HTS coils without HTS tapes:
Direct deposition and patterning on wide surfaces

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CCA 2023 Workshop, Houston 04-04-2023
A fusion of talents!

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Fusion Power Plant

\[ ^6\text{Li} + n \rightarrow ^4\text{He} + T \]

\[ ^7\text{Li} + n \rightarrow ^4\text{He} + T + n' \]
Deuterium-Tritium Fusion

Deuterium (D)
From water

Tritium (T)
From Lithium

Helium (He)

Neutron (n)

3.5 MeV

14.1 MeV
For D-T, Triple product $nT\tau_E > 3 \cdot 10^{21} \text{m}^{-3}\text{keV s}$

**INERTIAL**
Compression, e.g. by lasers

- Laser power
- Target nanofabrication
- Uniformity of compression
- Repetition rate

**MAGNETO-INERTIAL**
Magnets & Compression

- Uniformity of compression
- Compression ratio
- Plasma purity

**MAGNETIC**
Confinement by strong magnets

- Size of device
- Magnetic field strength
Tokamaks vs. stellarators

**TOKAMAK**

- Simple to build
- Difficult to operate (pulsed, unstable, subject to “disruptions”, regulatory issues)

**STELLARATOR**

- Difficult to build
- Simple to operate (steady-state, stable)
...and simplify HTS manufacturing

2 machines instead of 7
7x faster process
Multi-layer

3D $\rightarrow$ two 1D movements

Portable sub-assemblies
(cryostat + vessel + coil-set)

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Presentation given at Coated Conductors for Applications Workshop, Houston, TX, USA, April 2023.
Many other applications

MRI

Energy Storage

HTS tapes

Quantum Computing

Energy Storage

Electric Motors & Accelerator's Magnets
Coil Winding Surface (CWS)
Does it really have to be conformal to the plasma boundary?

W7-A: axisymmetric

Early modular designs: axisymmetric

W7-AS: ~ piecewise cylindrical?

W7-X: ~ conformal
HTS cylinders simplify stellarators’ Coil Winding Surface (CWS)

W7-X: ~ conformal CWS
Complex surface
Simple current-pattern

RF: piecewise cylindrical
Simple surface
Complex current-pattern
(but simple for the laser)
A **safer** reactor thanks to liquid metal walls

Increasing $jxB$ and/or $v$

- Parabolic
- Near-circular
- Circular (full coverage)
## Architecture of REBCO coated conductor

<table>
<thead>
<tr>
<th>Layer</th>
<th>Deposition technique</th>
<th>Thickness (±5%)</th>
<th>Max Deposition speed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>Magnetron</td>
<td>80 nm</td>
<td>120 m.h⁻¹</td>
<td>Diffusion barrier to metal ions from C-276</td>
</tr>
<tr>
<td>Y₂O₃</td>
<td>Magnetron</td>
<td>7 nm</td>
<td>400 m.h⁻¹</td>
<td>Seed layer for MgO</td>
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<tr>
<td>MgO</td>
<td>IBAD</td>
<td>10 nm</td>
<td>~14 m.h⁻¹</td>
<td>Template for the epitaxial deposition of REBCO</td>
</tr>
<tr>
<td></td>
<td>MOCVD</td>
<td>20 nm</td>
<td>100 m.h⁻¹</td>
<td></td>
</tr>
<tr>
<td>LMO</td>
<td>MOCVD</td>
<td>30 nm</td>
<td>100 m.h⁻¹</td>
<td>Buffer layer (Lattice match)</td>
</tr>
<tr>
<td>REBCO</td>
<td>MOCVD</td>
<td>2 µm</td>
<td>7.5 m.h⁻¹</td>
<td>HTS layer</td>
</tr>
<tr>
<td>Ag</td>
<td>Magnetron</td>
<td>2 µm</td>
<td>70 m.h⁻¹</td>
<td>Protection layer</td>
</tr>
</tbody>
</table>

*Layers not up to scale*
State of the art

Fig. 1. Quasi-equilibrium heater 1, 2, 5, 6 with a substrate tape 3 helically wound on the cylindrical tape guide 4.
MOCVD temperature distribution (FEA)
MOCVD machine with QEH reactor for 1 m wide tape
Instead of summary:

- MOCVD with QEH reactor should yield a sufficient surface homogeneity in wide tapes

- It should also exhibit a very high deposition efficiency suppressing material loss down to <20%

- Experimental confirmation of these features is expected in 2023
Backup foils
A clear roadmap to commercial fusion
+exit-point to early revenues

Skyfall III

Chartreuse X

Chartreuse P

**Milestone 1** (late 2024)

**Milestone 2** (2025 onwards)

**Milestone 3** (early 2030’s)

Enable

Integrate

Electrify

Business opportunities
Information for the session discussion: extra-wide tapes

- Gaps in technology: not found
- Conductor specifications – quantitative:
  \[ w=1 \text{ m}, \ L = 1000 \text{ m}, \ \text{Ic}(\text{SF}, \ 77\text{K}) \geq 250 \text{ A/cm-width} \text{ (or } 25 \text{ kA/m-width)} \]
- Conductor volume needed – 3 years, 5 years: 10 km / 50 km
- What improvements are needed in conductor – prioritize:
  it will be needed: to provide high Jc homogeneity
- Supply Chain issues: not yet found
- Potential areas of collaboration with other applications, conductor manufacturers:
  possible applications: (see slide 8) energy storage, quantum computing, + electromagnetic shielding, levitation, high field magnets
Tokamaks vs. stellarators

Coils simpler to build
Difficult to operate (pulsed, unstable, subject to “disruptions”, regulatory issues?)

Difficult to build
Simple to operate (steady-state, stable, no need for energy-intensive CD)