Status of High-Gradient R&D

- Structures tested in NLCTA since ISG-9
  FXB-002, H90vg3N, H60vg3N-6C, FXB-003,
  SW20a375, FXB-004, H60vg3S18

- Evolving picture of RF breakdown

- Latest developments in structure design

- Conclusion and Outlook
NLC Structure development

SLAC/NLC
C. Adolphsen, G. Bowden, D. Burke, J. Cornuelle, S. Döbert,
V. Dolgashev, J. Frisch, E. Garwin, R. Kirby, S. Harvey,
K. Jobe, R. Jones, F. Le Pimpec, Z. Li, G. Loew, D. McCormick,
R. Miller, C. Nantista, J. Nelson, C.K. Ng, M. Ross, R. Ruth,
T. Smith, S. Tantawi, J. Wang and P. Wilson

FNAL/NLC
T. Arkan, C. Boffo, H. Carter, D. Finley, I. Gonin,
T. Khabiboulline, G. Romanov, N. Solyak

KEK/JLC
Y. Higashi, T. Higo, N. Toge

Steffen Döbert, SLAC/NLC
NLCTA X-band power source

- 2 Test Stations with:
  - 2x50 MW Klystrons into a SLED system
  - 2 testing slots each
  - 150 MW per structure

- 60 MeV electron beam for energy and phase measurements
FXB002

First Fermilab structure high power tested

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>60 cm</td>
</tr>
<tr>
<td>Phase advance</td>
<td>150 deg</td>
</tr>
<tr>
<td>Group velocity</td>
<td>3 %</td>
</tr>
<tr>
<td>$\frac{E_s}{E_\text{acc}}$</td>
<td>2.2</td>
</tr>
<tr>
<td>$P_{\text{in}}$ (65 MV/m)</td>
<td>63 MW</td>
</tr>
<tr>
<td>Coupler</td>
<td>rounded</td>
</tr>
<tr>
<td>Preparation</td>
<td>external Ar-brazing, oxidized no vacuum bake</td>
</tr>
</tbody>
</table>

Steffen Döbert, SLAC/NLC
**H90vg3N**

Paired up with FXB002 afterwards alone

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>90 cm</td>
</tr>
<tr>
<td>Phase advance</td>
<td>150 deg</td>
</tr>
<tr>
<td>Group velocity</td>
<td>3 %</td>
</tr>
<tr>
<td>Es/Eacc</td>
<td>2.4</td>
</tr>
<tr>
<td>$P_{in}$ (65 MV/m)</td>
<td>82 MW</td>
</tr>
<tr>
<td>Coupler</td>
<td>rounded, inline taper</td>
</tr>
<tr>
<td>Preparation</td>
<td>$H_2$-bonding/brazing</td>
</tr>
<tr>
<td></td>
<td>Vacuum bake</td>
</tr>
</tbody>
</table>

Steffen Döbert, SLAC/NLC
H90vg3N

Breakdown-rates vs input power

- **H90vg3N**
- **H60vg3N-6C**

Breakdown rate per hour

Input Power (MW)

Steffen Döbert, SLAC/NLC
Breakdown rates vs surface field

- **H90vg3N**
- **H60vg3N-6C**

Steffen Döbert, SLAC/NLC

Next Linear Collider Test Accelerator

Steffen Döbert, SLAC/NLC
H90vg3N

Breakdown-rates vs pulse length

Slope: 8 MV/m per decade

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Pulse length dependence

100 MW, $\sqrt{400 \text{ ns}}$
60 MW, cubic-root(400 ns)

Data @ 1 breakdown/hour
Data @ 0.1 breakdown/hour

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Running at 65 MV/m - H90vg3N

H90vg3N

Avg Gradient (MV/m)

Time (h)

BD-rate per hour

Average rate: 1.28/h

Average rate: 0.11/h

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Dark currents - H90vg3N

Surface field: 156 MV/m (Eacc = 65 MV/m)
6 slotted cells brazed in the middle
Best H-structure so far!

Length: 60 cm
Phase advance: 150 deg
Group velocity: 3 %
Es/Eacc: 2.2
Pin (65 MV/m): 63 MW
Coupler: rounded, inline taper
Preparation: H₂-bonding/brazing
Vacuum bake

Steffen Döbert, SLAC/NLC
Clustering in space - H60vg3N-6C

Hot spots: dirt or defects?

Each Cross-Hatch = Cell

Steffen Döbert, SLAC/NLC
Clustering in time - H60vg3N-6C

Steffen Döbert, SLAC/NLC

Next Linear Collider Test Accelerator

Spit fests: damage or processing?

65 MV/m

70 MV/m

Time Between Trips (Minutes)
(Times > 30 Plotted at 30)

Number of Trips (162 Total)

Number of Trips (114 Total)
One month at 65 MV/m - H60 vg3N-6C

Breakdown Rate

Average Trips per Hour Each Day

Days

Steffen Döbert, SLAC/NLC
Dark currents - H60vg3N-6C

Fowler-Nordheim-Plots

Beta H60 at 50 ns: = 39
Beta H60 at 100 ns: = 37
Beta H60 at 400 ns: = 30
Beta H60 at 400 ns; 05/09/03: = 47

Steffen Döbert, SLAC/NLC
**FXB003**

**Congratulations! No.2 worked**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>60 cm</td>
</tr>
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</tr>
<tr>
<td>Group velocity</td>
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</tr>
<tr>
<td>Es/Eacc</td>
<td>2.2</td>
</tr>
<tr>
<td>Pin (65 MV/m)</td>
<td>63 MW</td>
</tr>
<tr>
<td>Coupler</td>
<td>rounded</td>
</tr>
<tr>
<td>Preparation</td>
<td>Ar-brazing, short H\textsubscript{2}-bake + Vacuum bake</td>
</tr>
</tbody>
</table>

Steffen Döbert, SLAC/NLC
Steffen Döbert, SLAC/NLC

Next Linear Collider Test Accelerator

Processing history - FXB003

Time with RF On (hr)

Structure Gradient (MV/m) and Trip Rate/3 (#/hr)

50 ns 100 170 240 400
65 MV/m run
No clear hot spots
But typical front bias
Dark currents - FXB003

- Normal machined
- Beta similar to H60vg3N-6C

Beta H60-FXB003 (170 ns): = 47
Beta H60-FXB003 (240 ns): = 38
Beta H60-FXB003 (400 ns; 04/29/2003): = 38
Beta H60-FXB003 (400 ns; 05/06/2003): = 38
Vacuum activity - FXB003

Processing > 70 MV/m

65 MV/m  65 MV/m

Steffen Döbert, SLAC/NLC
Standing wave structures

Length: 2x20 cm
Phase advance: 180 deg
Es/Eacc: 2.05
Pin (55 MV/m): 9 MW
Coupler: rounded
Preparation: H₂-bonding/brazing
Vacuum bake

Steffen Döbert, SLAC/NLC
Examples - SW20a375

Input RF pulse

Reflected Signals

SW 1

SW 2

Steffen Döbert, SLAC/NLC
Ratio SW1/SW2 = 5.8

Steffen Döbert, SLAC/NLC
Acoustic sensors - SW20a375

Upstream structure 1887 total breakdowns

Downstream structure 608 total breakdowns

Steffen Döbert, SLAC/NLC
<table>
<thead>
<tr>
<th>First fully slotted structure</th>
<th>Structure without Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length:</strong> 60 cm</td>
<td><strong>Length:</strong> 60 cm</td>
</tr>
<tr>
<td><strong>Phase advance:</strong> 150 deg</td>
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</tr>
<tr>
<td><strong>Group velocity:</strong> 3 %</td>
<td><strong>Group velocity:</strong> 3 %</td>
</tr>
<tr>
<td><strong>Es/Eacc:</strong> 2.2</td>
<td><strong>Es/Eacc:</strong> 2.2</td>
</tr>
<tr>
<td><strong>P_{in} (65 MV/m):</strong> 66 MW</td>
<td><strong>P_{in} (65 MV/m):</strong> 63 MW</td>
</tr>
<tr>
<td><strong>Coupler:</strong> mode launcher</td>
<td><strong>Coupler:</strong> waveguide coupler</td>
</tr>
<tr>
<td><strong>Preparation:</strong> H₂-bonding/brazing</td>
<td><strong>Preparation:</strong> Ar-brazing</td>
</tr>
</tbody>
</table>
H60vg3S18/ FXB004

Processing started June 11th

Stffen Döbert, SLAC/NLC
H-type-performance BD-rate

~ 6 MV/m / decade

Breakdown rate per hour vs. Average gradient

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Preliminary results!

- Inline taper helps
- Damage appears correlated to surface field distribution

Hot topic in working group

Steffen Döbert, SLAC/NLC
Evolving picture of RF-breakdown

Breakdown probability and damage threshold depends on:

- pulse length ($\tau^{-1/3}$)
- surface field (exp)
- input power (exp)
- RF-surface ($\sim A_s$)
- Material parameters ($T_m^{0.77} C_p^{0.53} D_m^{0.29}$)
- clean fabrication and handling helps
New generation of H-structures

Optimization strategy or Zenghai’s tricks

Input Power for 65 MV/m: Maximal surface field:
- H60vg3s18: 66 MW
- cell#10: 142 MV/m
- H60vg3s17: 59 MW
- cell#10: 130 MV/m

Benefits: ~10% in power and surface field

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Clamped constant impedance structure with Mo-irises

Length: 30 cm
Phase advance: 120 deg
Group velocity: 4.65%
$E_s/E_{acc}$: 2.2
$P_{in \ (65 \ MV/m)}$: 90 MW
Coupler: mode launcher
Preparation: Clamping, no bake

Steffen Döbert, SLAC/NLC
CERN - Mo/W - structures

Steffen Döbert, SLAC/NLC
Some Questions

- What is a hotspot and how to avoid
- Why is it breaking down in the front
- Exact dependence of BD-rate = f(P,Es,As,v_g,τ)
- Understand and characterize damage
- When does it occur
- Which preparation is really necessary
- ...

Steffen Döbert, SLAC/NLC
Conclusion and Outlook

Great results but not yet good enough
60 MV/m with NLC criteria demonstrated
65 MV/m is still somewhat marginal but very close
(beam loading and power ramp helps)
Slots appear to be OK
Road to 65 MV/m:
H60vg4S17: higher shunt impedance,
    lower surface fields
Standing wave and new materials (Moly, Tungsten)

Steffen Döbert, SLAC/NLC
Near future schedule

<table>
<thead>
<tr>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station1:Acc1</td>
<td>SW</td>
<td>CERN</td>
<td>FXB-05</td>
<td>CERN</td>
<td>Station1:Acc2</td>
<td>MO</td>
<td>H60vg3R17</td>
<td>W</td>
<td></td>
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<tr>
<td>Station2:Acc1</td>
<td>H60vg3NS18</td>
<td>FXB-06</td>
<td></td>
<td>8-Pack</td>
<td>Powering</td>
<td>8x60 cm</td>
<td>NLC-ready</td>
<td></td>
<td></td>
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<tr>
<td>Station2:Acc2</td>
<td>FXB-04</td>
<td>H75vg4NS18</td>
<td></td>
<td>structures</td>
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</table>

H60vg4S17-1,2,3,4
FXC001,2,3,4,..