The Micro Accelerator Platform: A Potential Injector for a DLA Based Collider

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Abstract

• The application of advanced accelerator techniques to high energy colliders places demands on the injector system that may be best addressed with advanced injector technologies. With Dielectric Laser Accelerators, the transverse and longitudinal bunch profile as well as the repetition rate required are ill suited for production in conventional injectors. In plasma based schemes, it is often suggested to use plasma based injectors. This talk will discuss the possibility of using a modified DLA--the Micro Accelerator Platform (MAP)--as an injector to a DLA. The MAP is a slab-symmetric laser-powered structure. The MAP is being studied as a sub-relativistic device with an integrated electron gun. There are many challenges in making the MAP, or any DLA, suitable for low-beta acceleration. This talk will very briefly outline some of these challenges, attempts to address them, and what advantages such an effort might have for a future collider.
What is the MAP?
At UCLA, we are designing, fabricating and testing a slab-symmetric, laser-driven, dielectric micro accelerator.

Periodic modulation in z is necessary to have an accelerating mode: a standing wave with $k_z = \omega / \beta c$.

resonant structure with good $E_z$ fields

Device schematic; structure variation in $x$ not shown
Typical values ($\lambda=1\mu m$)

- $a \sim 1\mu m$
- $b-a \sim 10$ nm
- number of periods ~ 1000
- overall length ~ 1 mm
The Micro Accelerator Platform (MAP) offers a number of collider friendly features:

- easy power coupling
- "easy" to scale & stage
- flat beams
- low wakefields

What about breakdown, Gil!?>50µm
The structure consists of a diffractive optic coupling structure and a partial reflector.

Ideal field profile in gap:
\[ E_z = E_0 \cosh\left(\frac{k_z y}{\gamma}\right)\cos(k_z z) \]

where \( k_z = \omega/\beta c \) varies with electron velocity.

Resonance condition: (\( a \) and/or \( b \) vary along structure)
\[ \frac{\gamma \beta}{\varepsilon} \sqrt{\varepsilon - (1/\beta)^2} = \coth\left(\frac{k_z a}{\gamma}\right)\cot\left[\sqrt{\varepsilon - (1/\beta)^2} \frac{\omega}{c} (b - a)\right] \]
We have a preliminary design of the all-dielectric structure.

Coupling structure on top of Bragg reflector etalon.

Periodicity and coupling in one structure element.

We still have a lot of work to do on the $\beta<1$ structure
The $E_z$ field quality is sensitive to the details of the coupler, Bragg stack and inner geometry.
Beam testing is planned at SLAC’s E163 facility which hosts a suite of micro accelerator tools.
How can we produce a low-beta structure?

at 1 GeV/m, each period only produces 1 KeV
1000 periods only yields 1 MeV
1 TeV requires 1 billion periods
Creating a sub-relativistic MAP is hard: the coupling and periodicity are one and the same.
An aperiodic coupling may allow for net acceleration at $v<c$.

The accelerating field may die off before the particle full dephases.
Ming Xie proposed alternating gradient acceleration for laser accelerators (~1998)

\[\Delta W_a = qE_a L_a T_a \quad \text{is the energy gain}\]

\[\Delta W_d = qE_d L_d T_d \quad \text{is the energy loss}\]

Net energy gain...

\[G_{2\pi} = \frac{\Delta W_a + \Delta W_d}{L_a + L_d} > 0\]

and this implies...

\[\frac{E_d}{E_a} \frac{L_d}{L_a} \frac{T_d}{T_a} < 1\]

\[
\frac{d\gamma}{dz} = -ka \cos \psi
\]

\[
\psi = \omega t - \int_0^z k_z(s) ds
\]

\[
a = \frac{eE(z)\lambda}{2\pi mc^2}
\]

\[
\frac{d\bar{\gamma}}{dz} = ka_s S_l \sin \psi
\]

\[
\Delta W \quad \text{is the energy gain}
\]

\[
\Delta W_d \quad \text{is the energy loss}
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\frac{d\bar{\gamma}}{dz} = ka_s S_l \sin \psi
\]
The dielectric “matching” layer can help to provide good fields over a narrow range.

As only certain values of dielectric constants are available, we examined alternating two materials, including vacuum gaps.
The MAP as a DLA-based collider injector
The nominal DLA-based collider parameters match well to a MAP-based injector

<table>
<thead>
<tr>
<th></th>
<th>ILC Nom.</th>
<th>Grating</th>
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<tbody>
<tr>
<td><strong>E_{cms}</strong> GeV</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Bunch Charge</strong> e</td>
<td>2.00E+10</td>
<td>1.00E+04</td>
</tr>
<tr>
<td><strong># bunches/train</strong></td>
<td>2820</td>
<td>375</td>
</tr>
<tr>
<td><strong>train repetition rate</strong> MHz</td>
<td>5.00E-06</td>
<td>20</td>
</tr>
<tr>
<td><strong>final bunch length</strong> psec</td>
<td>1.00</td>
<td>1</td>
</tr>
<tr>
<td><strong>design wavelength</strong> micron</td>
<td>230609.58</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Invariant Emittances</strong> micron</td>
<td>10/0.04</td>
<td>1e-04/1e-04</td>
</tr>
<tr>
<td><strong>I. P. Spot Size</strong> nm</td>
<td>554/3.5</td>
<td>0.5/0.5</td>
</tr>
<tr>
<td><strong>Enh Lumi/ top1%</strong> /cm^2/s</td>
<td>4.34E+34</td>
<td>4.58E+34</td>
</tr>
<tr>
<td><strong>Beam Power</strong> MW</td>
<td>22.6</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Wall-Plug Power</strong> MW</td>
<td>104.0</td>
<td>120.1</td>
</tr>
<tr>
<td><strong>Gradient</strong> MeV/m</td>
<td>30</td>
<td>830</td>
</tr>
<tr>
<td><strong>Total Linac Length</strong> km</td>
<td>33.3</td>
<td>1.2</td>
</tr>
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E. Colby (SLAC)
The development of a MAP-based collider injector is consistent with other long term goals.
The particle source
An integrated gun may solve the beam injection problem and enable micro self-contained sources.

We have obtained emission from a 300µm Li:Nb wafer.

test stand for piezo/pyro electric materials.
The micro patterned crystal produces quasi-continuous emission.
Can polarized electrons be produced?

hexagonal boron nitride (ferroelectric) coated cathode

Physics Institute, University of Zurich
end slides