What can we learn from the X-ray mirror coating community

report from the PXRMS conference Big Sky - Montana

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- Metallic and oxide coatings used to reflect X-rays
- Alternate reflective and “spacer” layers
- Different scale (nm instead of μm)
- Best reflectivities as high as 50%!
- Smoothness and stress equally important
- What can we learn from that community?

- A few examples and ideas.

Ion assisted magnetron sputtering

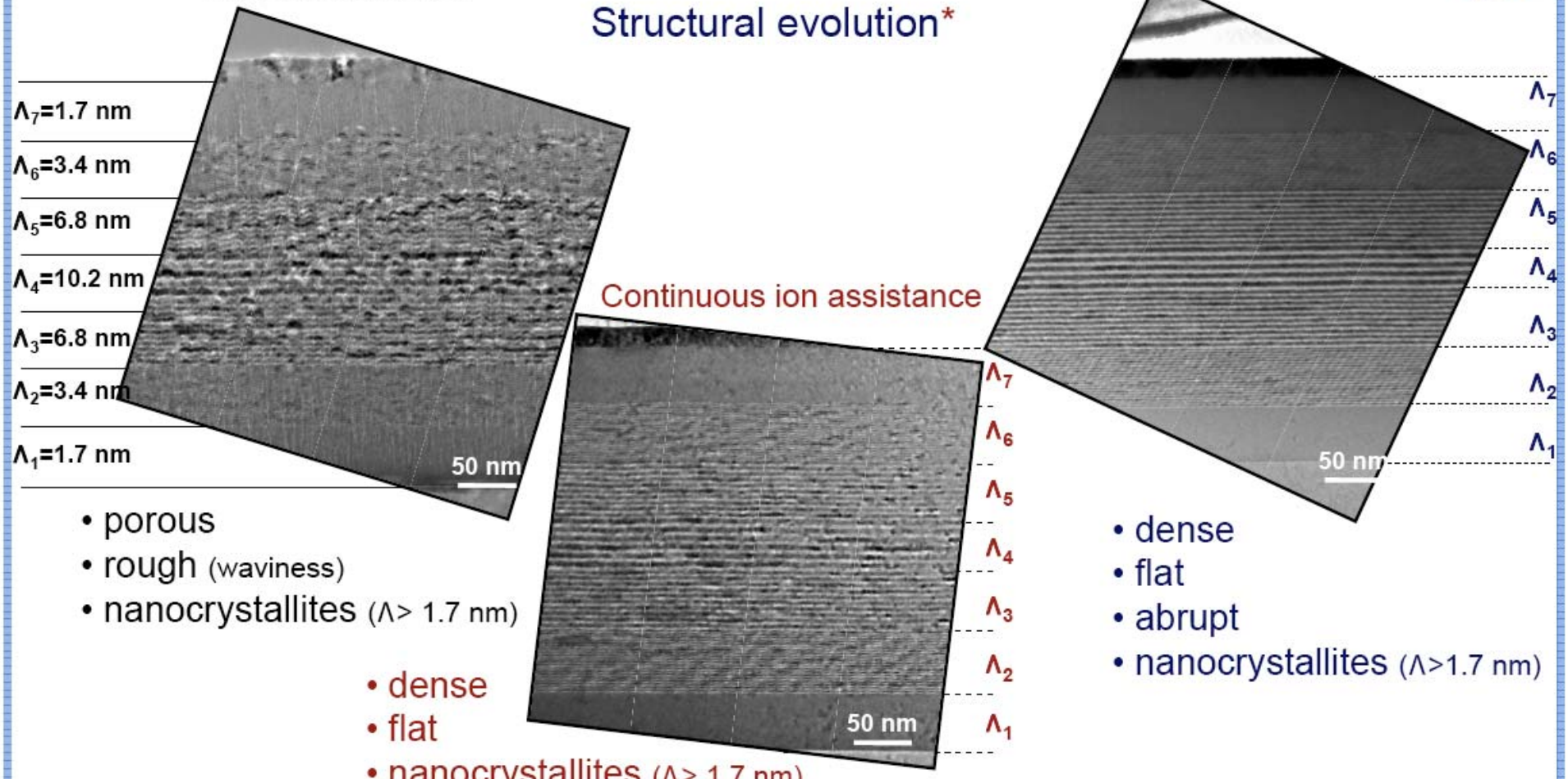
- Controlled Ion current bombard sample
  - Continuous and/or modulated
- Re-melting at nanoscale
- Compress excess voids (annealing)
- Promote glassyness and depress crystal formation
- Improve uniformity, density and boundary sharpness
- Can it be used on dielectric substrates?
  - RF ion currents
  - Ions + electrons?

Impact of low-energy high-flux ion assistance

No ion assistance

Structural evolution*

Modulated ion assistance



- porous
- rough (waviness)
- nanocrystallites (Λ> 1.7 nm)

- dense
- flat
- nanocrystallites (Λ> 1.7 nm)

- dense
- flat
- abrupt
- nanocrystallites (Λ>1.7 nm)

Modulated ion assitance → Trade off between roughness & intermixing

* N. Ghafoor, F. Eriksson, J. Birch et al., Thin Solid Films, 516 (2008), 982-990

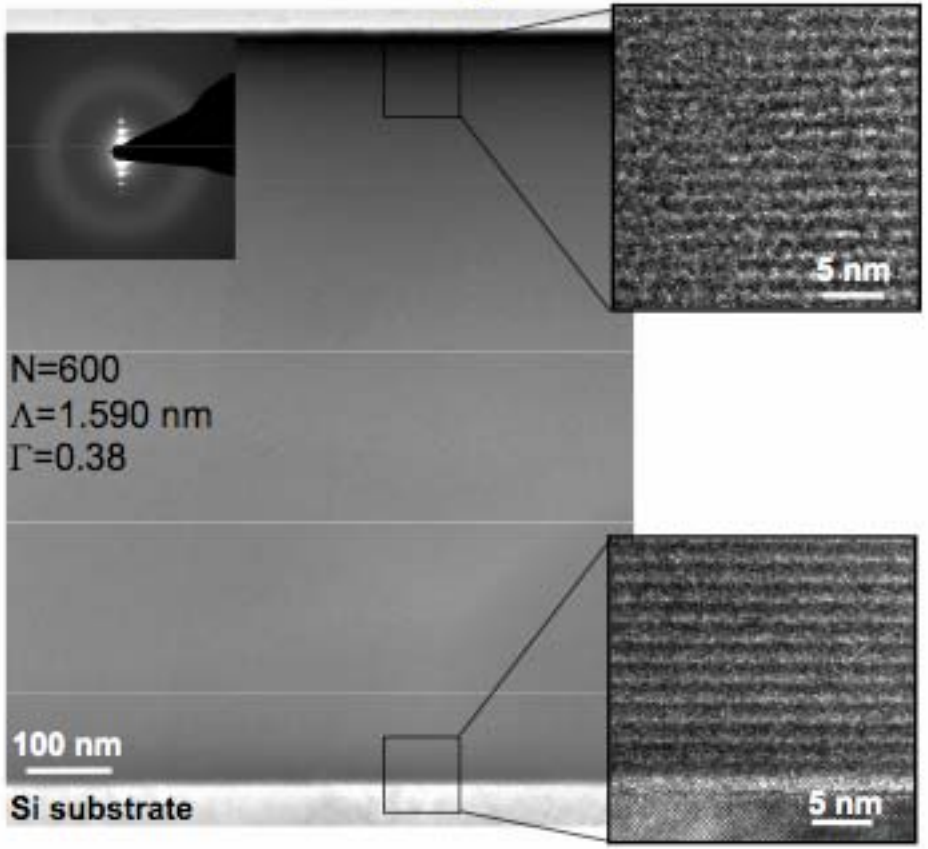
Incorporation of small size atoms into the glass

- Improves smoothness and glassyness
- They use Boron, Carbon, Nitrogen and even Beryllium

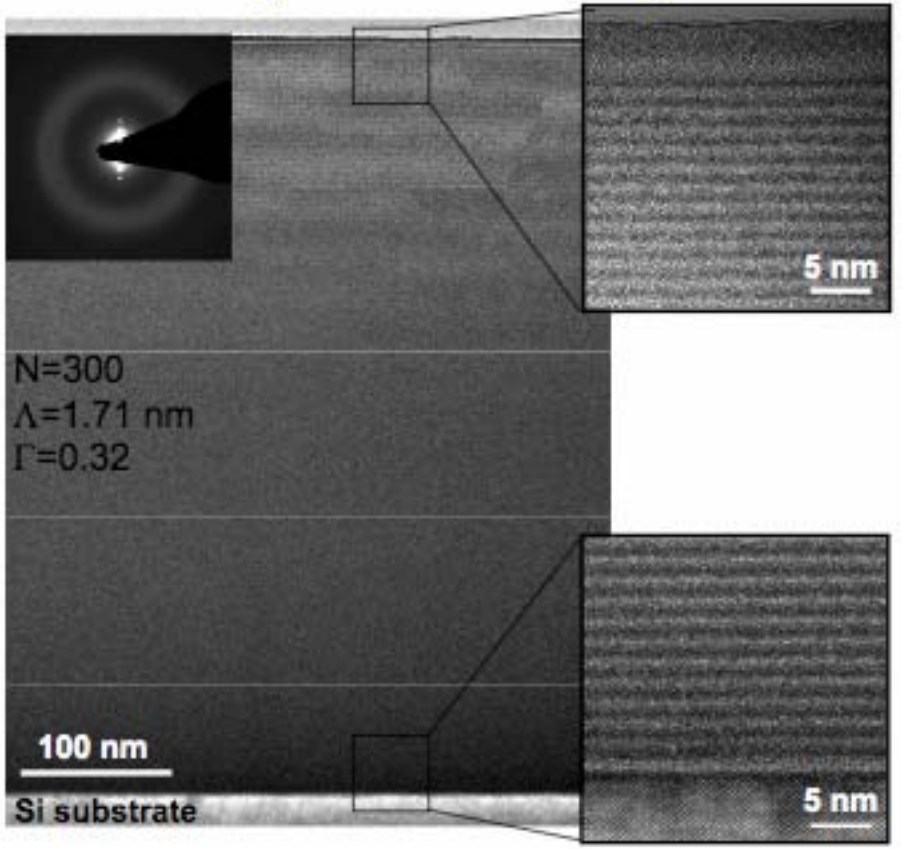
State-of-the-art

Structure (HRTEM)

Pure Cr/Sc multilayers*



Interleaved B_4C- Cr/Sc multilayers**



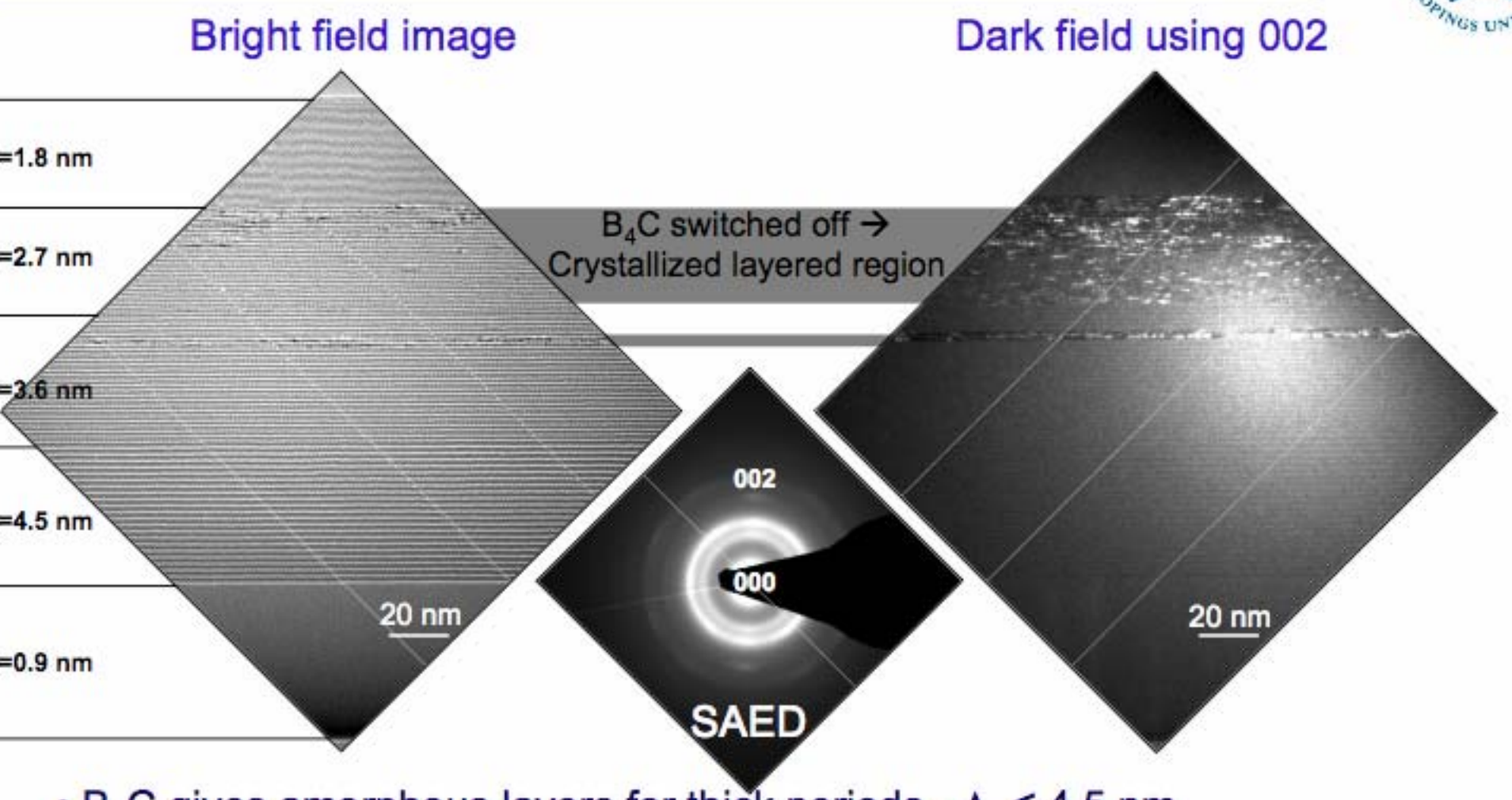
- How are light elements incorprated?
- How do they influence structure?

B_4C layers preserve layer flatness
"hinder the accumulating jaggedness

* F. Eriksson, N. Ghafoor, J. Birch, *et al.* PXRMS 2002.

** E. M. Gullikson, *et al.* PXRMS 2006

Structural evolution of Cr/Sc+B_4C multilayers



- B_4C gives amorphous layers for thick periods - $\Lambda \leq 4.5$ nm.
- B_4C prevents crystallization
- All amorphous multilayer periods have flat interfaces.

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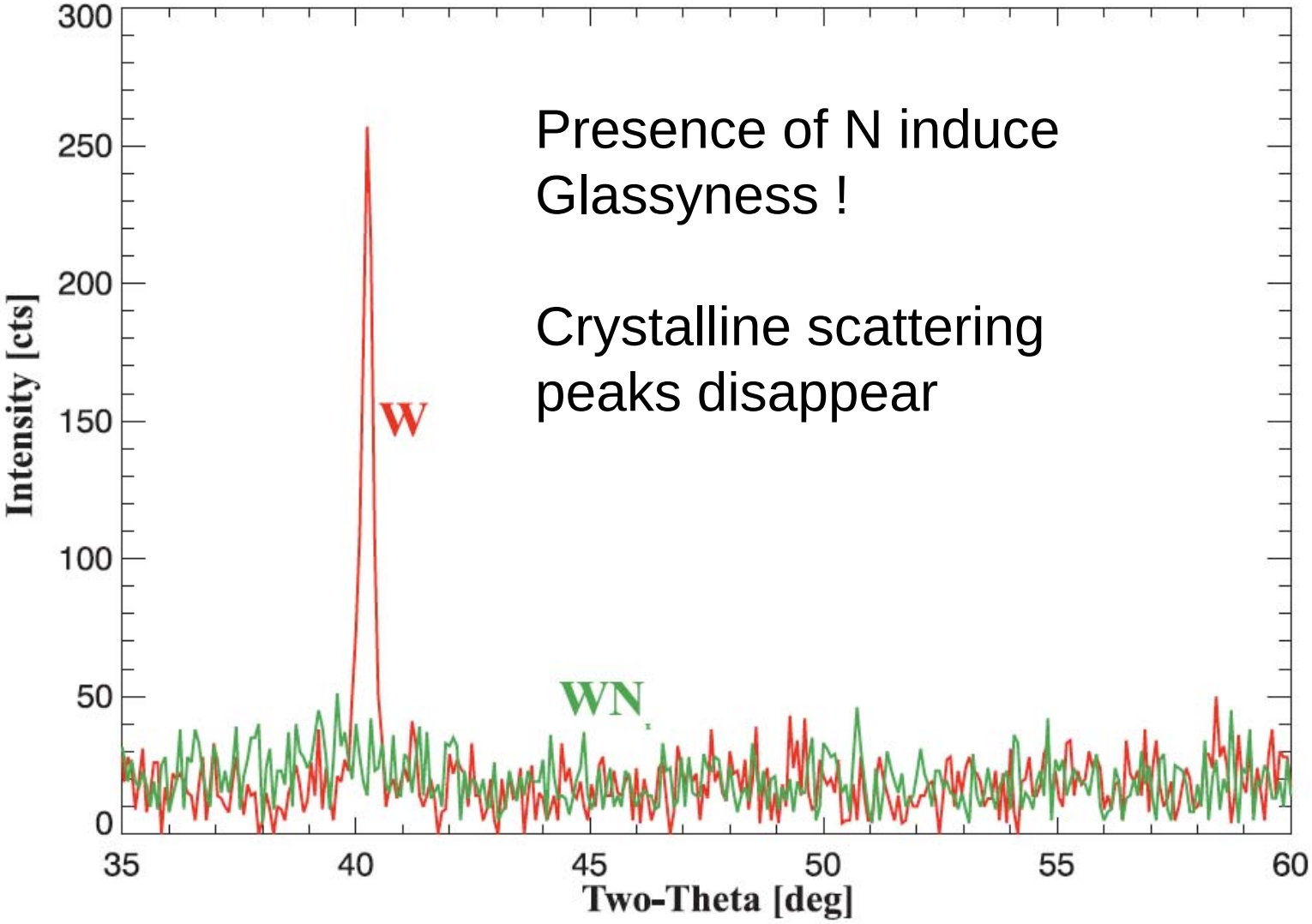
Reactive sputtering

- Incorporate Nitrogen in glass by admitting it into the Argon discharge during deposition
- Nitrogen reacts with materials forming nitrates
- Imprroved Glassyness induced in materials

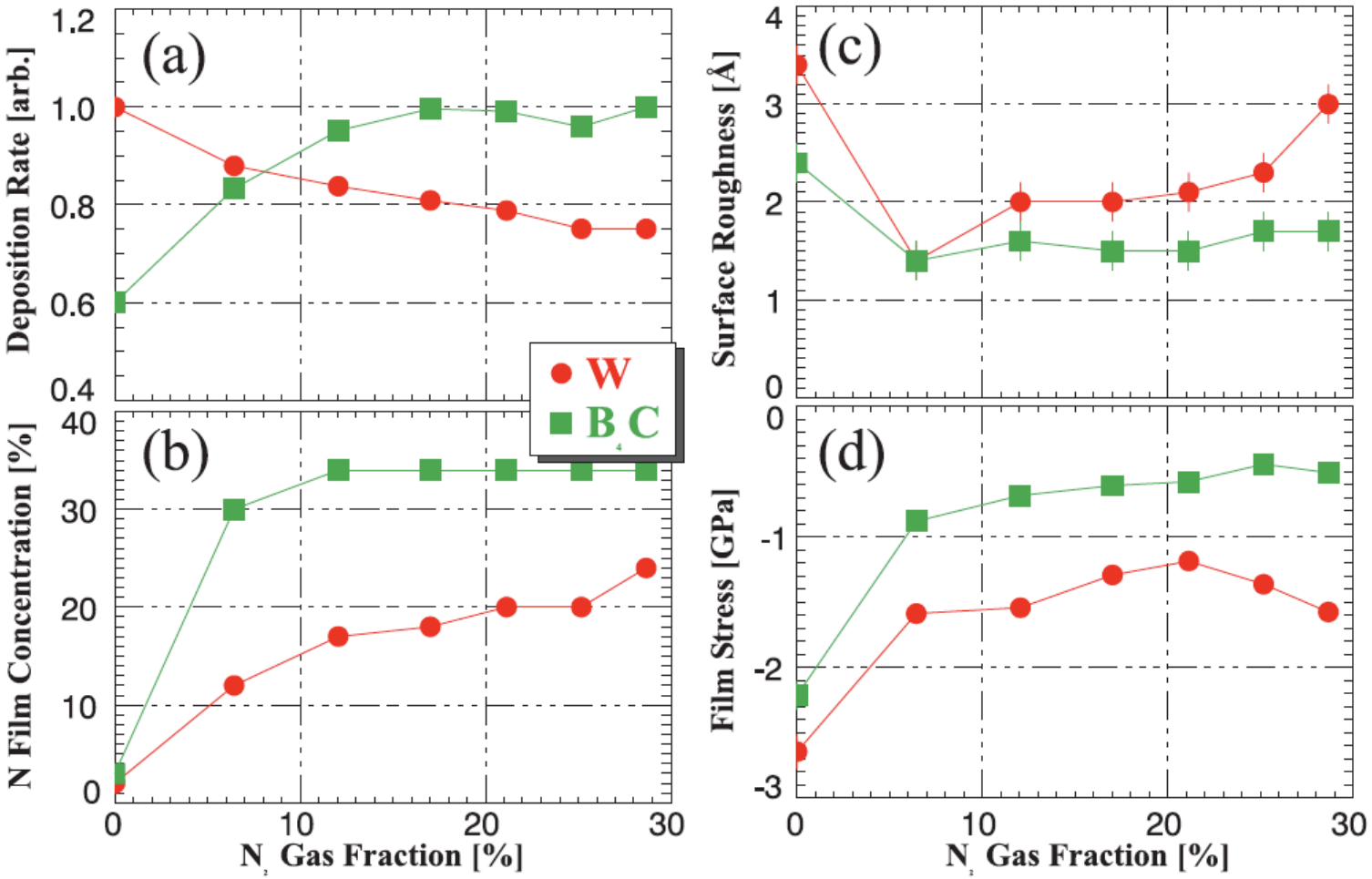
- Dramatically smoother layers and lower tension

- David L. Windt "Reduction of stress and roughness by reactive sputtering in W/B4C multilayer films" Proceedings of SPIE -- Volume 6688 (Sep. 20, 2007)

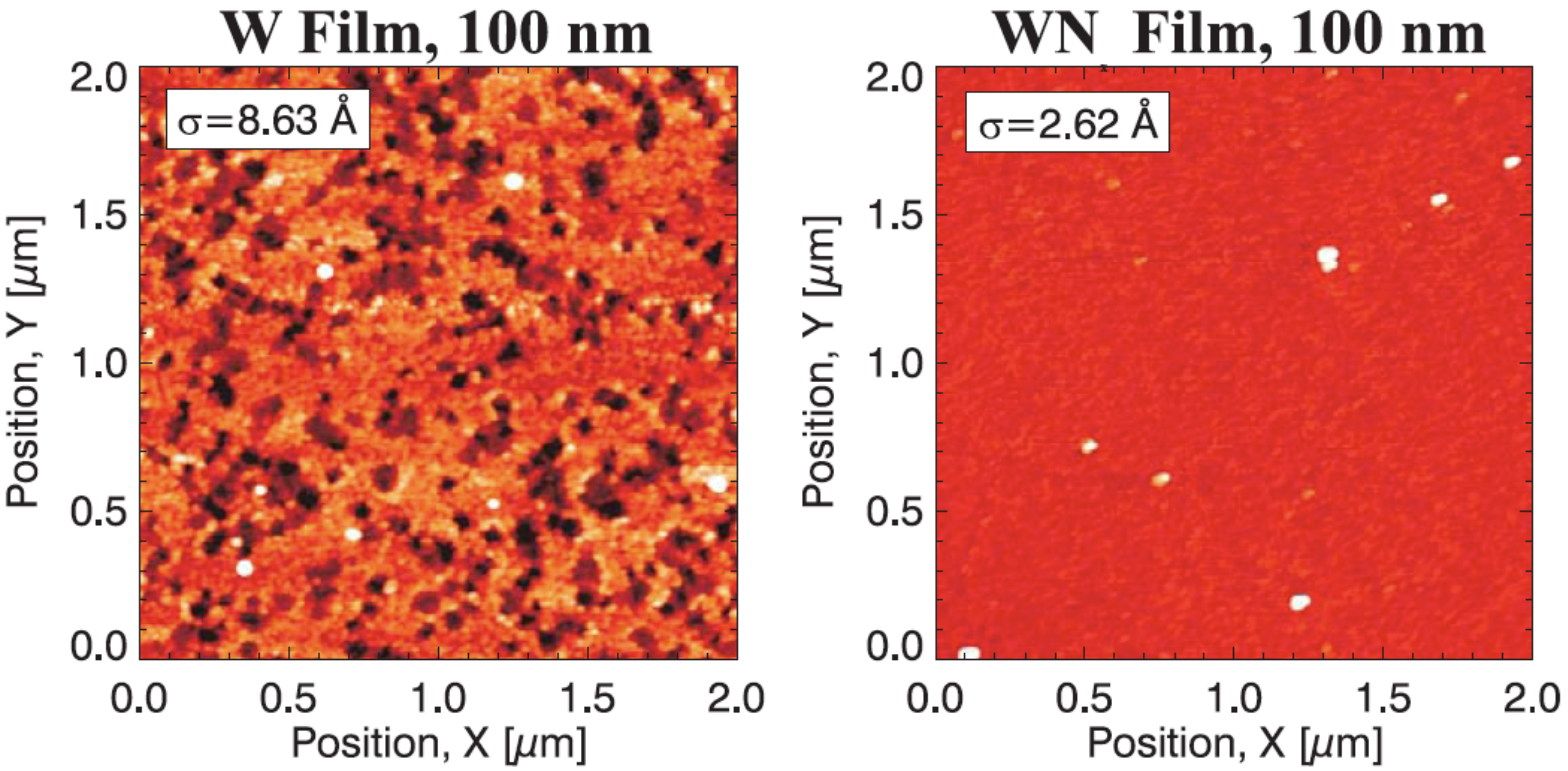


- X-ray Diffraction measurements for 100-nm-thick W and WNx films

- Reduced roughness and reduced stress
- Most effect with smaller concentration

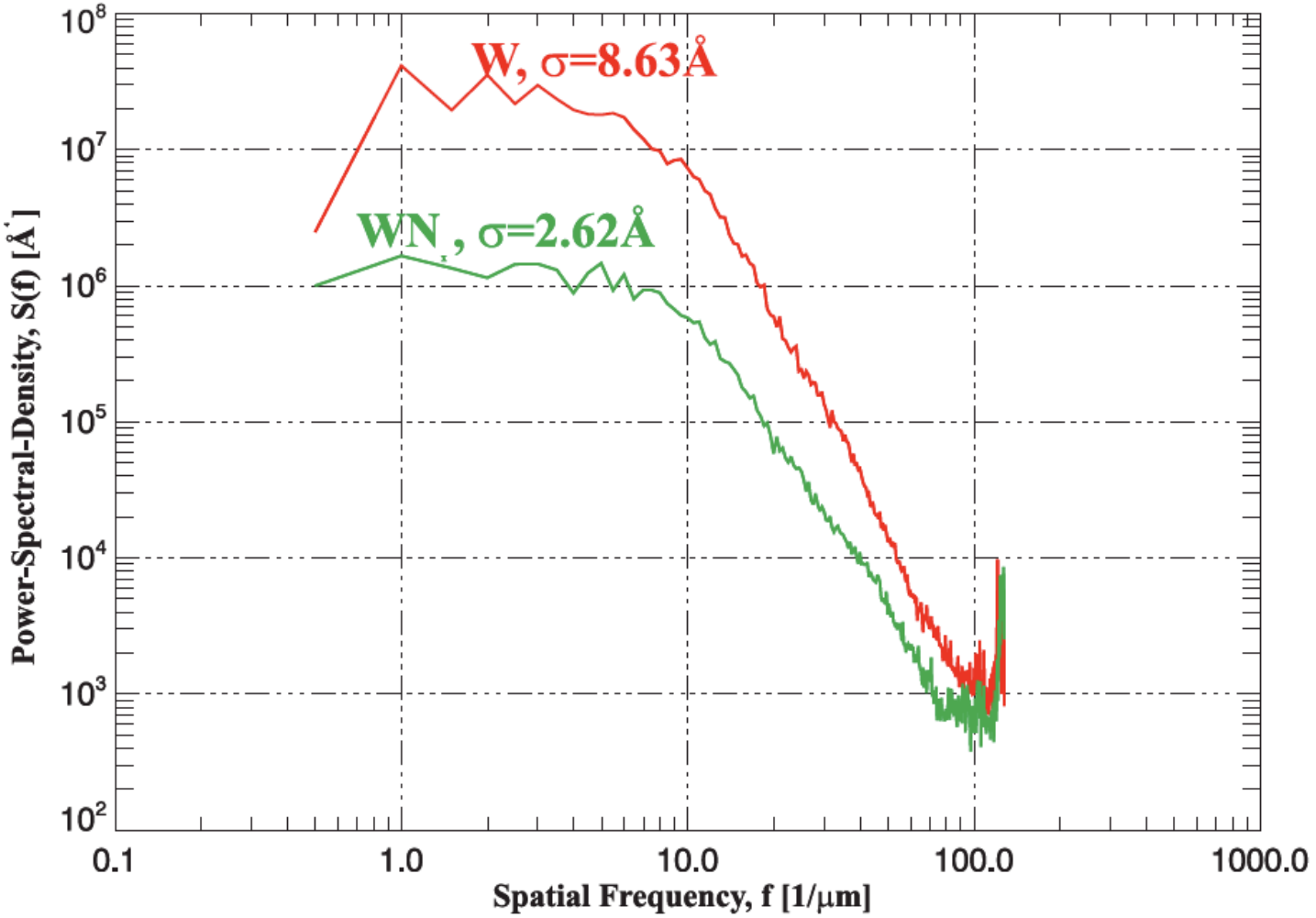


Smoother films



- "these films can be used as smoothing layers to reduce the surface roughness, thereby leading to reduced scattering"

Better smoothness power spectra

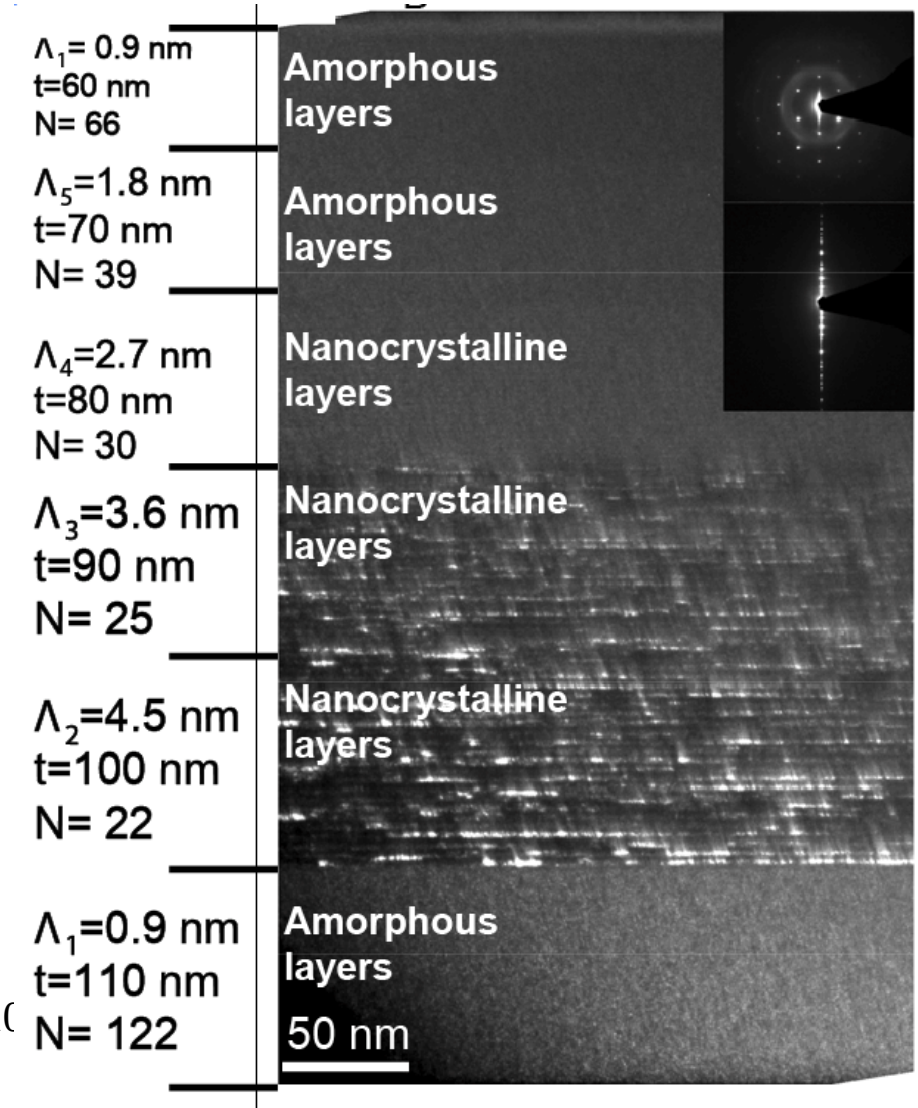


Incorporation of small size atoms in glasses (from the glassy metal community)

- Glassy metal people also use Beryllium, Boron and other small atoms to promote glassyness
- The small atoms:
  - fill the “empties” in the glass structure,
  - impede crystallization (they need to be physically displaced or segregate to form crystals) and
  - stabilize the glass
- Can we dope Oxydes with small atoms in our coatings to get the same stabilizing effects?
- Would this reduce mechanical losses?

Thin layers are more stable

- Can we take advantage of this?
- Would alternate thinner layers also improve the Quality factor?



Thin layers are more stable

- If thin layers are also less mechanically lossy,
  we could make a superlattice of alternated,
  nanoscale, high-n or low-n sub-layers

- TiO_2 has the highest refraction index available (barring diamond)
  but we do not use it because it does not glassyfy
- Guus Rijnders showed that thin
  TiO_2 glass layers are possible

Ideas with Thinner layers

- Alternate TiO_2 and Ta_2O_5 nano-layers to generate higher "n" super-layer?
  - Less layers needed, less losses maybe?
- Simply alternate nano-layers of different concentrations of TiO_2 doping in Ta_2O_5 ?
- Can nano-layers of TiO_2 and C, the two highest refraction index materials, be alternated to form a stable high-n layer in our coatings?

A few even more exotic ideas

- If thin layers are beneficial, can we revisit Kantor sequences (that we put aside because of thin layer concerns)?
  - They considered but for them layers end up being smaller than interdiffusion.
  - In our case the scale is 2-3 orders larger

- Andrew Aquila in super lattice structures the sequence order is important, can change sign of effect

Other ideas collected

- Ion gun sputtering can it be useful for us?
- Shown how it can be more versatile than magnetron
- Ion milling (etching) used, effective but different conditions (incident angle, pressure, rotation) lead to ordered structures
- An observation:
- Ion miling was shown to always forms a glassy layer, even on top of crystals. Can we take advantage of this during deposition?

Additional synergies

- Also, interaction with the X-ray community can lead to improved diagnostic techniques
- X-rays are powerful probes of the internal structure of coatings

Final comments

- The X-ray community , forced by the nature of X-rays, use larger variety of techniques and materials
- Wrestle with much thinner structures
- Use many more layers (thousands instead of tens)
- Need higher precision in coating thickness control (to maintain coherence)
- Most materials not transparent for light
- Many of the techniques that they explore may be adapted for our uses

Final comments

- Few of the ideas are of immediate, tactical, use
- In a more strategic view, exploration and development of some techniques used in X-ray coatings can provide new avenues to mitigate our technical problems
- Very Important synergies are possible