charged ions. For many applications in this megavolt range relatively modest beam currents are adequate, in fact, power density in the material being treated may require that low beam currents be used. Since quite large yields of doubly charged ions can be obtained from some ion sources, the capability of accelerating such ions greatly increases the usefulness of the invention. The microprocessor software is programmed to handle both the singly and doubly charged situation.

In choosing the parameters for the accelerator **16** the maximum gap acceleration voltage is of prime importantance. The higher this voltage, the fewer modules are required to achieve a specific final energy. However, the total rf power requirements increases roughly with the square of the gap voltage, and so there is a trade-off between cost of modules (and machine length) vs. the gap acceleration voltage. Value analysis for different gap voltages indicate that a maximum voltage of 80 KV peak is close to the optimum for most applications, although designs can be made within ±50% of that value. An 80 KV gap voltage with a well designed evacuated chamber and resonator circuit requires less than 3 KW, which is within the range of currently available solid state rf power amplifers.

The ions in the injected beam, in general, have a radial component of velocity. Typically, ions may be traveling at up to 0.04 radians relative to the central axis.

In each accelerating gap, the electric field lines are typically as shown in FIG. **8**. They produce radial focusing in the first half of the gap and radial defocusing in the second half of the gap. If the gap is operating at a phase which keeps the particles bunched in the axial direction, then more often than not, the electric field must still be increasing in magnitude, through its rf cycle, while a particle is passing through the gap. Consequently, the electric radial defocusing forces in the second half of the gap are stronger than the radial focusing forces in the first half of the gap. Thus, the net result is an overall radial defocusing.

The radial defocusing is compensated for by:

(1) using magnetic quadrupoles at various positions along the length of the accelerator **16**;

(2) Alternating the sign of the synchronous phase angle of the accelerating gaps along the length of the accelerator **16**. This can simultaneously maintain axial and radial stable motion at least over a narrow range of the rf phase, and

(3) using electrostatic quadrupoles, since the beam energies are quite low and electrostatic quadrupoles can be made compact.

An additional radial focusing method incorporates a quadrupole field in the region of the accelerating gaps. Electrodes **60, 63** having cylindrical azimuthal variations **60***a*, **63***a* in their profile are shown in FIG. **9**. These electrodes **60, 63** produce rf quadrupole focusing fields in Gap **2** and Gap **3** that counteract the defocusing effect shown in FIG. **8**.

The present invention has been described with a degree of particularity. It is the intent, however, that the invention include all modifications or alterations of the disclosed preferred embodiment falling within the spirit or scope of the appended claims.

What is claimed is:

1. Ion implantation apparatus comprising:
an ion source for directing charged ions having an initial energy along a travel path;
an ion accelerator including a plurality of spaced apart accelerating electrodes which, when energized, create an alternating electric field to accelerate the ions in stages through a plurality of accelerating gaps between electrodes to a second energy;
energizing means coupled to the ion accelerator for applying an alternating accelerating potential of a specific frequency and amplitude to each accelerating electrode of the plurality of accelerating electrodes to accelerate the ions through said plurality of accelerating gaps;
implantation means for positioning a workpiece so that charged ions accelerated to the second energy impact said workpiece; and
control means coupled to the energizing means to control the relative amplitude and phase of the electric fields in the accelerating gaps.

2. The apparatus of claim **1** wherein the energizing means comprises a plurality of tank circuits for controlling the amplitude and frequency of the accelerating potential applied to each of said plurality of electrodes.

3. The apparatus of claim **1** wherein the accelerating electrodes comprise generally annular structures, and where at least some of the annular structures have protrusions which, when energized, focus the ions along the travel path by creating a quadrupole field component at the accelerating region.

4. Ion implant apparatus where ions with different atomic numbers are accelerated to a desired energy for ion treatment of a workpiece, said apparatus comprising:
means for directing a beam of ions along an initial trajectory;
a plurality of spaced electrodes aligned along a direction of the initial trajectory and configured to define an acceleration region for said ions wherein each electrode is of a generally cylindrical shape spaced from adjacent electrodes to define accelerating gaps through which the ions accelerate;
energizing means for energizing alternate electrodes with an alternating current signal to create an alternating electric field in said accelerating gaps, said energizing means including a plurality of resonant energizing circuits, where each resonant energizing circuit is coupled to one of said alternate electrodes and has a resonant frequency that is adjustable in phase and amplitude to tune each of said alternate electrodes for accelerating a specific ion; and
means to position a workpiece in the path of said ions subsequent to acceleration by said electrodes.

5. The accelerator of claim **4** wherein each resonant energizing circuit includes an inductive coil coupled between an associated electrode and ground for tuning said resonant energizing circuit a specific resonant frequency.

6. The accelerator of claim **5** wherein the electrodes are positioned in an evacuated chamber and the reso-