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CW operation on APF-IH linac as a heavy ion implanter

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ABSTRACT

In this work we present details of the design and manufacture of a new alternating phase focus-interdigital H (APF-IH) drift tube (DT) linac. Using this apparatus we were able to successfully accelerate He^{+} ions from 80 up to 193.6 keV. The linac design employs an advanced power-efficiency configuration, APF-IH structure, which has high acceleration efficiency in the low-to-middle energy region. In the design process the relationships between frequency and power, and mesh, end ridge tuner) (ERT, and DT diameter were characterized. The unique aspect of this work is that the fabrication process was not based on direct measurement, which is the traditional design method; instead advanced computer numerical design and simulation methods were employed. A 5-axis numerical control machine was used to fabricate the integral main frame (including acceleration structure, which includes drift tubes, stems, and ridges) without alignment. The experimental results showed that measured values, including the operation frequency, the Q value, the axial electric distribution, and the consumed power for acceleration, were within the design limits; in particular, the measured operation frequency is 99.95% of the design requirement.

1. Introduction

A major aim of the current work is the design and fabrication of a new generation heavy ion implanter for the semiconductor industry. The reason for choosing the IH structure in the design process is that it has an extremely high shunt impedance value, resulting in enhanced power efficiency and acceleration efficiency in the low-to-middle energy region compared with other linear accelerators [1]. The beam focus was performed using a self-focusing method, the APF method [2], using the rf focusing force generated by the high-frequency phase to focus the accelerating particles. The APF method offers stronger transverse focusing forces for low energy particle beams than those possible when using permanent magnet quadrupole (PMQ) focusing. Furthermore, the cell length and the total cavity length can be shortened when using the APF method.

This new heavy ion linac can accelerate $^{11}B^{+}$ and $^{31}P^{2+}$ ions, whereas He^{+} ions were used in the CW test experiment. The experiment showed that measured parameters, including operation frequency, the Q value, the axial electric distribution, and the consumed power for acceleration, are well within the design limits. In particular, the measured operation frequency was 99.95% of the design specification of 60 MHz. An important design feature is the variability of the linac output energy spectrum peak, which can be varied by changing the feeding power, desirable in the semiconductor fabrication process.

2. Design procedure

In the past it was difficult to evaluate the high frequency electric field distribution and cavity resonant frequency for the IH linac. In this work the design process was based on CAD design software SolidWorks [3], and an advanced computer simulation technology—3-D electromagnetic solver Microwave Studio [4]. These softwares were utilized to perform simulations of the cavity electromagnetic distribution. Orbit calculation was simulated using PARMILA [5] and Pi Mode Linac Orbit Calculation (PMLOC), a program based on the thin lens principle, developed by this research group.

This IH-DT linac design consisted of 8 drift tubes and 9 cells. Firstly, the drift tube table, including drift tube lengths, gap lengths, phase, and energy on each cell, was created using PMLOC. Then PARMILA was used to evaluate the transit-time factor and the energy distribution. The profile of the last cell of the PARMILA simulation is shown in Fig. 1. Secondly, these drift tubes, based on the PMLOC calculation and an appropriate cavity based on experience, were sketched and assembled in SolidWorks. Next, the resonance frequency and the axial electric field distribution of the cavity were solved using Microwave Studio. Finally, based on the results of the Microwave Studio simulation, the cavity was adjusted to an optimal structure, where the resonance frequency

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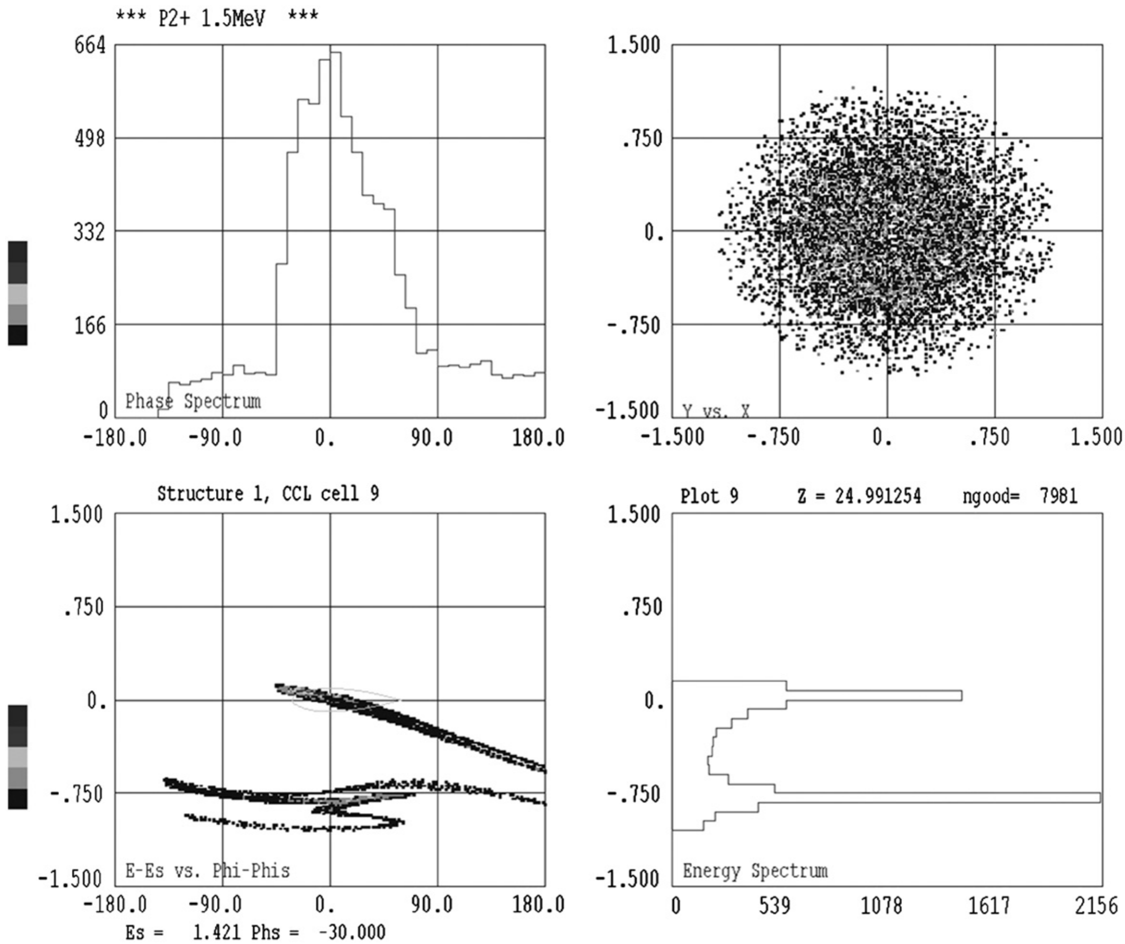

Fig. 1. Profile of the last cell.

Table 1
Main parameters of 9 cells APF-IH linac.

Charge to mass ratio q/A	2/31 (P^{2+}, He^{+})
Frequency (MHz)	60
Input energy (keV/u)	20
Output energy (keV/u)	49
Cell numbers	9
Cavity length (mm)	432
Cavity radius (mm)	505
RF power (kW)	4.56
Drift tube radius (mm)	22
Drift tube bore radius (mm)	9
Synchronous phase	-90° -30° 30° 30° -30° -30° …

and axial electric field distribution were correctly fitted to design limits. Simulation results of the electric field distribution were used to simulate further the beam orbit. The final parameters of the cavity are outlined in Table 1. A beam orbit simulated with APF focusing is illustrated in Fig. 2.

After the PMLOC simulation of the iterating phase patterns of the drift tubes, the phases, and the transverse acceptance of particles were determined. Furthermore, the double bunchers in the 1st and 2nd cell were selected in order to raise transmission. The determination of the optimum phases, listed in Table 1, was based on the simulation results that showed which phases could obtain the largest acceptance of transverse and longitudinal directions.

3. Cavity electromagnetic simulation

For cavity electromagnetic simulations, the relationship between the mesh, frequency, and power, was firstly investigated using Microwave Studio; see Fig. 3. The simulation began from mesh number of 110 thousand and ended at mesh number of 35 million. The results of the simulation showed that the frequency exhibited a linear increase as the mesh number increased. In particular, the frequency increased rapidly when the mesh number increased to 5 million; the simulated power did not show much variation and was constant from mesh number of 300 thousand. That may be considered to imply that the capacitance is enough for power simulation ($V \propto 1/C$, here V is voltage and C is capacitance), but is not enough for frequency calculation ($f \propto 1/\sqrt{LC}$, here f is frequency and L is inductance) [6] for the mesh number of 300 thousand. Based on the convergence tests of the simulation results an optimal mesh size of 5 million was used for all other models. The simulation results indicate that the necessary power for accelerating ions from 20 up to 48.4 keV/u is 4.56 kW. Additionally, the relationships between frequency and power, and the end ridge tuner (ERT), and the DT diameter were characterized. As shown in Fig. 4, both frequency and power decreased with increase in length of ERT. The decrease is due to the increase in the passage section of the magnetic flux, which would induce an increase in the current (voltage) and inductance. Shown in Fig. 5, the frequency exhibits a decreasing trend and the power shows an increasing trend with the increase of DT diameter. The decrease in frequency should be due to the