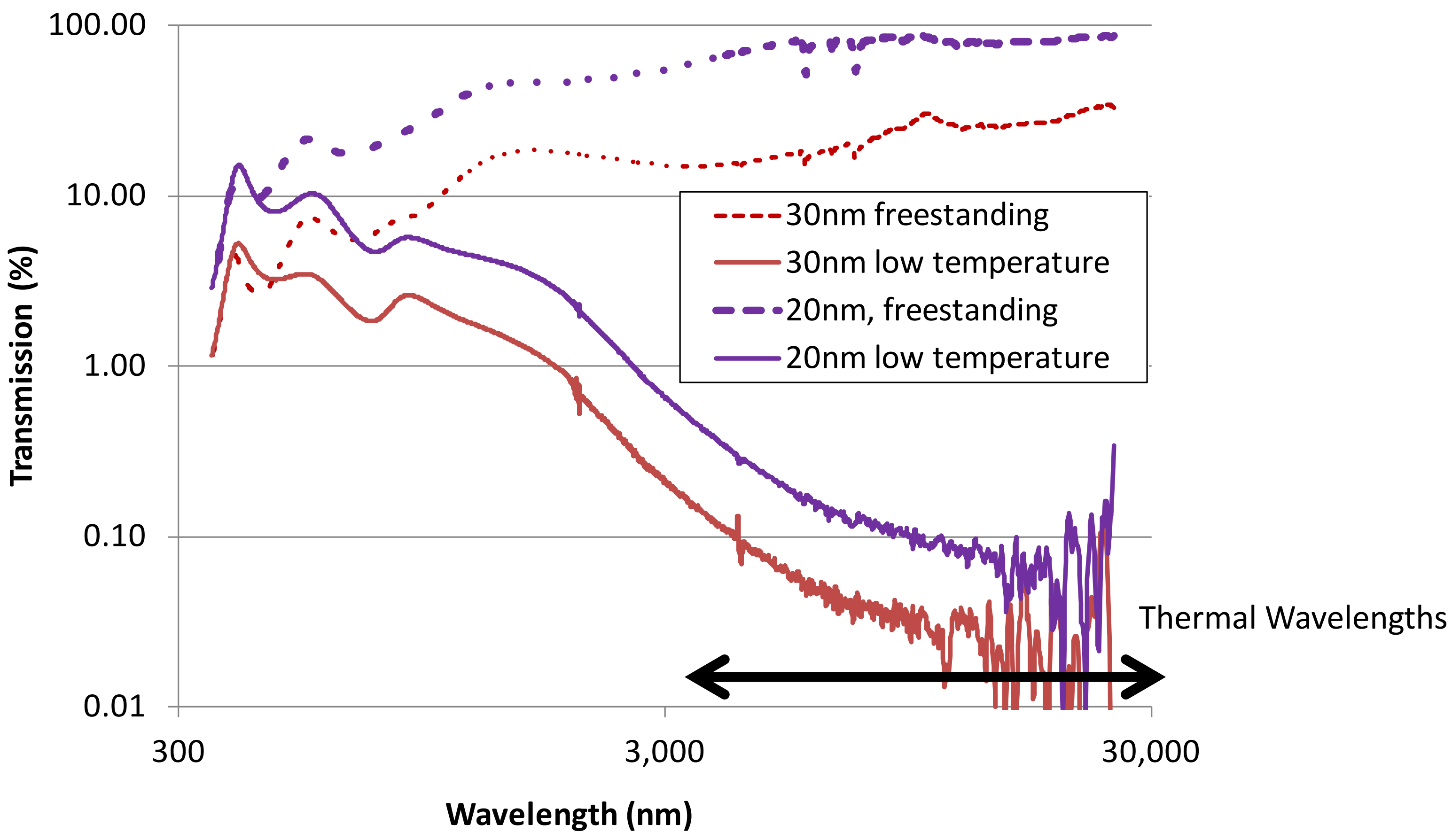
20nm Al/100nm Polyimide

Transmitted Light Image

-Need uniform thermal contact with heat sink

-Must avoid generating defects in ultrathin film

Far-Infrared Transmission of Low Temperature Aluminum/Polyimide Process



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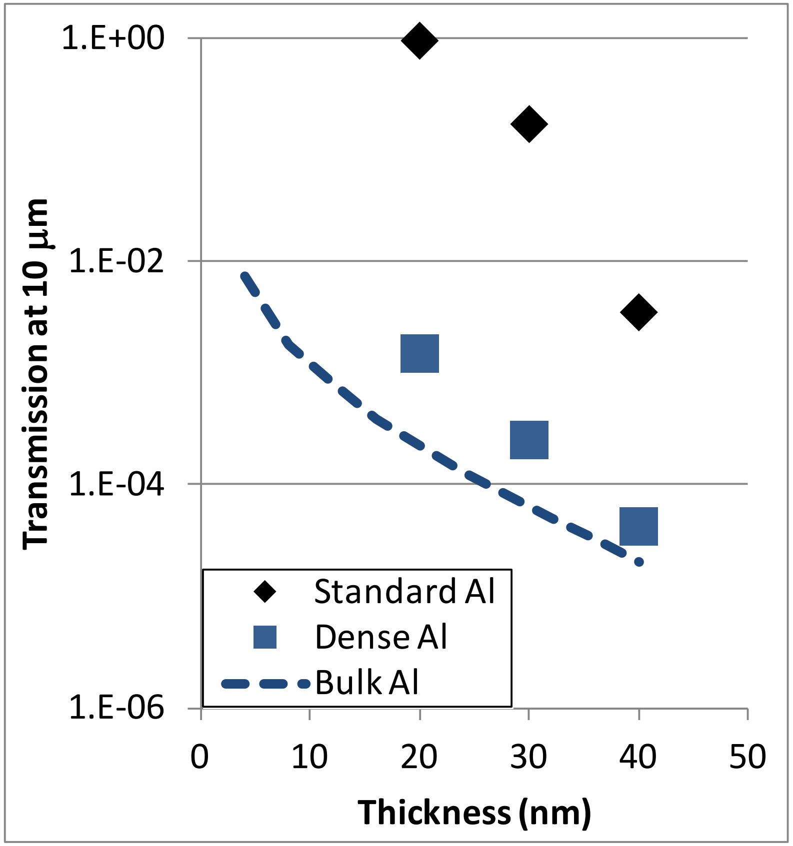
Infrared Density of Low Temperature Al/Polyimide Process

Various aluminum thicknesses



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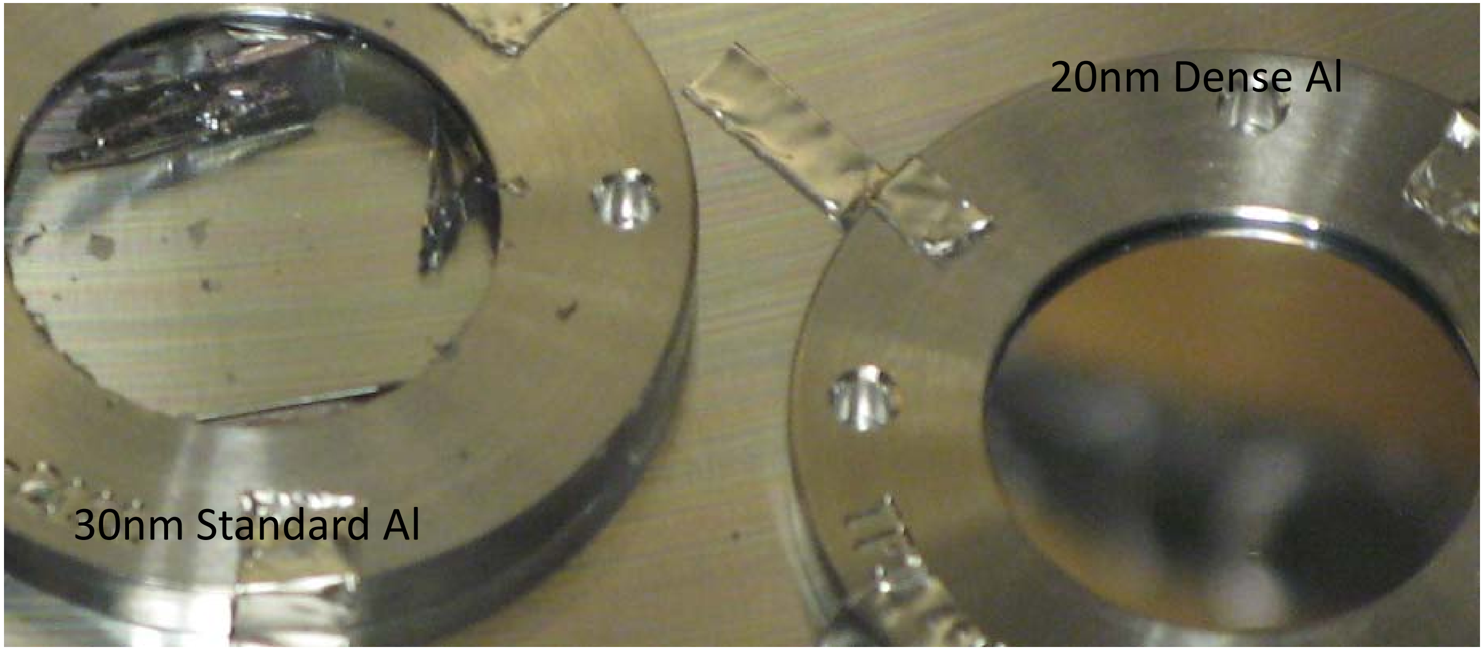
Atomic Oxygen Resistance of Low-Temperature Al Process

-Photograph of 200nm thick aluminized polyimide filters after 1.5E10 atomic oxygen atom exposure



-Low Temperature Aluminum process improves atomic oxygen durability

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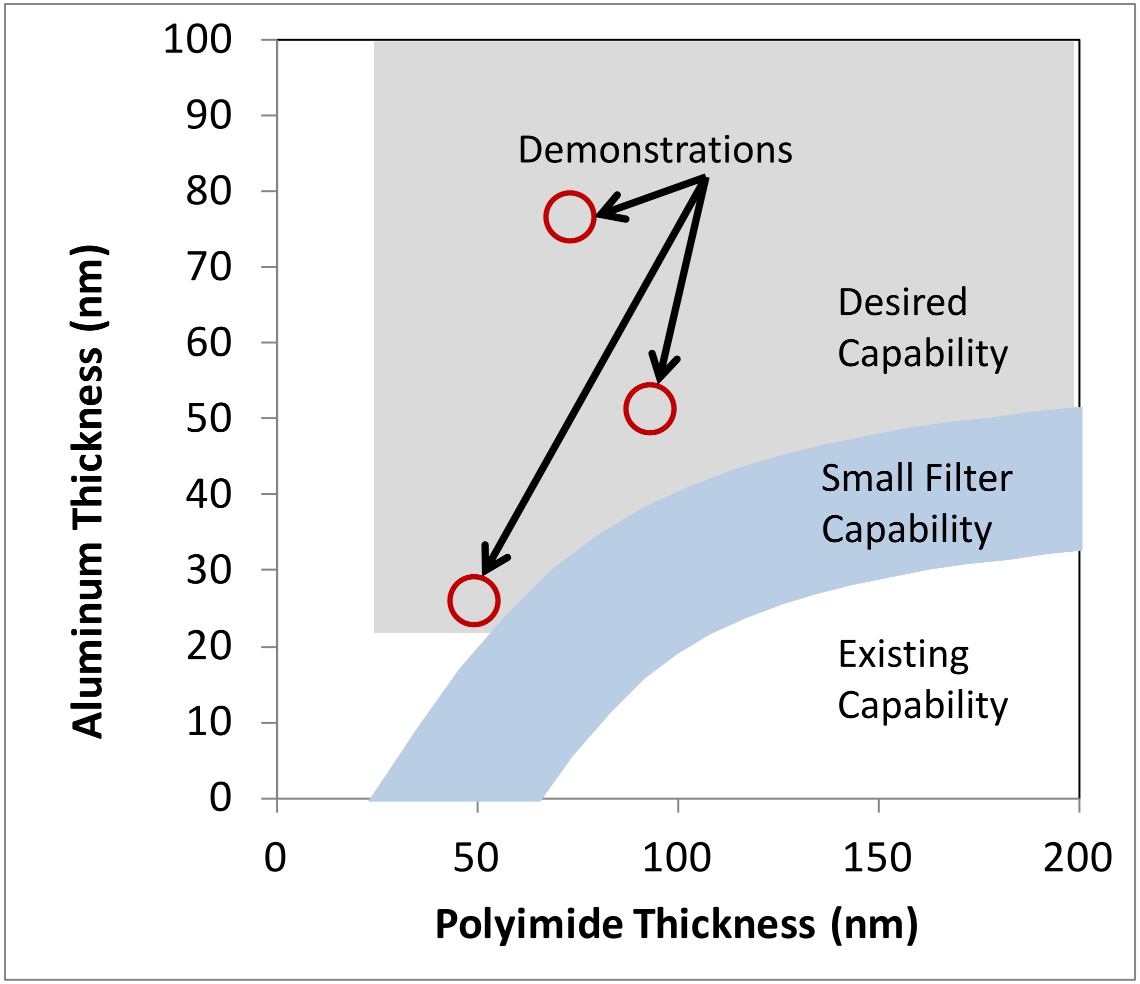
>75mm diameter low temperature Al demonstration films



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Conclusions:

-Poor infrared blocking of aluminum films on <200nm polyimide is due to discontinuity in the films

-Discontinuity is primarily caused by elevated temperature during coating of a freestanding film

-An optical model based on Lorentz oscillators (“islands and holes”) describes relative transmission changes in the visible to far infrared

-Reducing the coating temperature and implementing an ion clean improves Al to near-bulk optical properties