

# DEMONSTRATION OF THE WAKEFIELD ACCELERATION IN AN 11.7 GHz PHOTONIC BAND GAP ACCELERATOR STRUCTURE

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## Abstract

A beam driven acceleration experiment was conducted in a photonic band gap (PBG) accelerator structure operating at 11.7 GHz. The structure is installed at Argonne Wakefield Accelerator (AWA) test facility at Argonne National Laboratory (ANL). For the wakefield experiment, the PBG structure was excited by a high charge (up to 10 nC) electron bunch, and the second smaller charge witness bunch was accelerated/decelerated depending on the phase difference between the witness bunch and the drive bunch. Because the PBG structure was fabricated with electroforming, the AWA beamline includes the Be window placed before PBG structure that protects the cathode from contamination due to possible outgassing from the electroformed copper. The diameter of Be window is 9 mm and the beam tube diameter of the PBG structure is 6.4 mm. The size of the high charge electron beam on the Be window has to be minimized to minimize scattering. The size of the high charge beam has to be smaller than the diameter of PBG structure beam tube for the beam to pass through the PBG structure without interception. The high charge electron beam was passed through the PBG structure and acceleration of the witness bunch was measured. The results of the experimental measurements are reported here.

## INTRODUCTION

Photonic band gap (PBG) structures are periodic structures which damp higher order modes and confine the fundamental mode. Future compact high beam current accelerator may need them to reduce the beam breakup instabilities. PBG structures must be tested for suppression of higher order modes [1] and for their accelerating properties.

A high frequency (11.7 GHz) normal conducting travelling wave PBG structure is installed in the AWA beam line to test for the acceleration and wakefield suppression. This is a 16-cell travelling wave structure, which has 9 times the operational frequency of the AWA accelerator. The beam tube diameter of this structure is 6.31 mm. The structure is fabricated by attaching the electroformed copper components with the help of vacuum compatible epoxy. Due to electroformings and this epoxy a Be window has to be placed to separate the AWA main beamline and the PBG structure. Details of placing the Be window in the beam line and the effect of the Be window on the beam can be found in [2].

The higher order mode suppression in PBG structures was demonstrated in AWA beam line and reported in [1], and the acceleration by powering the PBG structure was shown see reference [3]. To show the acceleration in this structure by means of a wakefield, two beam collinear experiment is conducted. In this experiment a drive bunch of 20-25 nC was sent through the AWA beam line and because of the Be window and smaller size of the beam tube diameter of the PBG structure, only 9-10 nC could pass through the PBG structure. Similarly 5-6 nC charge was used as a witness bunch, which for similar reason got reduced to 1-2 nC in the PBG structure.

Before performing a collinear two beam acceleration experiment for the PBG structure, the effect of the wakefield of the AWA beamline was measured in a separate experiment see reference [4]. There is a significant change in the energy of the witness bunch due to the wakefield of the drive bunch in AWA beamline. To subtract these effect there were two spectrometers placed, one was before the PBG structure and the other after the PBG structure. The energy measurements were taken for each case on both the spectrometers. The wakefield effect of the AWA beamline was due to 20-25 nC beam, while the effect for the PBG structure was due to 8-9 nC beam because of the transmission losses of the Be window. As operating frequency of the PBG structure is 9 times higher than the AWA accelerator's operating frequency, a 20 degree phase difference in AWA beam bunches creates 180 degree phase difference for the same bunches in the PBG structure. The phase separation between the witness beam and the drive beam is obtained by changing the path length of the laser pulse used to produce these beams. The same optical setup is used to produces the bunch trains in the AWA beamline and with variable phase difference between bunches.

## EXPERIMENTAL RESULT OF THE TWO BEAM ACCELERATION IN THE PBG STRUCTURE IN AWA BEAMLINE

Figure 1 shows the experimental setup at AWA facility for collinear two-beam acceleration experiment. After the Be window there are three quadrupole magnet and two kicker placed to steer the beam through the PBG structure. A spectrometer is placed at the end of the beamline as shown in Fig.1.

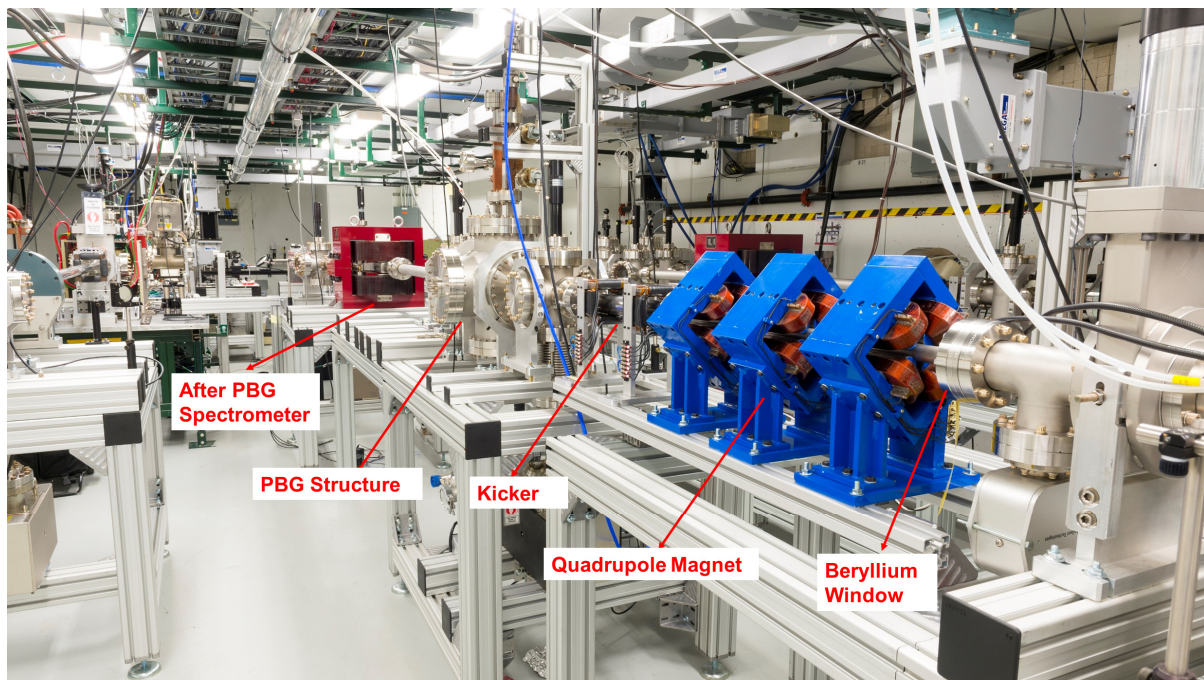


Figure 1: The experimental setup for the two beam collinear experiment for the PBG structure at AWA beamline.

These quadrupole magnets and kickers are used to focus the beam through the PBG structure. There are inductive current transformers (ICTs) placed in the beamline to measure the charges before the Be window and after the PBG structure to measure the transmission losses due to the Be window and the PBG structure.

In our experiment for the PBG structure, the first bunch was chosen as a drive bunch and the fifth bunch as a witness bunch. The charges of the first bunch was approximately 20-25 nC and the charge of the 5<sup>th</sup> bunch was 5-6 nC. Due to the Be window and smaller beam tube diameter of the PBG structure the charges passed through the PBG structure were 10-11 nC and 1-2 nC respectively.

As the phase of the witness beam is varied with respect to the drive beam, the initial energy of the witness beam changes. This difference in energy makes transmission losses of the witness beam through Be window and PBG structure harder, this is the reason to choose higher witness beam charges to begin with. It ensures that minimum 1 nC charges will go through the structure and that can be very well detected by YAG screen placed after the spectrometer. The phase of the witness beam was varied with respect to the drive beam by 0, 5, 10, 15 and 20 degree which corresponds to 0, 45, 90, 135 and 180 degrees in X-band. This was done in order to map the whole 180 degree phase variation of the wakefield of the PBG structure. There are YAG screens placed before both spectrometers in AWA beamline. The YAG screen data was taken to make sure that both the beam, the witness bunch, and the drive bunch are on the same positions on the beam axis.

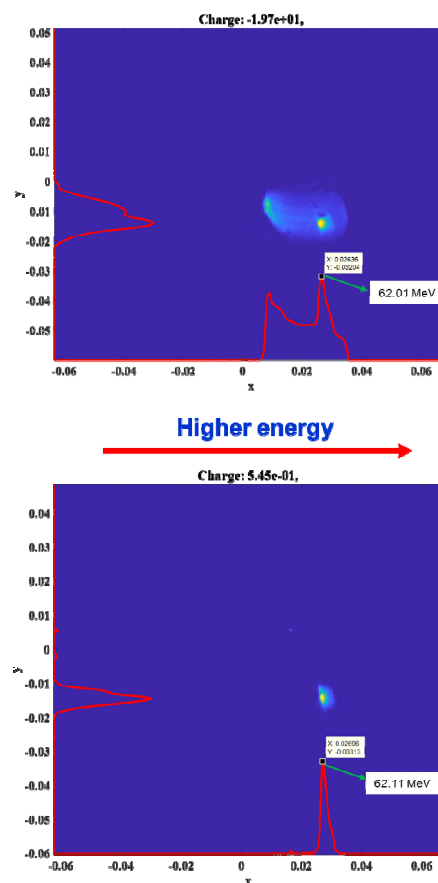


Figure 2: Beam positions of the witness and the drive beam together (top), and the witness beam (bottom) on the spectrometer before PBG structure.

The energy of the witness bunch on spectrometer placed before the PBG structure is shown in Fig. 2. The

image on the bottom of the Fig. 2 shows the energy of the witness bunch in the absence of the drive bunch while image on the top shows the witness bunch energy in the presence of the drive bunch. In this spectrometer the higher energy is on the right side of the YAG screen. It shows the witness bunch is losing 0.10 MeV of energy due to the wakefield of the AWA beamline. As there is clear position difference in the presence of the drive beam. The witness beam moves to the left side which correspond to the smaller energy side. This data is for the 20 degree phase difference between the drive beam and the witness beam.

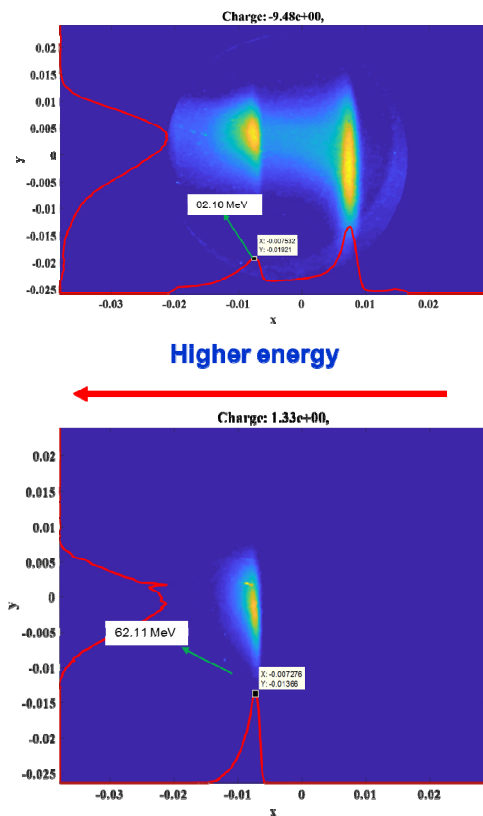


Fig. 3: Beam positions of the witness and the drive beam together (top), and the witness beam (bottom) on the spectrometer after PBG structure.

The energy measurement for the same phase difference and charges was taken on the spectrometer placed after the PBG structure as shown in Fig. 3. The higher energy on this spectrometer corresponds to the left side. These changes in the higher energy side between the spectrometers placed before and after the PBG structures are due to the different electrical connection of the spectrometers. These measurement show the witness beam shifts towards the left in the presence of the drive beam. It means that the witness beam gains energy of 0.05 MeV as shown the Fig. 3. The total energy gain due to the wakefield of PBG structure has to be calculated as a sum of the energy loss measured before PBG spectrometer and energy gain after the PBG spectrometer.

The wakefield of PBG structure compensates the energy loss of the witness bunch due to AWA beamline. The total energy gain due to wakefield of the PBG structure for this case is 0.15 MeV corresponding to the acceleration gradient of 1 MV/m. The experimental parameters used during the experiments are given in table. 1.

Table 1: The Experimental Parameters at AWA

Frequency of main linac in AWA	1.3 GHz
Frequency of PBG structure	11.7 GHz
Charge in the drive beam bunch	7-9 nC
Charge in the witness beam bunch	1.0 nC
Thickness of Be window	30 micron
Diameter of the Be window	9.0 mm
Diameter of the beam tube of PBG structure	6.31 mm
Energy of the electron beam	65 MeV

## CONCLUSION

We conducted collinear two beam wakefield experiment with the reduced thickness of the Beryllium window at AWA. We did two bunch experiments to measure the wakefield effect of the PBG structure placed in the AWA beamline. The charge of the drive bunch was around 20-25 nC, but only 10 nC made it through the PBG structure. The charge of the witness bunch was around 5-6 nC, but only 3 nC made it through the PBG structure. We have a spectrometer placed before the PBG structure and a spectrometer placed after the PBG structure for energy measurement. This setup allow for correction of energy due to the effect of wakefield of the AWA beamline. We measured energy before and after for each drive and witness charge combination and for each phase difference between the drive and the witness bunch. The acceleration and deceleration of the witness bunches were seen under the influence of the wakefield created by drive bunch in the PBG structure.

## ACKNOWLEDGMENTS

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