ADVANCES IN BEAM TESTS OF DIELECTRIC BASED ACCELERATING

A.Kanareykin\textsuperscript{1}, Antipov\textsuperscript{1,2}, C.Jing\textsuperscript{1,2}, V.Yakimenko\textsuperscript{3}, J.Butler\textsuperscript{1}, W.Gai\textsuperscript{2}

\textit{Euclid TechLabs LLC, Gaithersburg, MD}
\textit{Argonne National Laboratory, Argonne, IL}
\textit{ATF, Brookhaven National Laboratory, Upton, NY}
We present here three experiments carried out at the ATF, AWA and FACET – a direct wakefield acceleration and high gradient generation.

- High gradient material test with the Ka-band diamond based structure.
- A demonstration of a direct wakefield acceleration with the THz diamond based structure.
Motivation

\[ W_z(z) \approx \frac{Q}{a^2} \exp \left[ -2 \left( \frac{\pi \sigma_z}{\lambda_n} \right)^2 \right] \cos(kz) \]

- **Acceleration:**
  - Collinear acceleration
  - Two-beam acceleration (CLIC-type)
  - Externally driven

- **Structure:**
  - Type of ceramics: loss, multipactor, thermal management, fabrication
  - Power extraction
  - Coupling schemes
  - Tuning
  - HOM suppression

- **Beam:**
  - Phase space manipulation
  - Bunch trains
  - Beam shaping for transformer ratio
  - Beam transport and BBU studies
Our work across the spectrum and applications

- 7.8GHz power extractor (40MW)
- 100MV/m gradient demonstration
- Enhanced Transformer Ratio: 3.4
- Tunable DLA structure
- 26GHz power extractor
- Diamond breakdown experiment (300MV/m)
- Bunch Train generation at the AWA
- Wakefield Mapping diamond
- THz source at AWA
- Chirp correction
- Tunable THz
- GV/m

1GHz 10GHz 30GHz AWA 100GHz 300GHz 1THz 3THz

ATF BNL
FACET SLAC
Diamond

- $\varepsilon = 5.7$; $\tan \delta < 5 \cdot 10^{-5}$ at 30 - 145 GHz
- High breakdown threshold (DC~2GV/m)
- SEE reduction by surface dehydrogenation
- High thermal conductivity = 25 W·cm$^{-1}$·K$^{-1}$ (5xCopper)
- Hardness, low coefficient of friction
- Low thermal expansion
- Radiation resistant
High Grad. Breakdown Study of A Diamond Slab Structure @ ANL/ AWA

Our goal is to perform first WF experiment with Diamond-based DLA, test for breakdown

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch length</td>
<td>2~2.5 mm</td>
</tr>
<tr>
<td>Beam gap</td>
<td>4.0 mm</td>
</tr>
<tr>
<td>D thickness</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>width</td>
<td>8 mm</td>
</tr>
<tr>
<td>length</td>
<td>5.0 mm</td>
</tr>
</tbody>
</table>

*AWA facility can generate up to 100nC beam with $\sigma_z = 2.5$ mm (14 MeV)

Structure is short, TM$_{110}$ – based

Wake is a single mode at ~ 26 GHz

$Q = 2800$ ($\Rightarrow$ decay time $\tau \sim 35$ns)
Field Enhancement in the scratch

Avoiding hot spots on diamond holder

Diamonds (E6) ...scratched

50nC $\rightarrow$ 250 MV/m

Field is ~5 times higher
Diamond test at the AWA

<table>
<thead>
<tr>
<th>Frequency</th>
<th>24.81 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient (AWA 70 nC)</td>
<td>60 MV/m</td>
</tr>
<tr>
<td>Beam gap</td>
<td>4 mm</td>
</tr>
<tr>
<td>Diamond thickness</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Structure width</td>
<td>8 mm</td>
</tr>
<tr>
<td>Diamond length</td>
<td>4 mm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>5.7; tan(δ) = 10^{-4}</td>
</tr>
<tr>
<td>Q, quality factor</td>
<td>2800, τ ~ 35 ns</td>
</tr>
<tr>
<td>r/Q</td>
<td>11.4 kΩ/m</td>
</tr>
</tbody>
</table>

Single crystal CVD diamond (E6) Groove: 20um (wide) x 200um (deep) Field enhancement $\sim \varepsilon \cdot E \approx 300$ MV/m AWA transported 72nC through the structure

Upper half of the diamond resonator

Electron beam

Diamonds (E6) ...with a groove
High Gradient Beam Test

72nC ($\sigma_z=2.5\text{mm}$) went through which is $eqv.$ to $\sim 300 \text{ MV/m}$ gradient on axis for decay time $\tau \sim 35\text{ns}$.

Preliminary examination shows No evidence of breakdowns during the beam test. More examinations or additional test will be carried out.

SEM: Sergey Antipov, Euclid and Sergey Baryshev, MSD ANL
Wakefield Mapping

Witness → Drive beam → Wakefield structure → Spectrometer

Change in D-W spacing → Energy gain/loss of a witness

Experimental drive + witness visualization

Spectrometer measurement
Experiment at ATF: Wakefields and the Structure

Wakefield Mapping of a Diamond Slab Structure at BNL/ATF

- 1\textsuperscript{st} wakefield mapping experiment in THz regime (June 2011).
- 1\textsuperscript{st} wakefield acceleration observed in THz regime.
Energy chirp compensation

**FACET beam**

From M. Hogan, J. England (SLAC)

- Passive device (beam self-action)
- Can be tunable
- Ex. FACET 5% spread $\rightarrow$ 0.75% using a 5cm device

wake from $\sigma_z = 30\mu$, 1nC beam, 300$\mu$ ID / 400$\mu$ OD quartz tube

Initial energy spread after 4.5 cm in silencer
Energy chirp correction demonstrated ATF

Limited by spectrometer resolution
SS housing tubes
Quartz tubes (ε = 3.8)
(Gold sputtered)
Sizes (ID / OD):
1", 200 x 330 µ
1", 300 x 400 µ
2", 400 x 550 µ

Linear chirp correction / energy
Experimentally demonstrated direct wakefield acceleration using diamond loaded 0.25 THz planar structure. A THz diamond based structures tested at BNL/ATF showed no evidence of polycrystalline structure deformation.

Diamond samples have been tested at Ka-band with 300 MV/m wakefield 35 ns pulses - no evidence of polycrystalline structure deformation.