Operation of the Relativistic Heavy Ion Collider Au^- ion source

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The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is beginning its second year of operation. A cesium sputter ion source injecting into a tandem Van de Graaff provides the gold ions for RHIC. The ion source is operated in the pulsed beam mode and produces a 500-μs-long pulse of Au^- with a peak intensity of 290 μA at the entrance of the tandem. After acceleration in the tandem and post-stripping, this results in a beam of Au^{+32} with an intensity of 80 μA and an energy of 182 MeV. Over the last several years, a series of improvements have been made to increase the intensity of the pulsed beam from the ion source. Details of the source performance and improvements will be presented. In addition, an effort is under way to provide other beam species for RHIC collisions.
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I. INTRODUCTION

The acceleration scheme for the Relativistic Heavy Ion Collider is shown in Fig. 1. Negative gold ions are produced by a cesium sputter ion source operated in the pulsed beam mode.[1] The gold ions are accelerated to the terminal of the MP tandem, which operates at a voltage of +14 MV. The ions pass through a thin carbon foil (2 $\mu g/cm^2$) at the terminal and are stripped to a positive charge state. The ions are accelerated back to ground potential where they are stripped again to a higher charge state by another carbon stripper foil (15 $\mu g/cm^2$). At each stripper foil a charge state distribution is produced with approximately 15% of the ions being in the most abundant charge state. The 850-m-long tandem to booster transfer line (TtB), which connects the tandem Van de Graaff to the Booster Synchrotron, will transport only one specific charge state combination. For the experimental program in the years 2000 and 2001 the charge state combination used was +12 at the terminal and +32 after the postacceleration stripper. This combination had a beam energy of 182 MeV. The beam from the tandem is multi-turn injected into the Booster Synchrotron where it is capture and accelerated. After being extracted from the Booster the gold ions are stripped to the +77 charge state before injection into the Alternating Gradient Synchrotron (AGS). After acceleration in the AGS the last two electrons are removed and the Au^{+79} ions are injected into the two counter-rotating rings of the Relativistic Heavy Ion Collider (RHIC), where they are further accelerated and collided at the four interaction points around the ring.

The pulse length of the ion beam from the tandem is usually 500 μs although pulse lengths as long as 2 ms have been demonstrated. The tandem delivers four pulses spaced 200 ms apart to the Booster every AGS cycle. Each AGS cycle is approximately 3.5 s and delivers four bunches to RHIC. RHIC can accept 56 bunches of ions per ring and can store these bunches for as long as 10 h.[2]

II. ION SOURCE OPERATION FOR RHIC

The ion source and tandem combination have proved to be very reliable for RHIC operation. During the year 2000 experimental run only 11 h of down time were attributed to the tandem and an additional 6 h for TtB downtime over the 5 months of operation. The ion source delivered over 10 million pulses without any lost time due to ion source problems. So far in the year 2001 experimental run similar performance has been achieved.

The PSX-120 cesium sputter ion source[3] is operated in the pulsed beam mode as shown in Fig. 2. The pulser power supply provides a positive voltage to the cesium ionizer relative to the sputter target cathode. The positive cesium ions are accelerated to the cathode and sputter some of the cathode material as negative ions, which are then accelerated. Because the pulser voltage is tied to the cathode, the energy of the negative ions leaving the ion source remains constant. The pulsed beam mode of operation allows several orders of magnitude higher instantaneous beam current to be injected into the tandem without damage to the accelerator and also achieves higher beam intensities out of the ion source than can be achieved in dc operation. The 1.0 kV dc supply is usually run at between 100 and 200 V to provide approximately 100 nA of dc beam. This dc beam is used to regulate the terminal voltage of the tandem by way of a feedback loop using a pair of horizontal slits after the first 90° dipole magnet. The ion source parameters are summarized in Table I. Because the spacing between pulses is different for the first pulse compared to the other three, the intensity and position of the first pulse is slightly different. This is due to cesium coverage of the cathode and also possibly voltage droop of a power supply. In order to minimize variation between the four pulses to be injected into the Booster an extra pulse is added before the first pulse.

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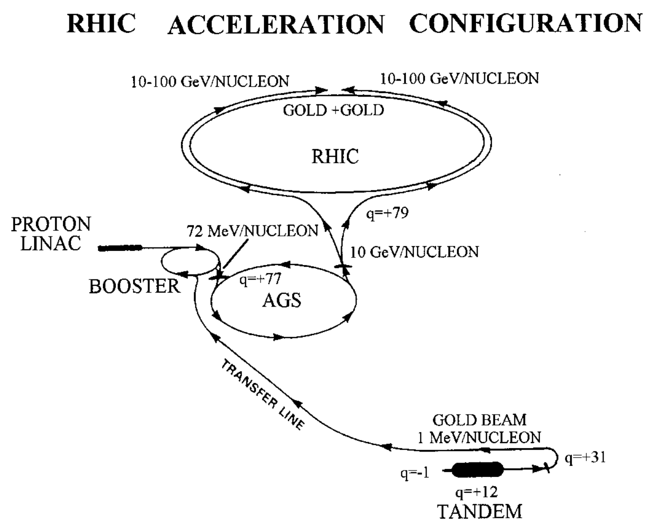

FIG. 1. Relativistic Heavy Ion Collider acceleration scheme.

Over the last several years there has been an effort to increase the gold beam intensity available from the tandem. The maximum gold intensity for each of the experimental runs (the charge state of the gold beam delivered to the Booster is shown at the top of each column) is shown in Fig. 3. The plot shows a steady increase in beam current available from the tandem. Although the stripping efficiency for the Au^{+32} beam is lower than the efficiency for Au^{+31} and results in approximately 15% less beam from the tandem, the Booster and AGS can accelerate the higher charge state more efficiently.

One of the ways used to increase the beam current available from the tandem was to increase the extraction voltage of the ion source to overcome the space charge forces of the beam. Between 1995 and 1997 the extraction voltage used while injecting the booster was increased from 30 kV, first to 32 kV and then eventually 35 kV. Figure 4 shows the effect of extraction voltage on the beam current at the low energy cup immediately in front of the tandem. The increase is linear from 205 μA at an extraction voltage of 30 kV to 366 μA at 45 kV. This increase can be due to an improvement in the extraction optics and transport efficiency at the higher energy. Unfortunately at extraction voltages much above 35 kV the present ion source is unreliable for long-term operation, due to voltage breakdown along the high voltage insulator surface, which can become coated with cesium. A new ion source has been purchased with an additional acceleration gap to allow reliable operation at up to 50 kV by spreading the gradient over two insulators. Further testing is required to fully evaluate this new ion source.

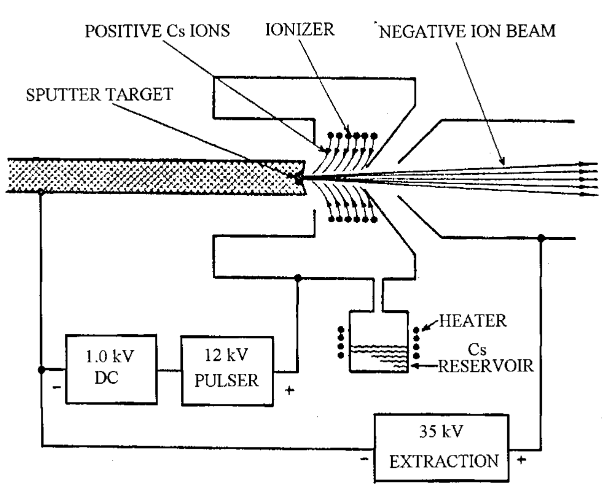

FIG. 2. Schematic diagram of the pulsed beam mode of operation.

TABLE I. Ion source parameters for the PSX-120 Cs sputter source.

Extraction voltage	35 kV
Ionizer current	23 A
Ionizer temperature	1100 °C
Pulser voltage	8.0 kV
Trace voltage	208 V
Cesium boiler temperature	60 °C
Au^- beam current	287 μA
Au^{+32} beam current	80 μA

Another improvement, which was first used in 1996, was the addition of a double gridded einzel lens immediately downstream of the ion source. With this lens 340 μA of Au^- was transported to the low energy cup at an extraction voltage of 30 kV and 610 μA at an extraction voltage of 50 kV. This einzel lens is now routinely used for all pulsed beam operation.

The result of these improvements is that during the year 2000 run, the PSX-120 ion source has produced 290 μA of Au^- at the entrance to the tandem. After acceleration there was 1300 μA of all charge states which after post-stripping resulted in 80 μA of Au^{+32} (7.2×10^9 ions per pulse for 500 μs) at the start of the TtB transfer line and 58 μA (5.1×10^9 ions per pulse) at the Booster end. During the year 2001 run, four pulses with an integrated intensity of 21.6×10^9 ions of Au^{+32} have been injected into the Booster.

III. OTHER ION SPECIES

With the success of the gold program in RHIC, there is growing interest in other species of heavy ions both for RHIC and also for the Booster Application Facility (BAF).

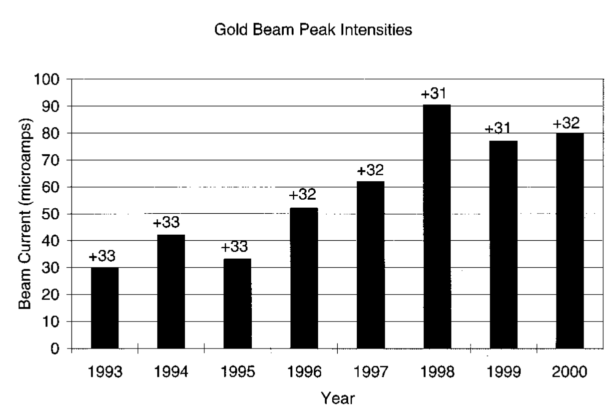

FIG. 3. Maximum gold beam current vs year (charge state run at the top of each column).

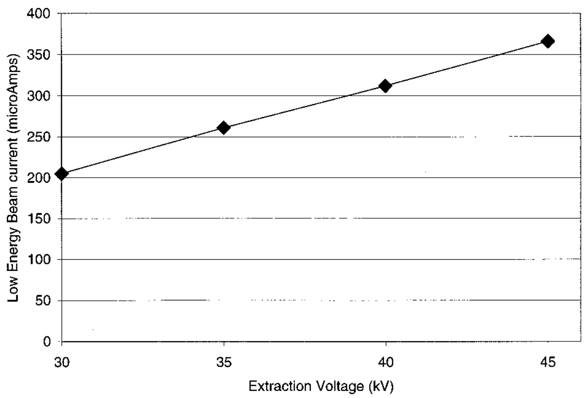

FIG. 4. Ion source extraction voltage vs gold beam current in low energy cup.

Already iron and silicon beams have been delivered to the Booster for radiobiology experiments on the AGS experimental floor. Using a FeO cathode the ion source produced 133 μA of FeO^- which after acceleration and stripping in the terminal resulted in 142 μA of Fe^{+10} at the end of the transfer line. For silicon, a crystal silicon cathode was used and the ion source produced 340 μA of Si^- in the low energy end of the tandem and 172 μA of Si^{+5} at the end of the transfer line.

There is also a proposal to collide asymmetric masses in RHIC. This would require the MP7 tandem to inject gold ions into one of the rings in the standard manner and then the recently upgraded MP6 tandem[4] to inject deuterons into the other ring. Because the two ion beams will have different magnetic rigidity, all of the magnets in the transfer line would have to be set to new fields. The goal is for both RHIC rings to be filled in less than 5 min. The preliminary testing with the ion source has produced 400 μA of D^- in the low energy cup from a TiD_2 cathode. With a transmission through the tandem of approximately 50% this should result in more than 100 μA being injected into the Booster. More testing (particularly in switching the transfer line quickly) needs to be done but this will be completed this fall.

IV. CONCLUSION

The PSX-120 cesium sputter source in combination with the MP tandem Van de Graaff has proved itself to be a reliable injector for RHIC. The ion source has provided enough beam intensity for the injector chain of accelerators to meet the RHIC specification of 1×10^9 ions per RHIC bunch. The ion source has also proved itself to be a reliable source of ions other than gold for fixed target experiments at the AGS. Work is continuing to further increase the gold beam intensity as well as developing other ion species.

ACKNOWLEDGMENT

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[1] P. Thieberger, M. McKeown, and H. E. Wegner, IEEE Trans. Nucl. Sci. **NS-30**, 2746 (1983).
[2] RHIC Design Maual, http://www.agsrhichome.bnl.gov/NT-share/rhicdm
[3] Distributed by Peabody Scientific, Peabody, MA, 01960.
[4] D. B. Steski, J. Alessi, J. Benjamin, C. Carlson, M. Manni, P. Thieberger, and M. Wiplich, presented at the 2001 Particle Accelerator Conference (to be published).