Acceleration by Audio Plasma

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ABSTRACT

Two adjacent tubes connected together, one (L = 20 cm, \( \phi = 4 \) cm) for plasma creation by AF supply (V = 830 V, \( f = 10 \) kHz) and the other (L = 10 cm, \( \phi = 4 \) cm) consider free electric field region for plasma transport and deposition on the CR-39 track detector. At the end of the plasma tube beam plasma is trusted from a thin orifice (\( \phi = 1 \) mm) and transport 10 cm towards the detector. This thrust is due to varying pressure between the tubes and the energy gained by the agglomeration ions from the plasma field. The experimental study is carried out twice, one when the far end electrode is made from aluminum and in the second experiment it is made from tungsten. The far end electrode is biased positive with respect to the second terminal which has a thin orifice at its center for plasma beam exit. Investigation study is carried out with electron microscope, X-Ray Florescence (XRF) and Energy Dispersive X-ray (EDX). It was found that the range of aluminum ions is 6.1 \( \mu \)m and of tungsten is 7.78 \( \mu \)m. Both the SRIM program and the plasma accelerating gradient field related to \( n_o = 5 \times 10^{12} \) cm\(^{-3} \) show high energy gained from the plasma accelerating field.

Key Words: Audio Plasma /SEM /XRF /EDX/ CR-39

INTRODUCTION

Plasma acceleration is a new technique, in which electrons or positive ions gain energy in plasma and it promises to overcome the size and expense of nowadays conventional high-energy accelerators. These plasma-based accelerators are of great interest because, unlike traditional acceleration structures, plasmas can sustain very strong electric fields without electric breakdown, since they are already fully ionized. Like a surfer on a good wave, in these accelerators, particles would ride the created plasma waves to gain greater and greater speeds.

The present work is an application of an audio-ultrasonic frequency (10 up to 100 kHz) that produces plasma in a long column from 27 cm up to100 cm tube, the later led in previous work to several interesting deductions. It clarifies that the generation of plasma electric fields shape and strength in the medium depends on the discharge voltage and the gas type. The gas does not deliver effectively its ions to the electrodes. Consequently, the discharge voltage and the gas atoms form the plasma media with its electric and magnetic fields that interact in turn and influence the motion of electrons and ions of the electrodes elements. A preferred direction sustains atoms emigration from one electrode to the other, overcoming both sheaths regions. Electrons injection have contributed in raising the plasma generated electrostatic fields assisting ions emigration\textsuperscript{(1)}.

Track detectors have been developed for several decades\textsuperscript{(2-5)}. CR-39 itself was developed as a nuclear track detector as from the 1980s\textsuperscript{(6)}. A significant work characterizing the response of CR-39 has been published in the last three decades; a recent comprehensive paper on the response of CR-39 to protons has been published by Simenian et al. along with a comprehensive bibliography of studies on CR-39 \textsuperscript{(7)}. The well-known CR-39 track detector has high sensitivity for energetic ions but is hardly
affected by energetic electrons, even if the number of electrons is large. This suggests that the CR-39 track detector can be effectively and conveniently used for the diagnosis of ion beams\(^8\).

In this study, CR-39 is used to detect the accelerated particles, thus by studying the effect of particles knock on the detector and analyze CR-39 surface. This method leads to define the accelerating plasma field.

**EXPERIMENTAL SETUP**

The plasma design system is shown in Fig. (1.a). It consists of two adjacent tubes, the first is 20 cm long and the second 10 cm long, both of them are 3.4 cm inner diameter. A discharge power of 400 watts is applied between two electrodes in tube 1, one of the electrodes is an aluminum plate at the right hand side of tube 1, (20 mm diameter, 1.5 mm thick) and the other is made from copper and is maintained between the tubes with an aperture of 1 mm diameter. The frequency of the ultrasonic power supply is maintained at 10 kHz and the discharge voltage of 830 Volt, which draws a maximum discharge current up to 320 mA. A rotary pump maintains air gas feed through a needle valve intube 1 at low pressure of 0.2 Torr.

![Experimental setup](image)

*Fig. (1): The experimental setup and a photograph of the plasma acceleration system.*

A second tube, 10 cm long, is connected to the previous tube, next to the copper electrode; it is evacuated up to \(10^{-3}\) Torr. This tube area is kept as a free electric field region. A copper disk of 20 mm diameter is fixed at tube 2 and connected to the ground through a meter to measure the collected current, passing through it. Fig. (1.b) shows the experimental photograph of the tubes system. In addition, a track detector CR-39 is used. The copper collector is fixed on a support and can be exchanged by the track detector CR-39 to study the exited plasma beam on the later.

A Scanning Electron Microscope (SEM) (type JSM-5600-LV) was used to study the variations that took place on the CR-39 surface. In conjunction, an X-Ray Florescence (XRF) device (type JSX-3222) and an Energy Dispersive X-ray (EDX) analyzer investigate the elemental compositions of the deposited materials of the CR-39.
RESULTS AND DISCUSSION

An output plasma beam is observed coming out from the electrode aperture and reaching the tube 2 collector. A set of investigation techniques have been introduced in order to prove the particles landing on the collector and to explore the nature, the abundance and the energy of these beam particles.

1. Collector Beam Current:

The plasma current from an aluminum electrode in tube 1 which reach the copper collector in tube 2 is shown in Fig. (2) against the discharge power of the audio supply at different collector positions from the second plate of the audio power in tube 1 from 1 to 10 cm. The frequency of the audio power supply is maintained at 10 kHz.

![Fig. (2): The plasma current from Al electrode.](image)

From Fig. (2), it is clear that the current doesn’t change a lot by changing the collector position, this explains that the particles from tube 1 emitted with high energy. The current reached 1.6 mA.

![Fig. (3): The plasma current from tungsten electrode.](image)
With a tungsten AF electrodes, the current reaches the copper electrode is as shown in Fig.(3), the current reached 10 mA at different distances along tube 2.

2. The Effect of the Accelerated Particles Energy on the Track Detector CR-39:

By inserting the track detector CR-39 instead of the copper collector and allow it to be exposed to the ions / electrons particles beam to study the effect of the beam on its surface.

The time of exposure was two hours, the time is made at intermittent periods so as not to heat the sample, avoid the deformation of its surface and its optical properties.

3. Effect of Aluminum Ion Beam:

Replacing the copper collector with the track detector CR-39 to study the effect of the accelerated ions from the Al electrode, the operating AF power, frequency is 400 W and 10 kHz respectively for two hours.

3.1 Al Electrode Analysis:

Fig.(4) shows the SEM micrograph and the EDX spectrum of the aluminum electrode surface before the gas discharge to identify the elements concentration before the experiment.

![Fig. (4): (a) SEM of the Al electrode before the gas discharge. (b) EDX spectrum of the Al electrode before the gas discharge.](image)

![Fig. (5): (a) SEM micrograph of Al the electrode after the gas discharge. (b) EDX spectrum of the Al electrode after the gas discharge.](image)
Fig. (5) Shows the SEM micrograph and EDX spectrum of the Al electrode after the experiment, and it is clear that the Al electrode surface is deformed and eroded, and the concentration of Al is decreased. This confirms the deposition of Al material on the CR-39 surface.

**Table (1).** Elemental composition of aluminum electrode before and after the experiment

<table>
<thead>
<tr>
<th>Element</th>
<th>Al before Conc. %</th>
<th>Al after Conc. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.30</td>
<td>5.34</td>
</tr>
<tr>
<td>O</td>
<td>10.77</td>
<td>15.31</td>
</tr>
<tr>
<td>Al</td>
<td>90.71</td>
<td>76.87</td>
</tr>
<tr>
<td>Si</td>
<td>0.25</td>
<td>0.13</td>
</tr>
<tr>
<td>P</td>
<td>0.13</td>
<td>0.18</td>
</tr>
<tr>
<td>Ar</td>
<td>0.63</td>
<td>0.61</td>
</tr>
<tr>
<td>Fe</td>
<td>0.35</td>
<td>0.31</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Ag</td>
<td>1.21</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Table (1): summarizes the change of elements concentration of the Al electrode before and after the experiment.

### 3.2 The Effect of Aluminum Ions on CR-39 Track Detector:

CR-39 is scanned before the experiment by SEM as shown in Fig. (6.a). After two hours, it was observed that the surface of CR-39 is coated by a material, and it can be seen by naked eye as in Fig. (6.c).

![SEM micrograph of CR-39 before the occurrence of the Al deposition.](image1)

(a)

![SEM micrograph of CR-39 after the occurrence of Al deposition.](image2)

(b)

![Camera photo of CR-39 after the occurrence of Al deposition.](image3)

(c)

**Fig. (6):** (a)SEM micrograph of CR-39 before the occurrence of the Al deposition.  
(b) SEM micrograph of CR-39 after the occurrence of Al deposition.  
(c) Camera photo of CR-39 after the occurrence of Al deposition.
The SEM micrographs of CR-39 after the experiment is carried out and reveals the deposition of a material on its surface as shown in Fig.(6.b), it is magnified ×2000 and it shows the surface of the CR-39, and it reveals the morphology of the deposited layer. It is a thin layer of deposited material of agglomerations\(^9\).

Fig. (7): XRF spectrum of CR-39 after the deposition.

<table>
<thead>
<tr>
<th>Element</th>
<th>ms%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>80.3943</td>
</tr>
<tr>
<td>Zn</td>
<td>19.6057</td>
</tr>
</tbody>
</table>

Fig.(7) shows the XRF spectrum of the CR-39 surface after the experiment, and it shows the Al peak which indicates the deposition of Al from the discharge tube on the CR-39 in the second tube which is the free field region, Zn appears on CR-39 as a result from the copper electrode having 1mm slit.

These optical observations in conjunction with the SEM and XRF investigations predict the migration of Al ions from the aluminum electrode and deposit of on the CR-39 surface. These ions gain energy to experience the acceleration due to the negative electric field created in the plasma these ions strike CR-39 surface with high energy. The material deposition from one electrode to the other is accompanied by agglomerates of ions.

3.3 Etching of CR-39:

Chemical etching is carried out for the CR-39 sample in a 6.25 N aqueous solution of NaOH at 70 °C for 2.3 hours. Energetic particles colliding with the polymer structure leave a trail of broken chemical bonds within the CR-39. When immersed in a concentrated alkali solution (typically Sodium Hydroxide) the hydroxyl ions attack and break the polymer structure, etching away the bulk of the plastic at a nominally fixed rate. However, along the paths of damage left by charged particle interaction the concentration of damage allows the chemical agent to attack the polymer more rapidly than it does in the bulk, revealing the paths of the charged particle ion tracks\(^10\).

The concept of two etching rats means that\(^11,12\) the chemical solution etches the surface of the detector material, but the etching process goes at a faster rate in the damaged region. One etching is bulk etching at a characteristic rate, \(V_B\), over the undamaged area, and the other is track etching at a rate \(V_T\) along the particle trajectory. The etch rate ratio \(V\) is, then, defined as \(V = V_T / V_B\).
Fig. (8): Sketch of an etched track for oblique incident ion in CR-39 detector.

Fig. (8) Shows the geometry of the track development, S is the initial surface and S’ is the surface after etching. D is the diameter of a pit on the surface, θ is the incident angle of a charged particle, and H is the track depth.

Fig. (9): (a) SEM micrograph of the etched CR-39. (b) Track under the optical microscope.

Fig. (9.a) shows the SEM micrograph of the etched CR-39 in which the Al ion effects are clear. Fig.(9.b) shows the track snapshot under the optical microscope with the help of a digital camera.

The thickness of CR-39 before etching is 1.92mm, and that after etching process is 1.91mm.

- The bulk etch rate \( V_B = 2.14 \, \mu m/h \).
- Distance between major axis \( 2a = 4 \, \mu m \).
- Distance between minor axis \( 2b = 1.6 \, \mu m \).
- Surface of projection \( D = 5.6 \, \mu m \).
- The track depth \( H = 2.5 \, \mu m \).
- The track Range \( R = 6.1 \, \mu m \).
These parameters are shown in Fig.(10.a)

![Diagram showing track parameters](image1)

**Fig. (10):** (a) The track parameters.
(b) The effect of Al ions agglomerations on CR-39.

Using Image J program V.1.46, the surface plot of the cavity which was carried out by the Al ions agglomerations is shown in Fig.(12.b). It reveals that the ions energy reach to a great value to make such hole in CR-39.

4. **The Effect of Tungsten Ions:**

Replacing the aluminum electrode with a tungsten one to study the effect of tungsten ions on CR-39.

![Camera photo and SEM micrograph](image2)

**Fig. (11):** (a) Camera photo of the CR-39 after the occurrence of the tungsten deposition.
(b) SEM micrograph of the CR-39 after the occurrence of the tungsten deposition.

Fig.(11.a) shows a camera photo of the CR-39 after the experiment, while the SEM micrographs of CR-39 after the experiment is carried out and reveals the deposition of a material on its surface as shown in Fig.(11.b), it is magnified ×270, shows the surface of the CR-39 and reveals the morphology of the deposited layer.
Fig. (12): XRF spectrum of CR-39 after the effect of tungsten ions.

<table>
<thead>
<tr>
<th>Element</th>
<th>ms%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu*</td>
<td>12.2019</td>
</tr>
<tr>
<td>W*</td>
<td>87.7981</td>
</tr>
</tbody>
</table>

Fig.(12) shows the XRF spectrum of the CR-39 surface after two hours of exposure to tungsten ions, it shows tungsten peaks which indicate the deposition of tungsten from the discharge tube on the CR-39 in the second tube which is field-free region. Cu appears on the CR-39 as a result from the copper electrode which have a 1mm aperture.

These optical observations, in conjunction with the SEM and XRF systems, predict the migration of tungsten ions from the tungsten electrode and deposition on the CR-39 surface. These ions gain energy to experience the acceleration due to the plasma negative electric field and strike the CR-39 surface with high energy.

4.1 CR-39 etching after tungsten deposition:

The CR-39 is etched in a 6.25 N NaOH aqueous solution at 70°C for 2.3 hours. Here we see that the range of tungsten is larger than that of aluminum, this is attribute to the tungsten high current reached the detector CR-39.

Fig.(13.a) shows the track snapshot under the optical microscope with the help of a digital camera.

The thickness of the CR-39 before etching is 1.92mm, and that after etching process is 1.91mm.

- The bulk etch rate $V_B = 2.14 \mu m/h$.
- Distance between major axis $2a = 6.4 \mu m$.
- Distance between minor axis $2b = 0.8 \mu m$.
- Surface of projection $D = 8 \mu m$.
- The track depth $H = 3.97 \mu m$.
- The track Range $R = 7.78 \mu m$. 
The track parameters are shown in Fig.(13.b).

![Image](a) ![Image](b)

**Fig. (13):** (a) Track under the optical microscope. 
(b) The track parameters.

Here it is noticed that the range of tungsten is larger than that of aluminum, and this is attributed to the tungsten high current reaching the detector CR-39.

![Image](a) ![Image](b)

**Fig. (14):** (a) SEM micrograph of the etched CR-39. 
(b) The surface plot of the tungsten ion effect.

Fig.(14.a) shows the SEM micrograph of the etched CR-39 in which a cavities due to tungsten ions effects are clear, while Fig.(14.b) shows the surface plot of the cavity made by tungsten agglomerated ions.

EDX analysis was carried out on the etched CR-39 specifically in the big cavity as shown in Fig.(15).
The EDX spectrum of the etched CR-39 shows the tungsten element deposition in the cavity analysis, this confirms the deposition of tungsten ions with high energy in the CR-39.

Several computer simulation codes have been developed to calculate the range of ions. The Stopping and Range of Ions in Matter (SRIM) (13) is a group of programs which calculate the stopping and range of energetic ions into matter using a fit to a full quantum mechanical treatment of ion-atom collisions. The most comprehensive of these programs is the Transport of Ions in Matter (TRIM).

Fig. (15): EDX spectrum of the etched CR-39.

Fig. (16): (a) Aluminum Ion ranges in CR-39 by SRIM code. (b) Tungsten Ion ranges in CR-39 by SRIM code.

Fig. (16.a) reveals that the Al ions of 0.83 keV can penetrate to a depth of 5.7 nm into CR-39, on the other hand, the tungsten ions of 0.83 keV can penetrate to a depth of 7.5 nm into CR-39 as clear in Fig. (16.b).

From the CR-39 etching process, the track range was 6.1 µm for Al ions and 7.78µm for tungsten ions, so that the Al and tungsten ions gain more energy from the plasma to be accelerated and penetrate into CR-39. SRIM shows that the energy of the accelerated aluminum and tungsten ions ranging from (4 – 18 Mev).
The plasma accelerating gradients field is\(^{(14)}\).

\[ E_0 \, [V/\text{cm}] \approx 0.96 \ n_0^{1/2} \, [\text{cm}^{-3}] \]

Where \( n_0 = 5 \times 10^{12} \, \text{cm}^{-3} \), so we can find that \( E_0 \approx 2 \times 10^6 \, \text{v/cm} \), from this result it can be predicted that the energy of the accelerating ions is in the range of MeV.

**CONCLUSION**

An AF plasma acceleration system is built, the plasma medium is created by nitrogen gas. In this system two pyrex tubes are used, the first to create the plasma medium between two electrodes (aluminum or tungsten and copper), the second tube is a field-free region and containing the track detector CR-39, a copper electrode with a slit of 1 mm diameter is maintained between the two tubes. After two hours of the exposure of aluminum ions, they leave the aluminum electrode and deposit on the CR-39 surface. Replacing the aluminum electrode with a tungsten one to expose the CR-39 to tungsten ions. SEM, XRF and EDX systems were used to investigate the deposition materials on the CR-39. SEM observation of CR-39 shows an agglomerate groups on its surface for each aluminum and tungsten. These agglomerates deposited with high energy. After the CR-39 chemical etching, the range of aluminum ions is 6.1 \( \mu \text{m} \) while the tungsten ions range is 7.78 \( \mu \text{m} \). These ions transmitted from the hot electrode of the first tube and emerge from the small aperture of the second electrode with high energy to reach the detector in the second tube which is the field- free region. From this study the AF plasma system promises a good ability in ions acceleration in low energy applications with simple apparatus, low cost and small size accelerator with good performance.

**REFERENCES**


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