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High Yield and High Throughput Reactive IBAD MgO Process for Long-length, HTS Wire Production at SuperPower

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Previous processes, thickness and speeds of IBAD buffer layers

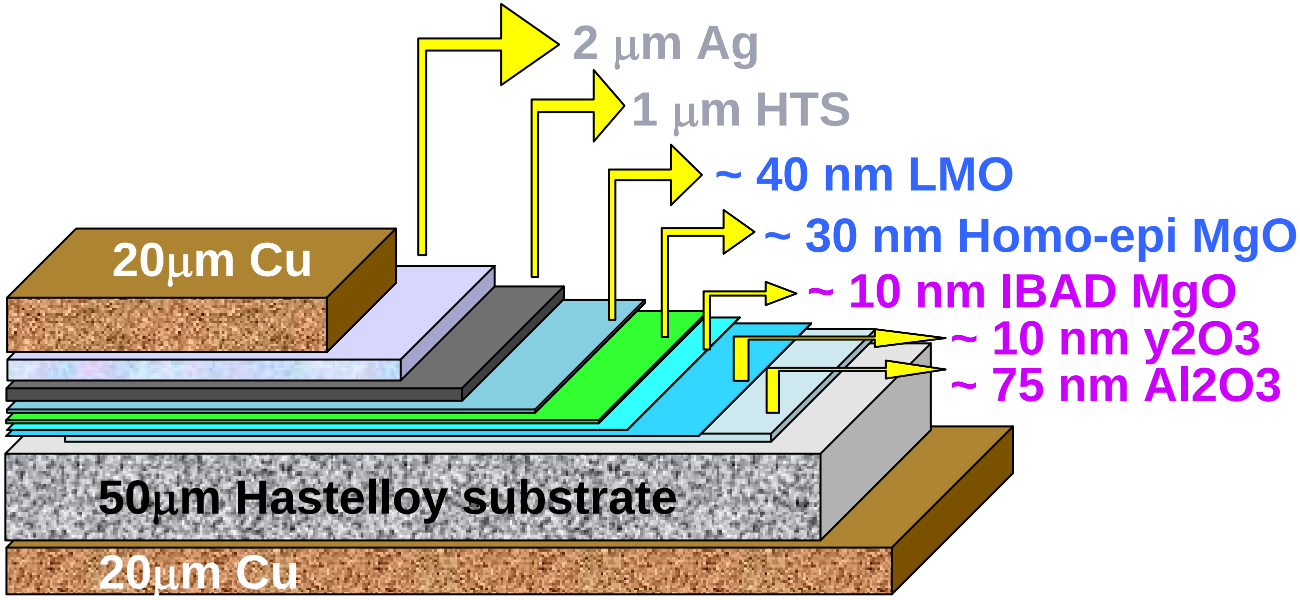
Al_2O_3 --- reactive ion beam sputtering, ~75 nm, speed=120 m/h*.

Y_2O_3 --- ion beam sputtering, ~10 nm, process speed=360 m/h

IBAD MgO --- IBAD and ion beam sputtering on oxide target, ~10 nm, speed = 195 m/h

Homo-epi MgO --- reactive magnetron sputtering, ~30 nm, speed=120 m/h

LMO --- RF magnetron sputtering on ceramic target, ~40 nm, speed=120 m/h



* All speeds in this presentation are equivalent speed of 4mm tape

Choice of barrier layer

- Excellent anti-diffusion ability
- Excellent structure/chemical stability at temperatures up to 900 degrees
- Good mechanical properties
  - Good adhesion and resistance to thermal shock, help delamination issue
- Low cost and easy processing by high throughput processes like reactive sputtering
  - Thickest buffer layer

- SuperPower is still using alumina as barrier
  - Proven excellent anti-diffusion ability, excellent thermal stability, good mechanical properties, very low cost, and easy processing. The cost of Al target is at least 20 times lower than Y metal target
  - Routine production thickness of alumina = ~70 nm, but several tapes with ~40 nm thickness show no degradation in Ic, **indicating that even 40 nm alumina is enough as barrier**
  - Process by reactive magnetron sputtering at transition mode >10,000 m/h in our Pilot Buffer system (routine production = 750 m/h due to a limit in tape driving). Much faster than the speed of other processes. Changing to another process would not benefit total throughput

Questions

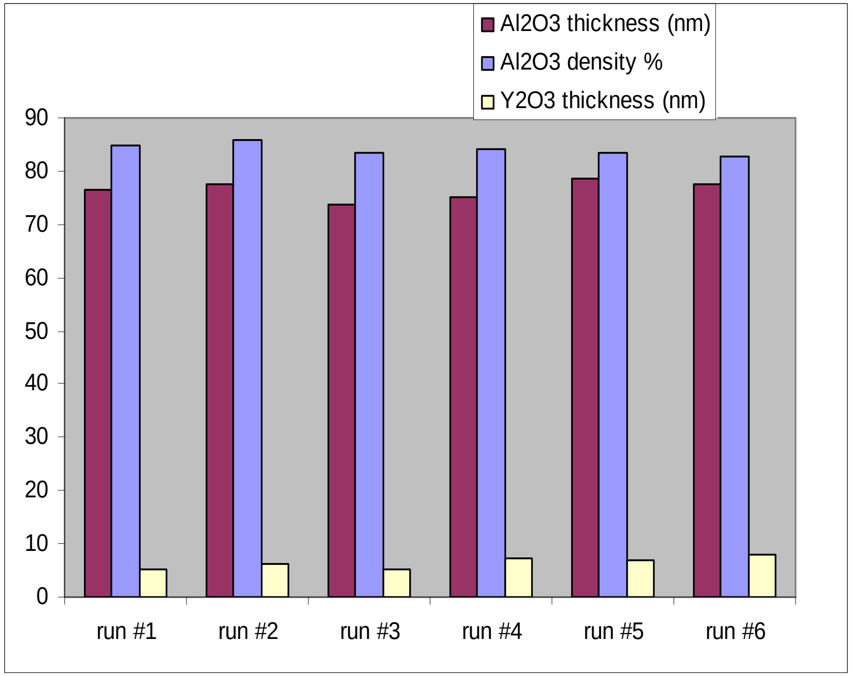
Reaction between MgO and alumina possibly starts at high temperature > 880 degrees (?) which is close to our MOCVD deposition temperature. Isolation (yttria here) between alumina and MgO is needed

What structure/physical/chemical properties are related to anti-diffusion ability? High bond energy, shorter bond length, no grain boundary, high crystallization temperature

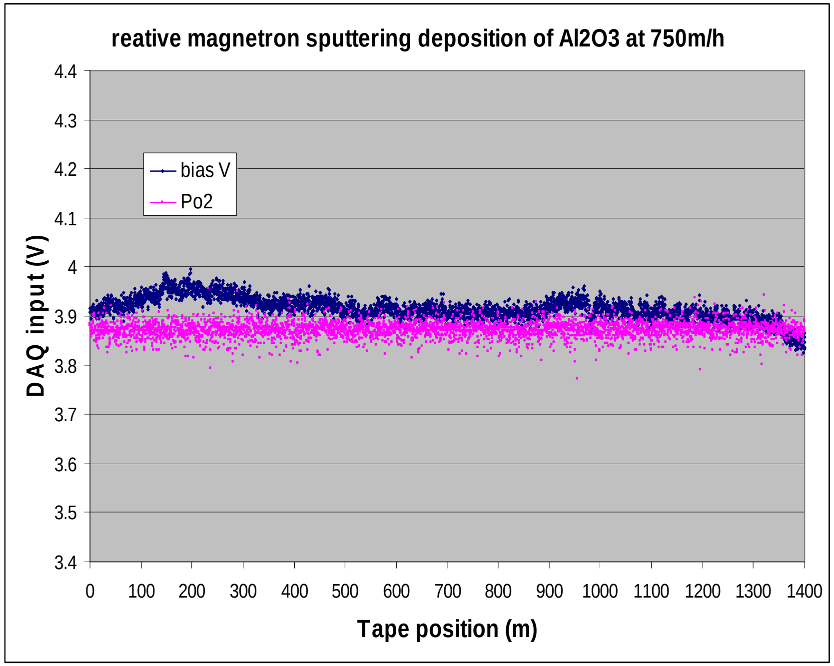
Effect of oxygen deficiency of amorphous alumina on its anti-diffusion ability and crystallization temperature?

Stable Al_2O_3 high throughput reactive sputtering process

- Yielded the same texture and Ic as the ion beam sputtered Al_2O_3 layer
- Reactive sputtering at transition mode has high throughput, but good feedback control is needed to get stable process during long length run and from run to run



Good stability from run to run, process speed = 750 m/h



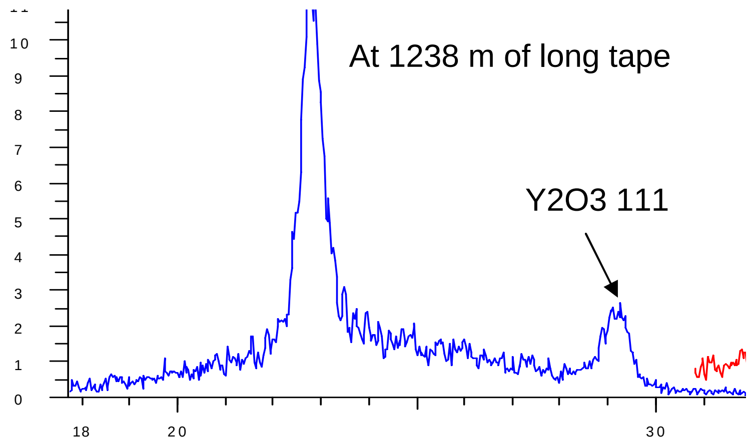
Good stability during run with feedback control

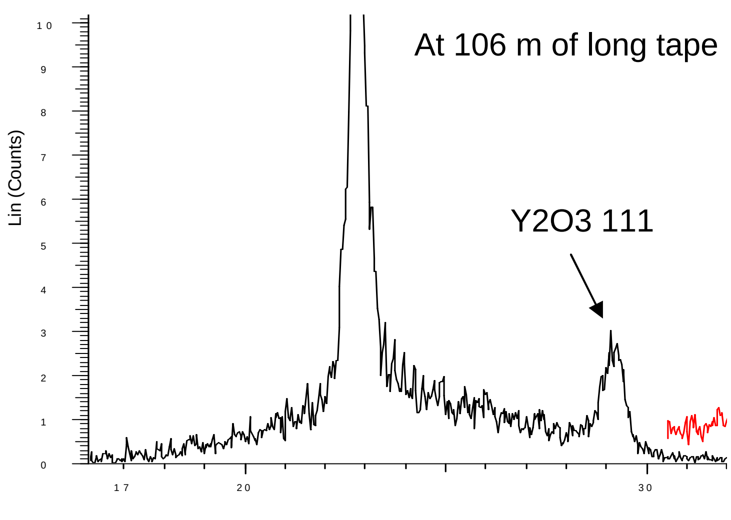
Choice of seed layer

Our understanding of Seed Layer requirement is

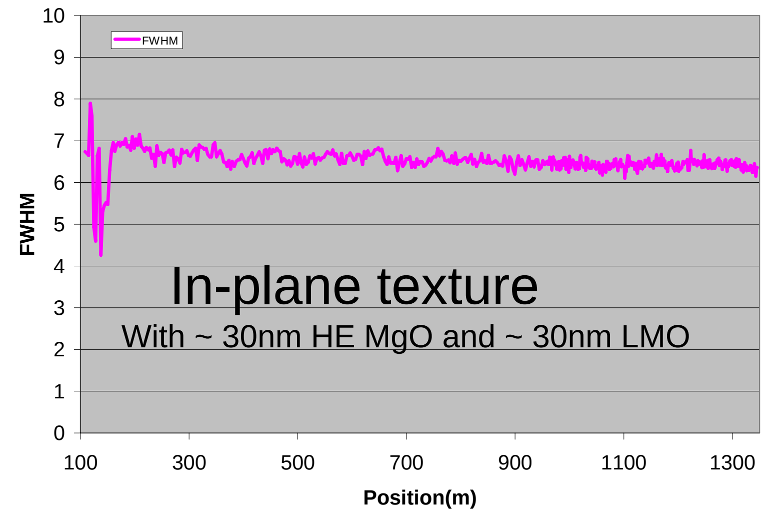
- Most important requirement of seed layer is its anti-epitaxial relationship with the IBAD MgO layer. It is more accurate to call it anti-epitaxial layer
  - The less epitaxial bonding between the seed layer and the IBAD layer, the easier for the IBAD layer to form good texture under external force of the ion beam
- An amorphous surface is not a key requirement for the seed layer as long as the crystalline surface is not too rough. The anti-epitaxial bonding between the seed layer and the IBAD texturing layer plays a more important role than surface crystalline form
  - Our result further verifies this by detecting clear yttria crystalline peak in X-ray 2-theta scan on one of our routinely produced IBAD MgO tapes
  - Our IBAD MgO optimization run on amorphous alumina gives very poor texture around 16 – 12 degrees. The bonding between Al-O and MgO is stronger than that between Y-O and MgO
- Choice of seed layer significantly affects IBAD texturing, and best choice depends on IBAD layer material
- The effects of seed layer roughness on IBAD MgO texture can also be partially explained, --- rougher surface ->larger contact surface -> the increased bonding between MgO and seed layer
- This roughness should be roughness of micro scale, the scale of grain size of IBAD MgO. The X-Y resolution of AFM scan should be nm to qualify the roughness of seed layer from view of IBAD MgO texturing

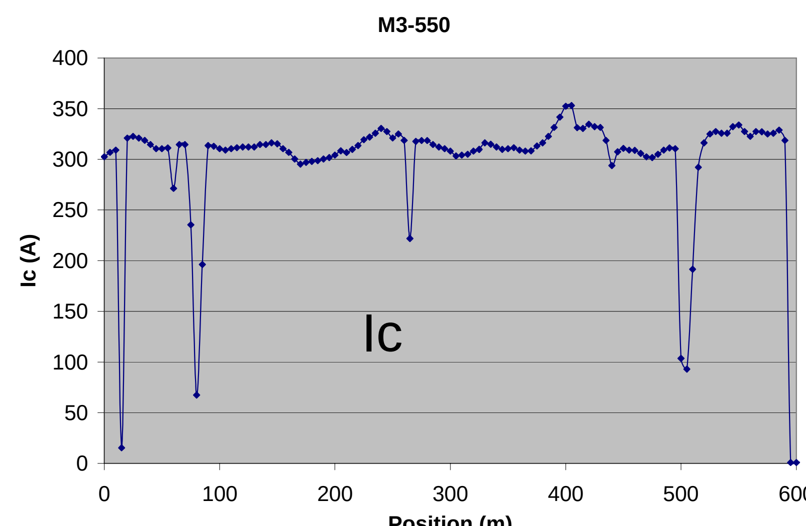
Polycrystalline Yttria gives same texture and Ic on one kilometer-long tape





X-ray 2-theta scan





SuperPower is still using Yttria as barrier

- Proven ability to get good IBAD MgO texture; until now, in our experience, the best IBAD MgO texture is obtained with yttria seed layer
- Process window is largest until now based on our knowledge
- We develop high throughput reactive magnetron sputtering at transition mode >30,000 m/h in our Pilot Buffer system (routine production = 750 m/h due to a limit in tape driving). Much faster than speed of other processes. Changing to another process would not benefit our total throughput
- Combined barrier layer and seed layer does not necessarily benefit production before asking the following questions
  – Throughput increased? Mainly dependent on the total thickness and deposition rate
  – Process yield improved? How about process window to get same texture?
  – Long length stability of production process improved?
  – Cost?

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Choice of IBAD texturing layer

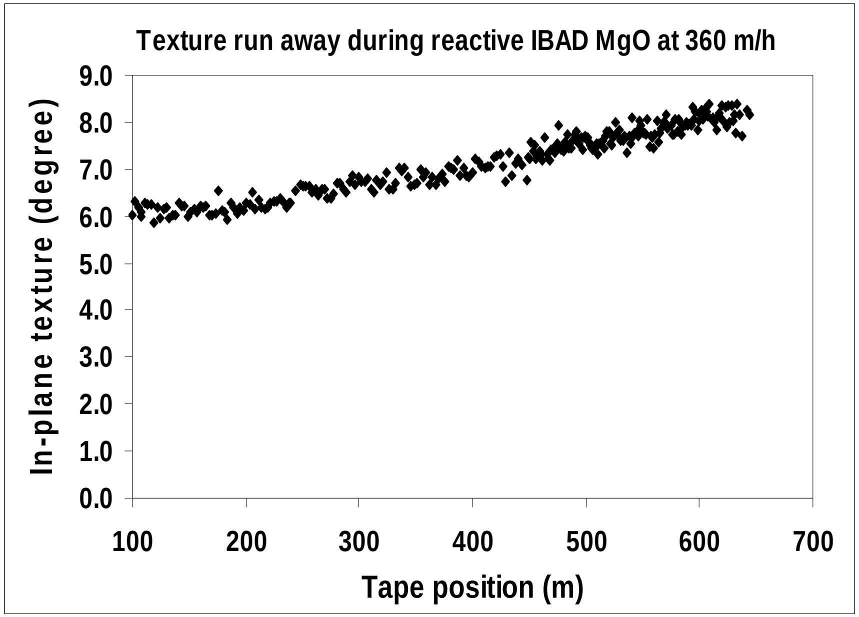
Requirements of IBAD texturing layer:

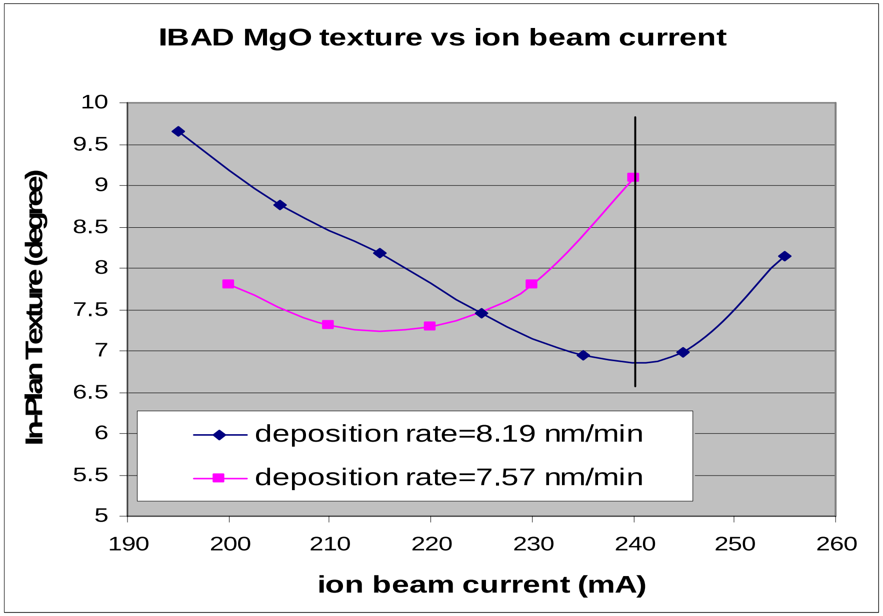
- Thermal/oxidation stability in order to withstand later buffer and HTS coating processes
- High enough mobility at room temperature in order to form good texture during the nucleation stage
- The co-existence of two such requirements points to a material with a high degree of ionic bond. This greatly limits the choice of IBAD texturing layer better than MgO
- Oxides of Group I and Group II metals in periodic table have high degree of ionic bond
  - Oxides of Group I are not practical for use in production due to their high activity, also have relatively lower melting points and antifluorite structure
  - BeO is not very good ionic bonding material due its relatively higher electronegativity
  - CaO reacts quickly with CO_2 and H_2O, so it is not stable in air without protection. Could its texture be increased with seed layer other than yttria?
  - BaO reacts violently with H_2O, is difficult to use

The hope of finding better IBAD texture material than IBAD MgO is very challenging

IBAD MgO process speed increased to 360 m/h

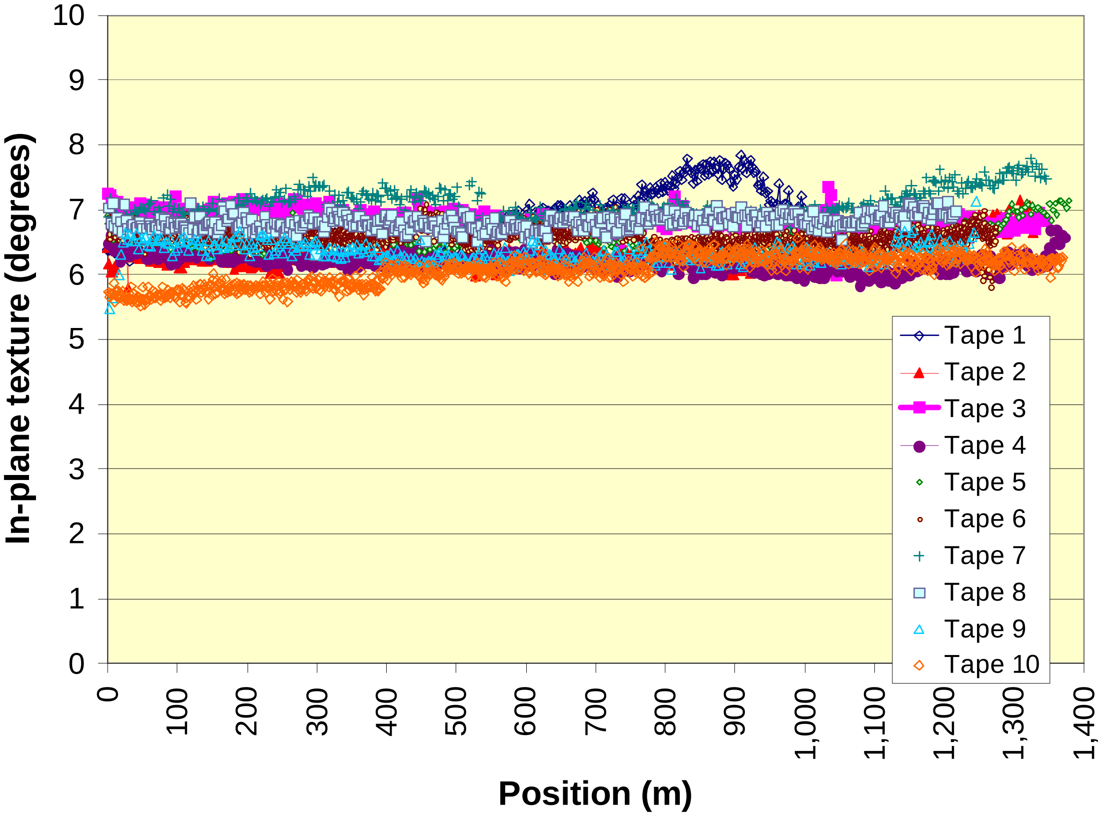
- Using reactive ion beam sputtering with Mg metal target to get ~60% higher deposition rate
- But reactive process is delicate, easy run away during a long run and from run to run





- Reactive sputtering is very sensitive to small shift during process. Additionally, the IBAD MgO process is a sensitive process creating a significant change in texture with a change of just a few percent
- Feedback control was developed to achieve good long length stability with this reactive IBAD MgO process.

Good stability of long length run and from run to run

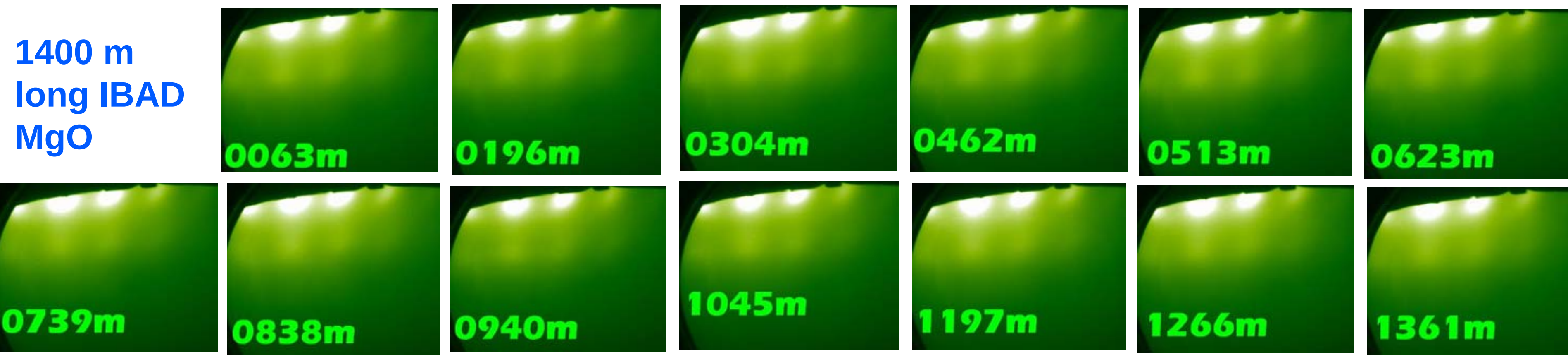


Tape	Length (m)	In-plane texture (°)			Uniformity
		Average	Min	Max	
1	1,001	6.79	6.20	7.84	6.2%
2	1,343	6.33	5.80	7.16	3.3%
3	1,346	6.85	6.00	7.35	2.1%
4	1,372	6.20	5.83	6.68	2.2%
5	1,375	6.58	6.23	7.14	2.5%
6	1,277	6.59	5.80	7.09	2.1%
7	1,346	7.09	6.66	7.79	2.9%
8	1,265	6.81	6.30	7.12	1.7%
9	1,246	6.33	5.47	7.13	2.4%
10	1,369	6.18	5.95	6.26	1.2%

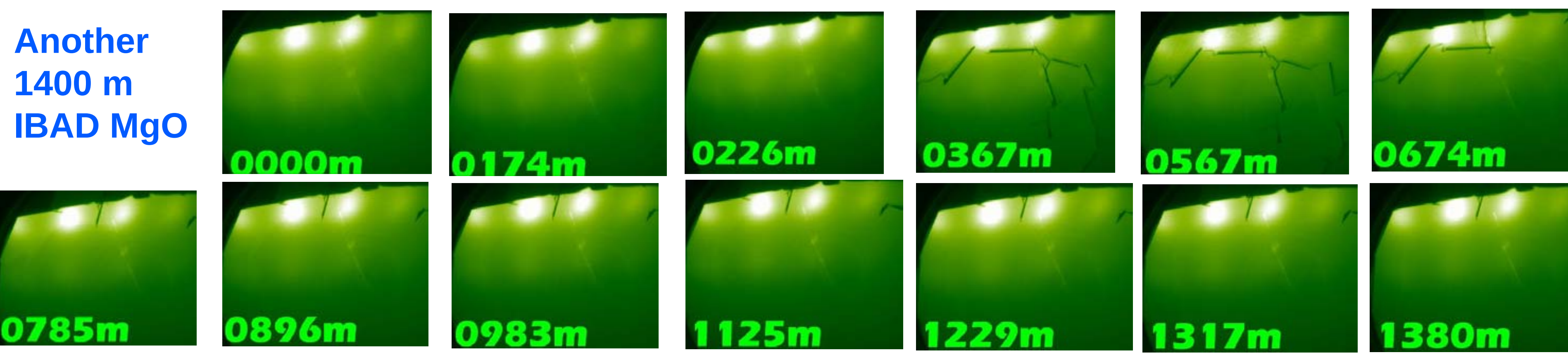
Routine manufacture of high quality, ~1.4 km IBAD MgO templates with excellent uniformity

Online RHEED shows stable 1.4 km long IBAD MgO production, 360 m/h

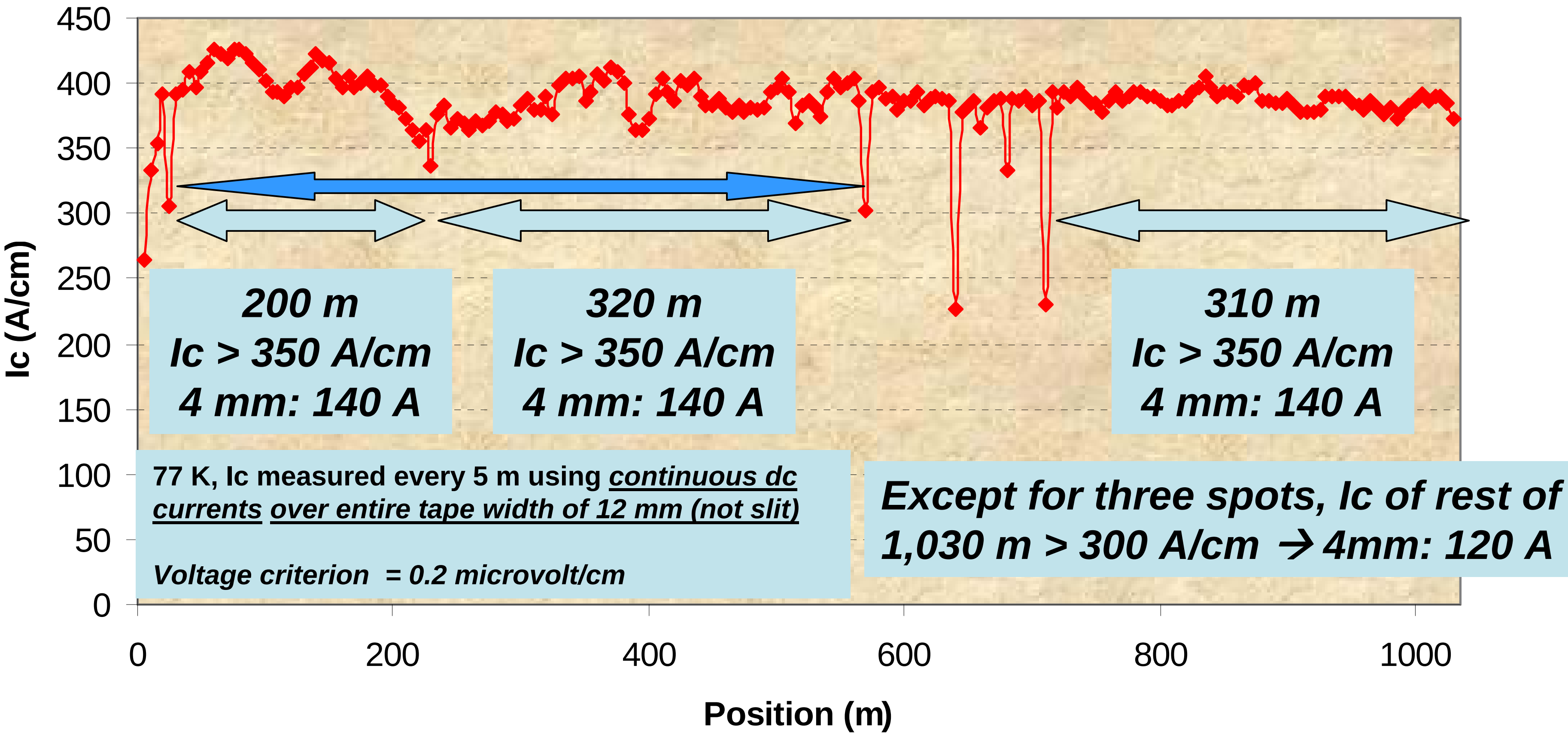
1400 m long IBAD MgO



Another 1400 m IBAD MgO



Aug. 2008: Yet another world record!



Length (m)	Minimum Ic (A/cm) @ 0.2 μV/cm	$I_c \times$ Length (A-m)
1030	227	233,810
630	302	190,260
540	337	181,980