PLASMA WAKEFIELD ACCELERATION EXPERIMENTS USING TWO SUBPICOSECOND ELECTRON BUNCHES*

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Abstract

Two subpicosecond electron bunches, separated in energy by approximately 2 MeV and in time by 0.5-1 ps, are sent through a capillary discharge plasma. The plasma density is varied from ~10^{14} cm^{-3} to ~10^{18} cm^{-3}. A 1-D plasma wakefield acceleration (PWFA) model indicates the net wakefield produced by the bunches will depend on their relative charge, temporal separation, and the plasma density. The wakefield of the first bunch will also affect the amount of energy gain or loss of the second bunch. During measurements of the energy spectrum of the bunches, we observed a difference in the amount of loss depending on the plasma density. Indication of gain was also observed.

INTRODUCTION

Plasma wakefield acceleration (PWFA) is a promising method for accelerating electrons to high energies [1]. In PWFA, an ultrashort drive electron bunch passes through a plasma, thereby creating a wakefield. Electrons from a witness bunch following the drive bunch or electrons from the back of the drive bunch can be trapped and accelerated by the wakefield. In multibunch PWFA [2], a resonant enhancement of the acceleration gradient can be achieved if a train of bunches is sent through the plasma such that the spacing between bunches is the same as the plasma wavelength. Essentially, the wakefields generated by each bunch add coherently with the wakefields from the preceding bunches.

A multibunch PWFA experiment [3] is currently underway at the Brookhaven National Laboratory Accelerator Test Facility (BNL-ATF) where the aim is to generate a train of bunches and send it through a capillary discharge. Both ablative [4] and gas-filled [5] discharges are being utilized. An inverse free electron laser (IFEL) [6] and a masking technique [7]-[8] are being considered as means for generating the bunch train.

The BNL-ATF also has a method for generating two ultrashort bunches [9]. Measurements indicate that the bunches are subpicosecond in duration, separated by approximately 2 MeV in energy, and roughly 0.5 – 1 ps in time. Although these characteristics cannot be easily varied, they are suitable for demonstrating the basic principles of multibunch PWFA.

This paper describes preliminary PWFA experiments performed using these two bunches passing through a polypropylene capillary discharge.

DESCRIPTION OF EXPERIMENT

The double-bunch formation process is a complex one that entails interaction between a 4-dipole chicane bunch compressor, two downstream dogleg dipoles, and coherent synchrotron radiation (CSR) effects. The process is still being studied and modeled [10], but tests have shown the process is reproducible and stable [9].

The double-bunch PWFA results presented here were performed before the double bunches were more completely characterized using various diagnostics [9]. In particular, the length of the bunches was not measured for this particular set of data. Subsequent bunch length measurements indicate that the nominal lengths are in the subpicosecond range. As explained later, this length is consistent with the data presented here.

Table 1 lists the basic parameters for the experiment. “1st bunch” refers to the leading bunch, “2nd bunch” to the trailing bunch. It should be noted that the absolute electron energies are only estimates. This does not affect the interpretation of the results since only relative changes in the energy are of interest.

Table 1: Double-bunch experimental parameters.

Parameter	Estimated Value
1st bunch mean energy	58.5 MeV
1st bunch charge	<80 pC
1st bunch focus size at capillary	~100 μm rms
2nd bunch mean energy	60.5 MeV
2nd bunch charge	<80 pC
2nd bunch focus size in capillary	~100 μm rms
Estimated time delay between 1st and 2nd bunches	~0.5 ps
Capillary diameter	1 mm
Capillary length	6.6 mm

An important parameter during the experiment is the plasma density in the capillary at the time of arrival of the bunches. This arrival or delay time is adjustable. Since

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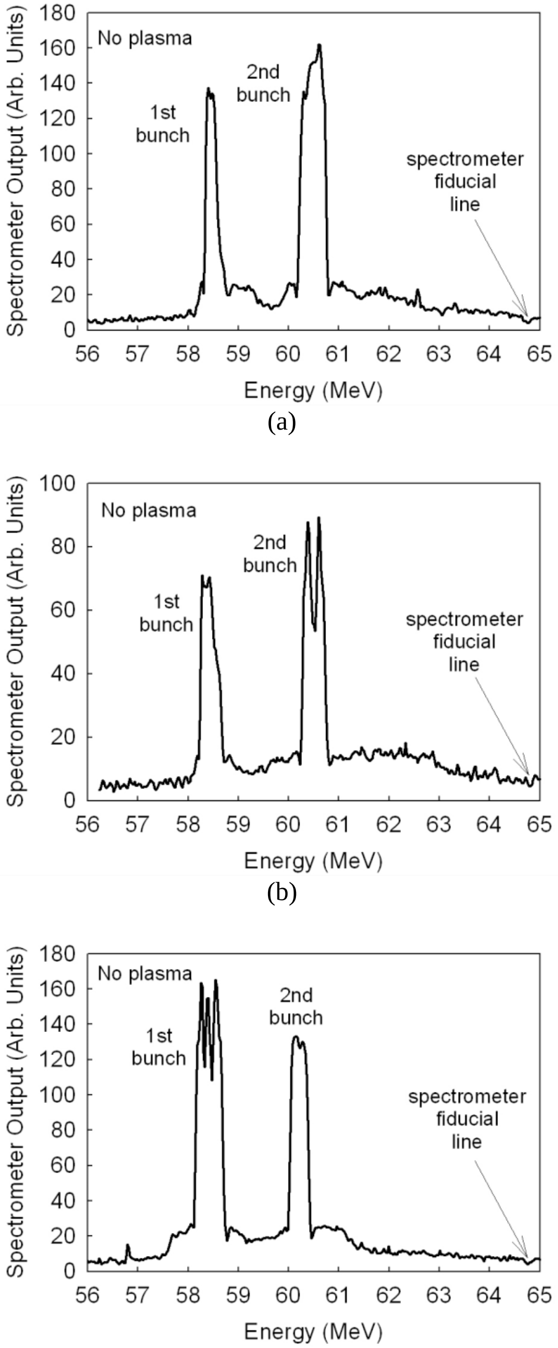
the plasma density decreases over time after the start of the discharge, this means the plasma density seen by the electrons can be chosen by selecting an appropriate delay time. This decrease in density was measured beforehand [11] by observing the amount of Stark broadening of the hydrogen *H*_ line (_ = 486 nm) as a function of delay time after the discharge start, using a spectrograph fast-gating video camera. It should be noted the accuracy of this method diminishes at densities less than approximately 10^{15} cm^{-3} because the amount of linewidth broadening becomes comparable to the instrument resolution.



(a)

(b)

(c)

Figure 1: Three examples of no-plasma energy spectrums demonstrating the stability of the energy distributions.

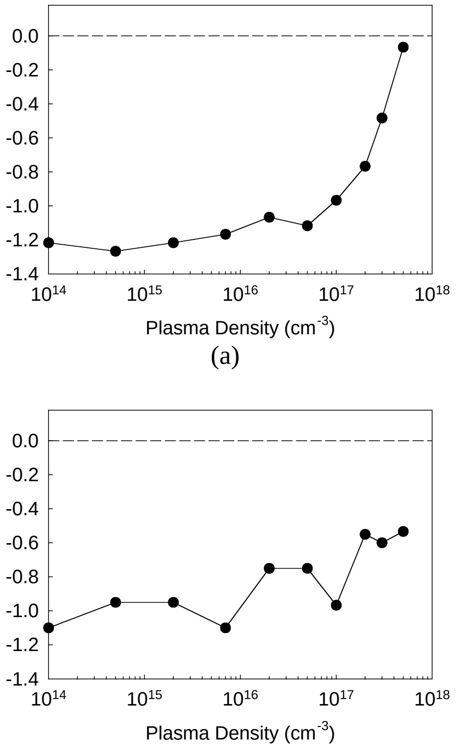
Downstream of the capillary discharge is an energy spectrometer for measuring the change in energy of the bunches. A fiducial line on the spectrometer output image provides a convenient means for ensuring all the spectrums are aligned to each other. This is important because the energies of the bunches shifted with respect to each other as a result of some electrons losing energy to produce wakefields and other electrons gaining energy from the wakefield.

EXPERIMENTAL RESULTS

Figure 1 shows spectrums for three datum taken widely separated in time without the plasma present. This demonstrates the good stability of the double-bunch formation process, especially the mean energy positions.

Figure 2 summarizes the energy loss for the bunches as a function of the plasma density. Figure 2(a) displays a definite energy loss trend for the 1st bunch, which tends to maximize at around 10^{14} – 10^{15} cm^{-3} plasma density. The 2nd bunch [Fig. 2(b)] follows this same behavior; however, the amount of loss tends to be less and the trend is more erratic. This erratic behavior could be linked to the fact the 2nd bunch electrons are also experiencing the effects of the wakefield from the 1st bunch.

A maximum energy loss of the 1st bunch occurring at 10^{14} – 10^{15} cm^{-3} plasma density implies a bunch length of order 1 ps. However, as mentioned there is considerable uncertainty with the density at these low values, therefore, it is possible the actual bunch length is shorter than 1 ps.



(a)

(b)

Figure 2: (a) Median energy loss of 1st bunch. (b) Median energy loss of 2nd bunch.

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The data also displayed evidence of gain by some of the electrons in the 2nd bunch, which we presume is due to the effects of the wakefield produced by the 1st bunch. The energy spectrums in these cases are difficult to interpret because the 2nd bunch electrons are also simultaneously losing energy as they generate their own wakefield.

Due to this complex interaction, proper interpretation of the data requires using the model. This in turn points to the need for precise characterization of the bunch parameters, i.e., bunch length, charge per bunch, etc.

CONCLUSION

We have observed energy loss of two bunches as a result of generating wakefields in a plasma. The amount of energy loss of the 2nd bunch is less than the first one and there is clear evidence of energy gain. This confirms the basic premise for the multibunch PWFA scheme.

Thus, this preliminary double-bunch PWFA experiment has set the foundation for multibunch PWFA experiments to follow. Meaningful comparisons with the model will require accurate measurements of the bunch characteristics. Such measurements will be obtained during the forthcoming experiments and will be published elsewhere.

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