Non-Plasma Accelerator Session

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Thirteen presentations were made in this session (see attached hardcopy) representing a variety of methods in differing stages of development. Some are relatively well-established and capable of immediate impact, while others are still in the conceptual stage. Several new ideas have appeared in the last two years. The three largest areas of work are: IFEL, dielectric wake field acceleration (DWFA), and small vacuum structures.

1. Inverse Free Electron Laser (IFEL)

The IFEL is the most developed of all the areas, as its roots are in the theory and hardware technology of FEL which developed rapidly in the 1980's. In the 1990's, proof-of-principle experiments were done. Recently, a microwave IFEL experiment at Yale successfully related experimental data to 3D theory, and the STELLA IFEL experiment at ATF demonstrated prebunching on an optical scale of distance and injection/capture/acceleration of the short (3.5u) bunch in a following IFEL stage using higher CO2 laser power related in phase to the first stage. Approximately 50is ready for some ambitious acceleration tests using higher power (100 GW–1 TW) CO2 lasers (ATF [Pogorelsky and Kimura] and UCLA "Neptune"[Musumeci and Pellegrini]) which can accelerate the bunch 50 MEV and demonstrate gradient 90 MeV/m while maintaining high beam quality. The UCLA IFEL uses an undulator with a very rapid taper. Both these new experiments will use tapered undulators of about 50cm in length. It is worthwhile to recall that, by using a constant K tapering, an IFEL might ultimately achieve a bunch energy 200 GV given sufficient laser power, without excessive synchrotron radiation from the wiggler. Given the recent results from STELLA, one would expect that there should not be trouble in staging IFEL sections. Nevertheless, new variations on the IFEL theme keep coming up: an example of this is a "single half-period" wiggler concept presented by Hartemann: in this, the bunch encounters in its axial motion a short region of specially determined transverse magnetic field; under conditions of very high power, a very favorable scaling of acceleration with laser power is obtained. As with many new ideas, the exploratory work is done with 1D analysis, but further effort on 3D effects is needed to justify an experiment. Clearly, a very high power laser which delivers many joules of energy in a pulse is needed to accelerate a bunch to meaningful energy; there is also the need for several repetitions per second, and for an acceptable overall efficiency for the system. It would appear unlikely that a 1/2TEV accelerator would be entirely made up of IFEL sections; yet the IFEL development has permitted a valuable study of laser acceleration and staging, and has developed a proven method for producing fsec bunches, which have many applications even outside of accelerator physics. A STELLA workshop is planned for December 2001 in Tucson.

2. Dielectric Wake Field Acceleration (DWFA)

These devices use an injected "drive" bunch, or train of bunches, in either a co-linear or two-beam configuration, to develop high longitudinal electric fields which can accelerate a "test bunch" to high energy. As the bunches move in vacuum at nearly the speed of light, they set up in a surrounding low-loss dielectric a co-moving Cerenkov wake, and thereby experience energy loss or "drag." The wake fields of several drive bunches may be superimposed to build up field pulses 100 MEV/m to 1 GEV/m moving at the speed of light. No plasma or laser sources are required, or for that matter new microwave sources either, and thus if dielectric wake field accelerators are successful, they have incredible significance for future linear colliders. The energy-delivering hardware is the conventional rf linac. There would appear to be two very important issues: the matter of dielectric failure, and the question of the "transverse" (or

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dipole) instability. The performance of the dielectrics when exposed to transient electric field pulses of < 1 psec duration indicates that a gradient 1 GV/m is reasonable to expect (this is far greater than the breakdown field for a dielectric exposed to microsecond pulses of rf). Modern dielectrics such as alumina exhibit very low loss tangent, high dielectric constant, almost zero dispersion in the microwave/millimeter band, and do not accumulate charge on the surface. The matter of the instability is being dealt with in a number of ways. Argonne described an external damping system useful for stabilizing a bunch train; Park and Hirshfield presented results of their calculations showing that a FODO system could be designed that would delay the onset of the instability in the first bunch. Marshall described a wake field "resonator" system that, by accumulating the wake field energy of several bunches, would decrease the length of the resonator module below the threshold limit of the instability; the drive bunch train energy could be partly recovered in the original linac that provided the drive bunches. The consideration of the resonator has turned attention to the effect of axial boundaries on the wake fields, now receiving analytical attention by Park. If the DWFA becomes operational, one might expect some cooling problems to emerge.

Argonne [Wei Gai and Conde] described their upgraded facility (new laser and PC rf gun that should give higher gradients and better stability) for wake field studies and their research program (which dates back many years) plans for the future. A successful test has been made of their two-beam accelerator concept, and higher energy tests are planned that may demonstrate gradients in excess of 100MeV/m shortly. Indeed, the drive beam line would be carrying about 500MW in power in this test! The previous experiment demonstrated a transformer enhancement of about two between the drive beam line (3.5 MeV/m) and the test beam line (7 MeV/m). Their work on hybrid dielectric irises may favorably impact mainline accelerator work by reducing surface fields a factor of two. A test at NRL of a dielectric-loaded slow wave TM01 structure using high power X-Band microwaves generated by a magnicon is planned soon. John Power of ANL described a method to increase the "transformer ratio" (and thus efficiency) of a co-linear wake field accelerator from the canonical value of 2 to as much as 8, using a series of about four carefully timed drive bunches of progressively increasing charge (eg, 1 : 3 : 5 : 7). The method may also be applied to plasma wake field accelerators too. A 40 cell ramped bunch train iris-loaded TW structure experiment is planned for operation this fall.

Whereas most wake field work involves exciting a spectrum of microwave TM modes in a cylindrical dielectric wake field device, Marshall (Columbia) pointed out that one might well imagine tall rectangular dielectric structures having optical-scale dimensions, that would be excited by fsec bunches containing pC of charge. These could deliver wake fields in excess of 1 GV/m; however, new dielectric optical materials must be created and the use of microfabrication would be necessary.

The field of wake field accelerator research is demonstrating great progress, and results permitting an assessment of its ability to develop an advanced accelerator technology should be obtained in the next 3–5years.

3. "Vacuum" Acceleration Techniques

This has always been an attractive method because of the simplicity of the hardware. A variety of approaches is being examined.

At ATF, Pogorelsky described several configurations of vacuum accelerators which are a "byproduct" of the discontinued ICA experiment. These use a combination of axicon or spherical focusing of radially-polarized annular CO2 laser beams. A 0.5nC bunch with a diameter $10u$ has been achieved, and will be propagated through tiny holes in mirrors and screens that restrict the bunch-optical interaction to the dephasing length; tests begin this fall. A collaboration with Tsinghua University (Taiwan), which will develop a TEM01 "lens" array was described. If the laser power were 50 GW, it is believed that an energy gain of 2 MeV might be demonstrated in a proof of principle experiment. There are challenges, such as adjusting the angle of injection between the electrons and the photons correctly. In experiments of this type, one must deal with diffraction of the light from apertures, formation of plasmas and erosion at mirrors pierced by holes which transmit the bunches, and in the broader context of a TeV device, the issue of coherent diffraction radiation (CDR) from the bunch as it passes through tiny holes in mirrors (this could considerably reduce the energy gain per stage). Steinhauer has begun to model acceleration in the optical bounded medium.

Calculations by Ho (Fudan University, China) have revived interest in exploiting a finite path electron interaction in an intense optical beam. In certain parts of the radiation field, it turns out that the phase velocity of the light can be $< c$, and so there is potential to accelerate electrons there. The electrons must be injected in a particular way, and it is not clear now, given the substantial ponderomotive forces which can scatter electrons, that acceleration of more than a few electrons can be achieved. Nevertheless, Cline (UCLA) has proposed to examine the feasibility of such a technique, given that the potential payout could be high.

Another technique, LACARA, is in a special class. It was described by Hirshfield (Yale, Omega-P): acceleration of an entire psec bunch can occur in a solenoidal magnetic field, using a circularly-polarized TW CO2 laser beam which sets up a cyclotron auto-resonance with the electrons. In the 2m length of a 6T field, an energy increase of over 50MeV is to be expected, with little synchrotron radiation. The LACARA is being assembled at ATF. Apart from its use as an accelerator component, the LACARA can be configured to produce a series of ultrashort current pulses, containing about 1pC of charge each within an envelope of 3.5 fsec duration, with $10.6u$ spacing. These current pulses might be injected into dielectric structures having optical dimensions where the problem of CDR is minimized (Marshall), injected into a LWFA as a "test bunch," injected into a PWFA as a train of "drive bunches," or used in a variety of spin-off applications such as producing a train of short X-Ray pulses (competing with Compton backscattering of laser pulses off of relativistic charge bunches). The short bunch technique in LACARA is referred to as "chopping" rather than "bunching," since it is geometrical in origin, and indeed it may be superior in some respects to the bunching that is produced in the FEL and IFEL at present insofar as applications are concerned.

Mikhailichenko (Cornell) described an accelerator system in which a series of coupled open-sided cavities is illuminated by an intense laser beam which is swept as a traveling-wave focus over the structure synchronous with the bunch. The accelerator hardware is a microfabricated structure, and the laser beam is moved electro-optically. The question of laser damage in such a structure is important, but that is also true of conventional structures, and relates to the expected lifetime of the system. Damage tests would yield guidance in this connection.

4. Summary

The areas of IFEL and DWFA are becoming mature, and are capable of truly informative demonstrations in the next few years. Tests of the smaller optical structures are planned for the near future, and it is too early to reach a conclusion about their prospects. The IFEL, while it cannot achieve TEV energies, can contribute to parts of a staged accelerator system, or as an injector for plasma-based accelerators. New tests are planned which should obtain large energy increases and gradients approaching 100 MeV/m. A new method of chopping psec bunches into fsec pieces by the LACARA has been devised and should be tested, as it may have some advantages over methods in current use. Providing issues of stability and breakdown can be successfully resolved, the DWFA may play an important role in accelerator physics of the future, as it uses no plasma, and does not require power from a laser source but rather from a conventional rf linac which is capable of very high efficiency. One might anticipate gradients in the range of 100 MeV/m to 1 GeV/m from the DWFA. All areas of this topic have contributed "spin-offs" to the rest of accelerator physics, and potentially to the science community at large.