AE52: Beam Manipulation by Self-Wakefield at the ATF

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• **AE52 - Beam manipulation by self-wakefield**

• Various structures
  – dielectric loaded, corrugated, single mode, multimode

• Study of wakefield (/THz)

• Study of self-wakefield
  – Dechirper, energy modulation, transformer ratio

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


Correlated energy chirp from linac

Nguyen, NIMA 96
P. Emma, PRL 04
Collinear wakefield acceleration


Transformer ratio measurement at ATF

- Small witness beam: spectrometer

Beam profile after the mask in a dogleg

Drive (77 pC) and witness (3.5 pC)

Theoretical: 4.5
Measured: 3.5

Drive head energy loss (21keV)

Drive beam head

x 1.75

S. Antipov, AAC 2014
Energy Chirp Correction Experiment at ATF

Triangular-shaped (current) beam with energy chirp

Self-deceleration!

Spectrometer image of the original beam

Spectrometer image after chirp corrector

Chirp corrector – passive wakefield tube: dielectric loaded waveguide

Tunable Energy Chirp Correction Experiment at ATF


dechirper: multimode rectangular dielectric loaded waveguide with tunable beam gap

Triangular-shaped (current) beam with energy chirp

Correlated energy spread was removed by closing the dechirper gap
Semiconductor dechirper - collimator!

<table>
<thead>
<tr>
<th>Dechirpers tested</th>
<th>ATF Ceramic</th>
<th>PAL Copper</th>
<th>ATF Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, pC</td>
<td>54</td>
<td>150</td>
<td>90</td>
</tr>
<tr>
<td>Structure, L, m</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Gap size, mm</td>
<td>1</td>
<td>5</td>
<td>2.4</td>
</tr>
<tr>
<td>ΔE, keV</td>
<td>165</td>
<td>175</td>
<td>90</td>
</tr>
<tr>
<td>Strength, MeV/mm/m/nC</td>
<td>61</td>
<td>2.7</td>
<td>33</td>
</tr>
</tbody>
</table>

S. Antipov IPAC 2016

- Semiconductor – resistivity for charge drain
- Balance between σ and ε
- Silicon – doping, radiation hard
- In the experiment: 5kOhm × cm resistivity but skin depth is 35 mm
- **Propose: Dechirper – Collimator!**

With A. Zholents (APS)
Observation of energy modulation at ATF

Periodic self-deceleration!

Simulation

Measurement: spectrometer

Original chirped beam

0.95 THz structure

0.76 THz structure

Sub-picosecond bunch train production at ATF

PM chicane is used to convert energy modulation into density modulation

CTR interferometry shows that THz periodicity can be tuned by energy chirp

We proposed a high power terahertz radiation source based on this scheme (electron beam wakefields). A third stage, yet another dielectric tube will be installed after chicane to coherently extract THz power from the bunch train.

THz generation at ATF
THz generation at ATF

Dielectric loaded waveguide

Numerous measurements by UCLA and Euclid

G. Andonian, PRL 113, 264801 (2014)

Bragg structure

Corrugated waveguide

K. Bane (SLAC), S. Antipov
NIM-A, Volume 844, 1
February 2017, Pages 121-128

Woodpile structure

G. Andonian, P.Hoang, UCLA
Tunable: $f = 0.1 – 2$ THz, BW = 1-100%

Bunch train – multimode structure interaction

G. Andonian et al., APL 98, 202901 (2011)

Dielectric Dechirper – multimode wake
Corrugated Dechirper – single mode wake


S. Antipov et al., IPAC 2015
Efficient power extraction


0.5 THz, 10uJ – outside the beamline available for experiments
THz parameters attainable at the ATF

- Frequency tunable 0.1 – 3 THz
  - 0.4 – 12.4 meV photons
- Bandwidth tunable: 1 – 100%
  - 100% - single cycle
  - 1% - 100 oscillations in a signal
- Energy in a pulse outside beamline ~10µJ
- Peak power ~ 100kW
- THz pump – THz probe available:

Actual measurement at ATF. Efficient THz extraction. 10µJ
AE52 Summary

Large number of experiments over the years:

• Wakefield mapping
• Beam energy modulation
• Microbunching
• Tunable dechirping
• Enhanced transformer ratio measurement
• Numerous THz measurements:
  – DLA – cylindrical, planar
  – Corrugated structure (with K.Bane (SLAC))
  – Selective mode excitation in a multimode structure
  – Efficient power extraction
• Multistage THz generation experiment – limited by electron-optics and complex alignment
Laser Ablation Examples

- Fresnel lens: quartz
  Diameter = 2 mm
  Depth = 240 um

- Fresnel lens: copper
  Diameter = 2 mm
  Depth = 200 um

- Tapered half-cylinders: quartz
  Each cylinder = 1.25 mm
  Depth max = 570 um

- Depth = 600 um
  1mm X 2mm parabolic trench: copper

- Depth = 100 um
  Polished copper parabolic mirrors

- Periodicity = 90 um

diamond, quartz, copper, tungsten
Femtosecond laser ablation for next generation wakefield structures

Ablation of quartz

Groove polarizer: linear $\rightarrow$ circular (300 GHz)
Future plans

• Next generation wakefield / THz structures
• THz manipulation (polarization, detection ...)
• THz “user” experiment (possible complementarity to UED program?)

Acknowledgements

• **Accelerator User Facility Team** (ATF-BNL)
• Wei Gai, Sasha Zholents (ANL)
• E. Gomez, R. Kostin, S. Kuzikov (Euclid)
• D. Wang, L. Yan (Tsinghua)
• D. Schegolkov, E. Simakov (LANL)
## Electron Beam Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal</th>
<th>Requested Experiment Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy (MeV)</td>
<td>50-65</td>
<td><strong>57 MeV</strong></td>
</tr>
<tr>
<td>Bunch Charge (nC)</td>
<td>0.1-0.5</td>
<td><strong>500 pC</strong></td>
</tr>
<tr>
<td>Compression</td>
<td>Down to 100 fs (up to 1 kA peak current)</td>
<td><strong>Motorized beam masking</strong></td>
</tr>
<tr>
<td>Transverse size at IP (sigma, um)</td>
<td>30 – 100 (dependent on IP position)</td>
<td><strong>75 um</strong></td>
</tr>
<tr>
<td>Normalized Emittance (um)</td>
<td>1 (at 0.3 nC)</td>
<td><strong>1-2 um</strong></td>
</tr>
<tr>
<td>Rep. Rate (Hz)</td>
<td>1.5</td>
<td><strong>1.5 Hz</strong></td>
</tr>
<tr>
<td>Trains mode</td>
<td>Single bunch</td>
<td><strong>Single bunch</strong></td>
</tr>
</tbody>
</table>

Special Equipment: **bolometer/interferometer setup required**
Multi-meter collinear wakefield acceleration

Use of **FODO lattice** for beam confinement

**BNS damping**, i.e., use of drive beam energy chirp to desynchronize transverse particle oscillations and thus reduce the resultant transverse electric wakefield

**High gradient hybrid quad**
- Bore radius = 1.5 mm.
- Peak gradient = 0.96 T/mm.
- Sub-micron precision in the magnetic center position.
- Length = 40 mm.
- Weight = 2.5 kg.
- Magnetic force between top and bottom parts = 30.5 kg.

**Collaboration: APS-AWA-Euclid-LANL**

**D. Shegolkov, E. Simakov (AAC 2014)**