Participants in the Collaboration

• Los Alamos Neutron Science Center (LANSCE) at LANL: Tsuyoshi Tajima, Jianfei Liu, Alan Shapiro, Frank Krawczyk, Dale Schrage, Bill Clark, Rich Sheffield
• Superconductivity Technology Center (STC) at LANL: Alp Findikoglu, Fred Mueller
• Superconductor Technologies, Inc. (STI): Brian Moeckly
• University of California, San Diego (UCSD): Vitali Nesterenko and his group
• Cornell University: Alexander Romanenko, Hasan Padamsee
• Johannes Kepler University in Austria: Markus Kuehberger (now in industry)
• Ohio State University: Ted Collings
Outlook

• Which materials should be studied for the application of SRF cavities? $\text{Nb}_3\text{Sn}$ and $\text{MgB}_2$

• What we have done at LANL in collaboration with other institutions

• Summary and some thoughts for the future
Nb\textsubscript{3}Sn and MgB\textsubscript{2} are good candidates – Refer other materials to Palmieri’s review

### Superconductivity parameters for Nb, Nb\textsubscript{3}Sn, and MgB\textsubscript{2.}

<table>
<thead>
<tr>
<th>Material</th>
<th>$T_c$ [K]</th>
<th>GL Parameter $\kappa_{GL}$</th>
<th>$H_c$ [mT]</th>
<th>$H_{c1}$ [mT]</th>
<th>$H_{c2}$ [mT]</th>
<th>$H_{sh}$ [mT]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb (0K)</td>
<td>9.2</td>
<td>0.78</td>
<td>200</td>
<td>170</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Nb\textsubscript{3}Sn (0K)</td>
<td>18.2</td>
<td>22.8</td>
<td>535</td>
<td>52</td>
<td>17300</td>
<td>401</td>
</tr>
<tr>
<td>MgB\textsubscript{2} (4 K)</td>
<td>39</td>
<td>36.3</td>
<td>429</td>
<td>30</td>
<td>22000</td>
<td>321</td>
</tr>
<tr>
<td>MgB\textsubscript{2} (20 K)</td>
<td>39</td>
<td>25.4</td>
<td>278</td>
<td>25</td>
<td>10000</td>
<td>209</td>
</tr>
</tbody>
</table>

$H_{sh}$ was calculated using the following formula.

$H_{sh} = 1.2H_c$ for $\kappa_{GL} \approx 1$

$H_{sh} = 0.75H_c$ or $\kappa_{GL} >> 1$

However, as shown later, these formula do not seem to be consistent with experimental results.

T. Tajima, EPAC2002
If $H_{sh}$ limits the field, Nb$_3$Sn and MgB$_2$ can exceed Nb theoretically.

$$\frac{H_{peak}}{E_{acc}} = 40 \text{ (Oe/MV/m)}$$

<table>
<thead>
<tr>
<th>Material</th>
<th>Operation Temp. [K]</th>
<th>Theoretical Limit $E_{acc}$ [MV/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>4</td>
<td>49</td>
</tr>
<tr>
<td>Nb$_3$Sn</td>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>MgB$_2$</td>
<td>4</td>
<td>80</td>
</tr>
<tr>
<td>MgB$_2$</td>
<td>20</td>
<td>52</td>
</tr>
</tbody>
</table>
Which Material Should Be Studied First?

• In my opinion, Nb₃Sn should be the first material to be pursued because
  – If $H_{sh}$ limits the field, the $E_{acc}$ could exceed that of Nb
  – $T_c = 18.6$ K, energy gap ratio $2\Delta_0/k_BT_c = 4.5$ are attractive for higher Q cavities at the same operation temperature
  – There has already been some success with real cavities, refer to EPAC96 paper by Mueller et al.
  – Nb cavities can be converted to Nb₃Sn cavities and could show better performance, which saves fundamental investment on materials
Some data on Nb$_3$Sn

- Unfortunately, our effort to get internal LANL funding for developing Nb$_3$Sn cavities has been unsuccessful. We only got some small funding for MgB$_2$ evaluation.

- The following data are from Cornell, SLAC and Wuppertal/Jlab.
Experimental results disagree with $H_{sh}$ theory for Nb$_3$Sn

Pulse length $\sim 100$ $\mu$s

Nb: 1.3 GHz single-cell cavity with RRR$\sim$460

Nb$_3$Sn: 3 GHz single-cell cavity, coating by Wuppertal and etched at Cornell

An older SLAC data show higher limit (130 mT) vs 110 mT (Cornell) with shorter pulse tests: This indicates that the experimental results of the field could be higher.

3 GHz single-cell cavity
Pulse length ~ 1 μs
One 1.5 GHz single-cell cavity result has shown that CEBAF accelerator could be operated at 4.2 K with Nb$_3$Sn cavities instead of using Nb cavities at 2 K

Cavity $Q_0$ was $\sim$50x Nb at low field at 4.2 K!!

Best $R_{res} = 2.2 \text{ nΩ}$!

Nb$_3$Sn coating at Wuppertal and measurement at JLAB

G. Mueller, P. Kneisel et al., EPAC96.
Magnesium diboride ($\text{MgB}_2$)

This material has been known for many years, but it was discovered to be superconducting ($T_c=39\text{K}$) in 2001.
MgB$_2$ samples made with a Hot Isostatic Press Technique developed at UCSD

Figure 7. Examples of machined samples from HIPed magnesium diboride. Notice mirror like quality of polished sample on left and third from left. Three small parallelepipeds with sharp corners were machined for high accuracy RUS measurements of elastic constants.


LA-UR-04-6730
First RF Surface Resistance measurement at STC of LANL

- No increase of $R_s$ from 0.2 to 4 Oe as compared to significant increase with YBCO.
- This material is not optimized for low $R_s$, i.e., there is room for improvement
- $R_s$ (BCS) of Nb (4K, 10 GHz) $\sim 40 \mu\Omega$


LA-UR-04-6730
Magnetic Susceptibility Measurement for the HIPped bulk MgB₂

- Zero magnetization with field cooling (FC) compared to -1 with zero field cooling (ZFC) indicates that there is significant amount of flux pinning sites, which contributes to the increase of residual resistance.

RF Surface Resistance Measurement of HIPped bulk MgB$_2$ at LANSCE of LANL: Results converted to 10 GHz

- No degradation with high-pressure water rinse
- Surface polishing with 0.1$\mu$m diamond lapping paper reduced $R_s$ significantly

T. Tajima, J. Liu et al., 6$^{th}$ European Conference of Applied Superconductivity, Sorrento, September 14-18

LA-UR-04-6730
400nm film on sapphire substrate showed further $R_s$ reduction, lower than Nb at 4 K!!

Alp Findikoglu of STC at LANL, unpublished
Film prepared by Brian Moeckly of Superconductor Technologies, Inc.
Polycrystal, non-epitaxial film
Intrinsic (BCS) Resistance could be about one order of magnitude lower than Nb at 4 K!!

Alp Findikoglu of STC at LANL unpublished
An attempt to coat MgB$_2$ on metals such as Nb has started at STI

- Using the same technique on Sapphire, two 1.46 cm-diameter Nb disks (1 mm in thickness) were coated with MgB$_2$ by Brian Moeckly of STI.
- This is the first attempt and no optimization has been done yet.
- A parallel plate measurement was carried out by Alp Findikoglu of LANL. About one order of magnitude higher $R_s$, but could be improved with better substrate preparation, etc.
$R_s$ vs. Magnetic Fields
Measurements are Underway

- Tests with $\sim 760$ MHz Nb coax cavity at LANSCE of LANL
- Tests with 6 GHz $TE_{011}$-mode cavity at Cornell
Tests at LANSCE using a 760-MHz coaxial cavity

Magnetic field plots

- Magnetic field of up to ~140 mT can be obtained at the sample port with $E_{\text{peak}} \sim 0.46$ MV/m if it quenches at 200 mT at maximum magnetic field region.
- Necessary cavity power is less than 1 W with $Q_0 \sim 1E9$
- Samples will be placed at a high magnetic field region

Calculation by Frank Krawczyk of LANSCE at LANL

LA-UR-04-6730
Tests at Cornell with 6-GHz TE$_{011}$ Cavity is underway

Measurement by Alexander Romanenko

Magnetic field calculation and test data will be shown when they are obtained.

Magnetic field can be raised up to ~20 mT
Other collaborations

• Electro-polishing of MgB$_2$ samples at Johannes Kepler University in Austria.
  – It was found that MgB$_2$ can be electro-polished to get a smooth surface, which is more suitable polishing method for SRF cavities application. Electro-polished samples have not yet been prepared for $R_s$ measurements.

• Making solid MgB$_2$ by Hot Isostatic Press (HIP) technique at University of California at San Diego (UCSD). As soon as more funding is obtained, we will start optimizing the process to lower residual resistance.

• Ted Collings of Ohio State University is interested in this development. A paper on the possibility of MgB$_2$ written by him and Tajima will be published in SUST soon.
Summary

• $\text{Nb}_3\text{Sn}$ work should be restarted.
• $\text{MgB}_2$ has already shown RF surface resistance lower than Nb at 4 K and has the potential of reaching about one order of magnitude lower than Nb at 4 K.
• Magnetic field dependence measurements are critical for SRF cavity applications and they are underway.
• Attempts to coat $\text{MgB}_2$ on metals such as stainless steel and Nb have started in industry.
Some thoughts for the future

• More funding is necessary for rapid developments on new materials if our target to replace Nb cavities within 5 years, especially for Nb$_3$Sn and MgB$_2$.

• For MgB$_2$ and other promising materials, it is better to form a strong collaboration internationally to expedite the study and cavity development.