Progress in Development of Silica Aerogel for Particle and Nuclear Physics Experiments at J-PARC

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Highlights

- We are developing silica aerogels for use in particle and nuclear physics experiments at J-PARC.
- Modernized conventional method allows us to produce highly transparent aerogels at n = 1.03–1.05.
- Pin-drying method enables us to generate ultrahigh-refractive-index aerogels up to n = 1.26.

References

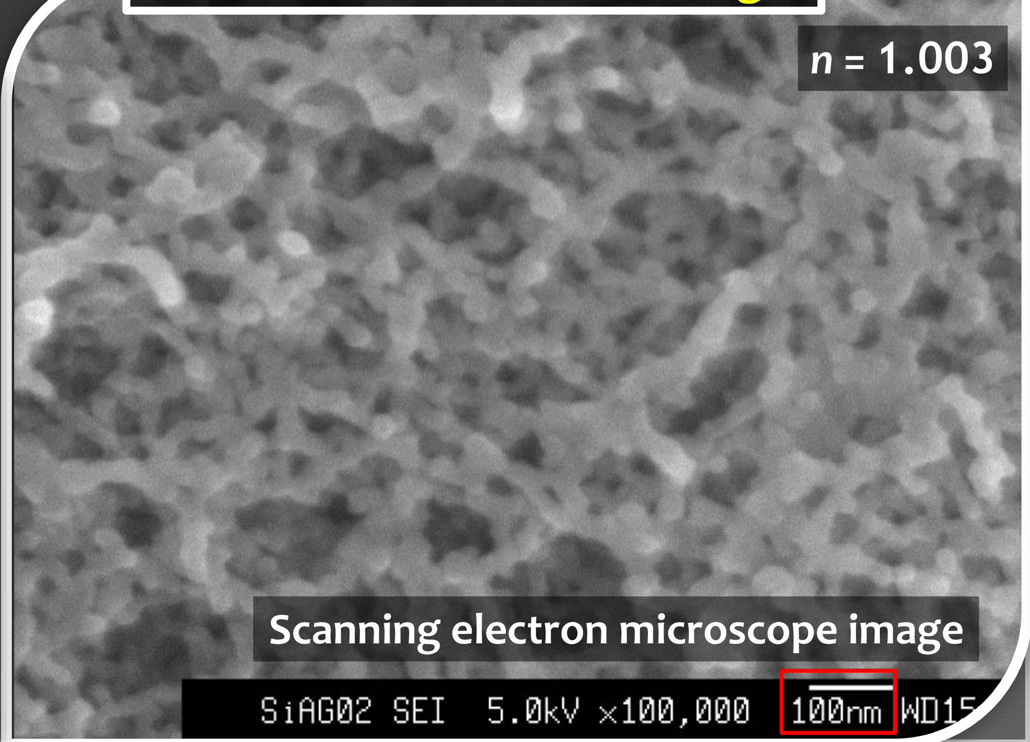
- M. Tabata *et al.*, *Nucl. Instrum. Methods A* 623 (2010) 339.
- M. Tabata *et al.*, *Nucl. Instrum. Methods A* 668 (2012) 64.
- M. Tabata *et al.*, *Physics Procedia* 37 (2012) 642.

Introduction

- Silica aerogel
  - Tunable refractive index, n (determined by silica–air volume ratio)
    - n = 1.003–1.11 (by our conventional KEK method)
    - n = 1.05–1.26 (by novel pin-drying method)
    - → density, ρ = 0.01–1.0 g/cm^3
  - Long transmission length, Λ_T
    - e.g., Λ_T = 40 mm at n = 1.05 (λ = 400 nm)
  - Hydrophobic material (by our production method)
    - Suppressing age-related degradation caused by moisture absorption
  - Large volume, V
    - V_{max} = 18 × 18 × 2 cm^3 (n ~ 1.05), 15 × 15 × 3 cm^3 (n ~ 1.03)
- To be used in several particle and nuclear physics experiments at J-PARC
  - As a Cherenkov radiator (particle identification)
    - Threshold Cherenkov counters
      - e.g., E03 (n = 1.12), E07 (n ~ 1.17), E14 (KOTO, n = 1.03), E36 (TREK, n = 1.08), E42 (n = 1.05)
    - Ring imaging Cherenkov counter
      - e.g., E50 (n =1.03–1.05)
  - As an ultra-cold muon source (muonium production target)
    - E34 (muon g–2/EDM, ρ = 0.03 g/cm^3, n = 1.008)

Dropped water

Nanostructure of silica aerogel

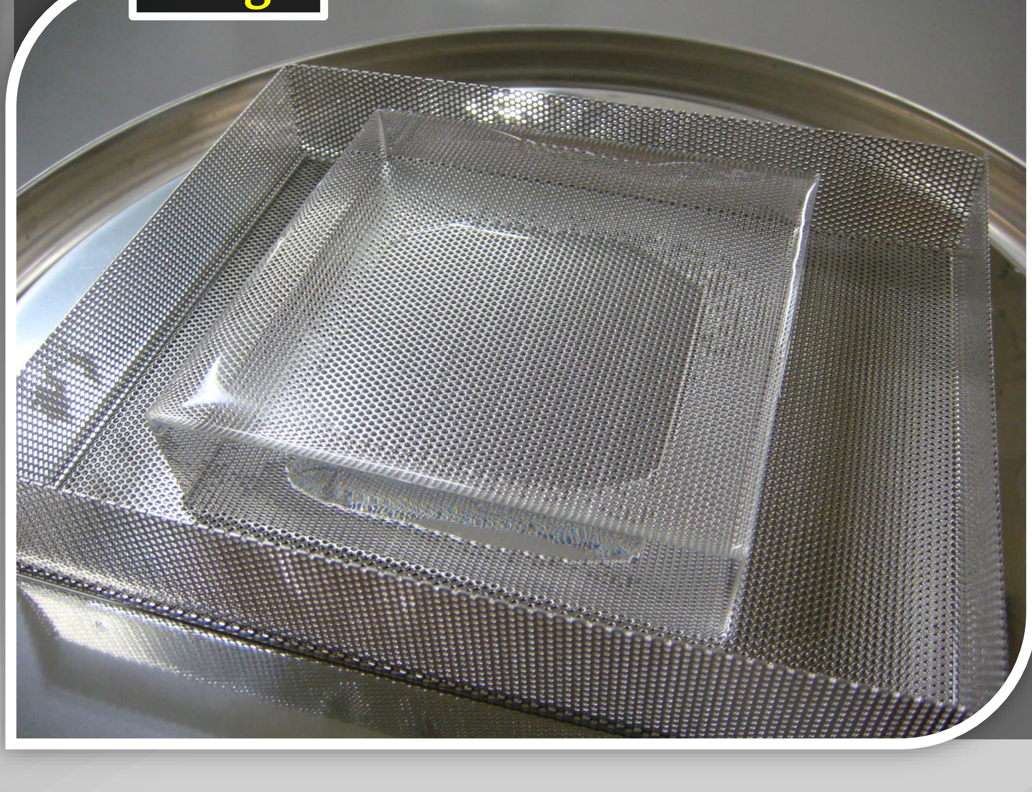


Our Conventional (KEK) Production Method

- KEK method: our standard method for producing hydrophobic aerogels
  - Developed for producing aerogels with n = 1.01–1.03 in 1990s
    - For use in the aerogel Cherenkov counters (ACCs) of Belle experiment at the KEKB collider
  - Using ethanol or methanol as solvent in the wet-gel synthesis
    - Down to n = 1.003 (for use as cosmic dust intact capture medium)
- Modernized conventional method
  - Developed for producing aerogels with n = 1.045–1.06 in 2000s
    - For use in the aerogel ring imaging Cherenkov (A-RICH) detector of Belle II experiment scheduled at the SuperKEKB collider
  - Using *N,N*-dimethylformamide (DMF) or mixture of DMF and methanol
    - Up to n = 1.11
- Production procedure (~ 1 month)
  1. Wet-gel synthesis (molding)
  2. Aging and mold detachment
  3. Hydrophobic treatment
  4. Solvent replacement (using ethanol)
  5. Supercritical drying with an autoclave (using carbon dioxide or ethanol)

Ethanol autoclave
31 ℓ

Wet gel



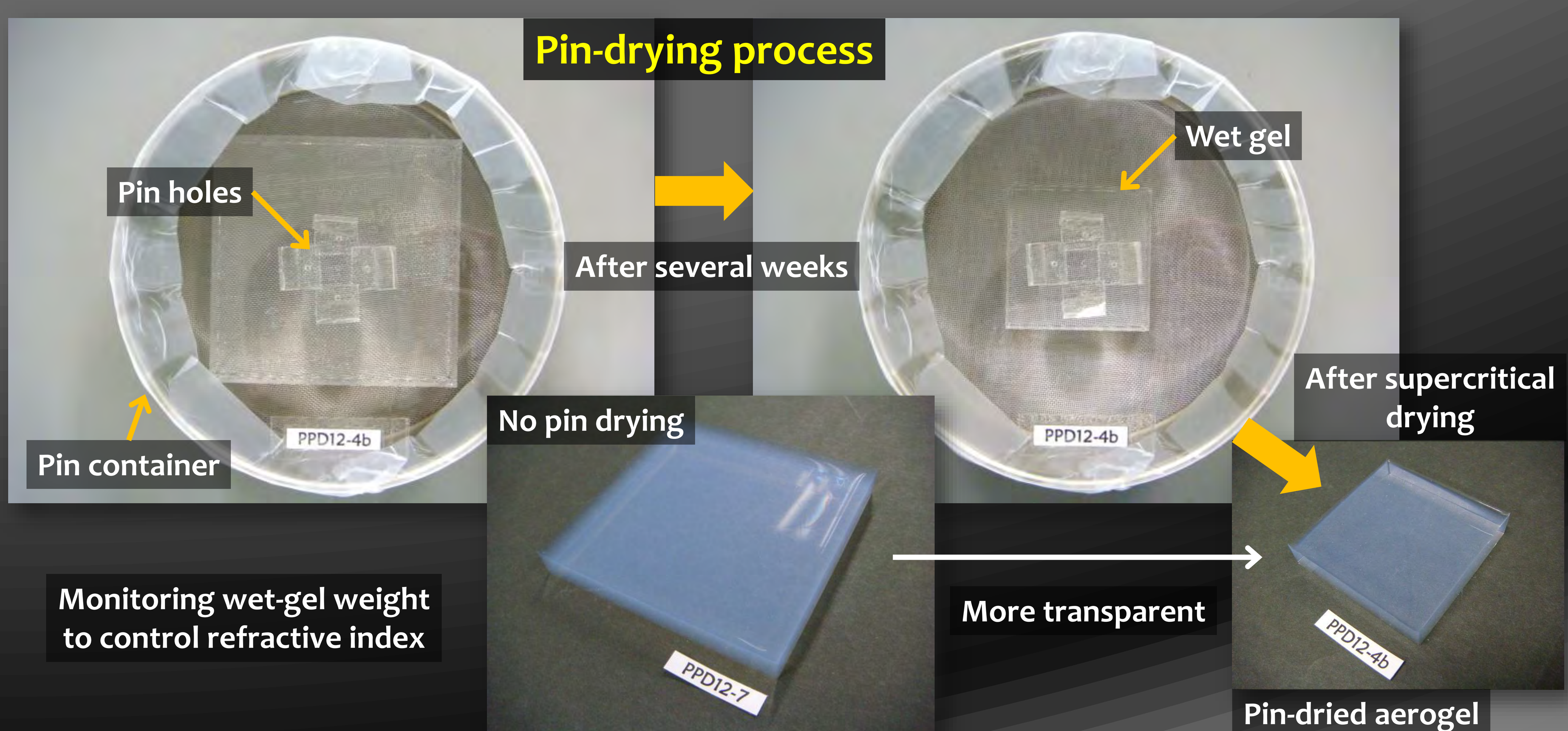
CO_2 autoclave
7.6 ℓ

Pin-drying Method

- Recently developed for producing aerogels with ultrahigh refractive index (n > 1.10)
- Production procedure
  1. Wet-gel synthesis
  2. Aging and mold detachment
  3. ← Pin-drying process
  4. Hydrophobic treatment
  5. Solvent replacement
  6. Supercritical drying

Pin-dried aerogel sample

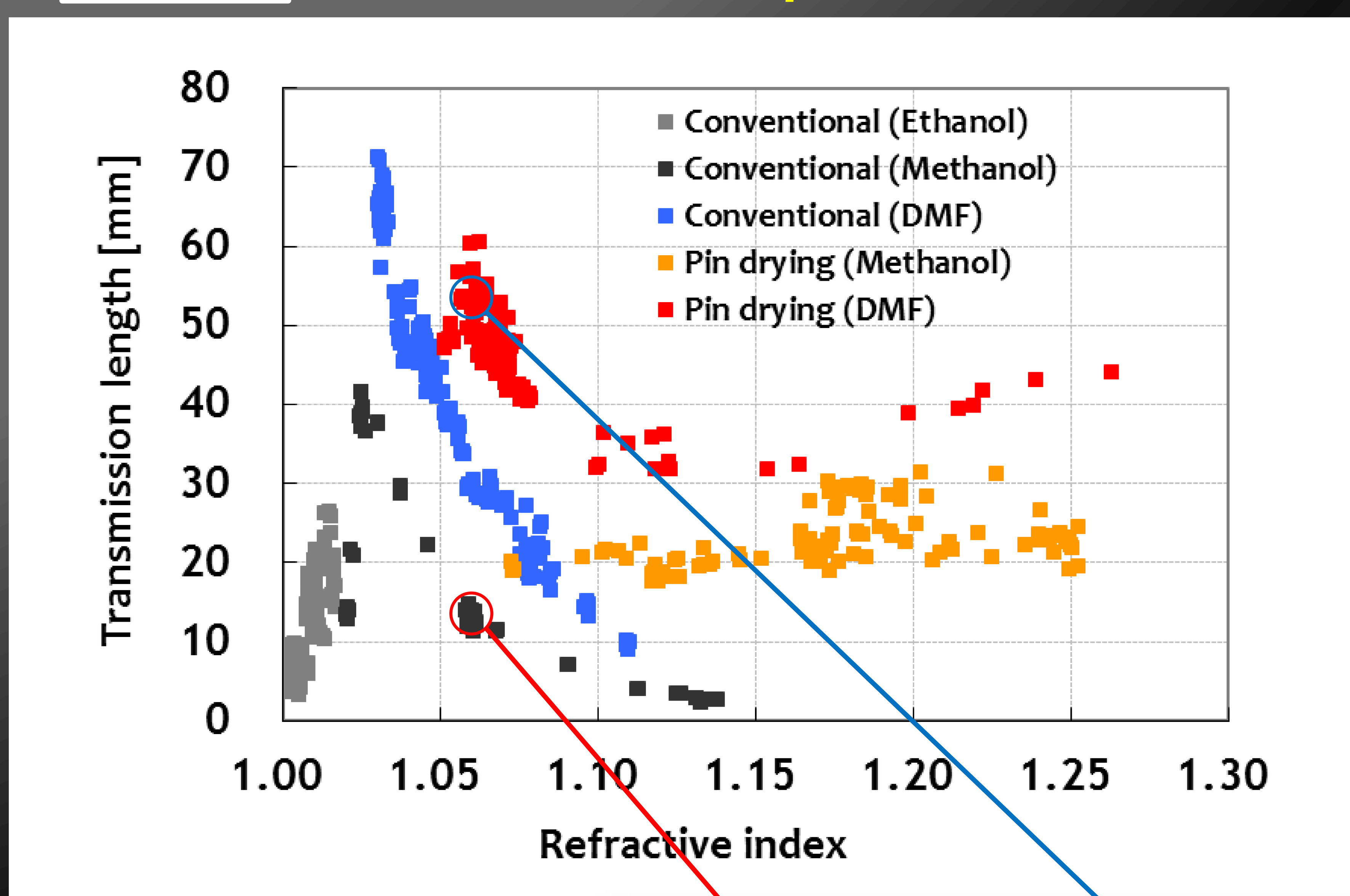
Pin-drying process



- Before hydrophobic treatment, to increase silica density, the wet gel is shrunk by partial drying (solvent evaporation) in a semi-sealed container punctured with pin holes to suppress cracking the wet gel.
- More transparent aerogels can be obtained after supercritical drying.

Optical Characterization

Aerogel plot



- Using the modernized conventional method:
  Λ_T = 40–70 mm at n = 1.03–1.05
- Using the pin-drying method:
  Λ_T = 40–60 mm at n = 1.05–1.075
  Λ_T > 20 mm at n = 1.075–1.26

n = 1.06, thickness = 1 cm