열전변환장치 다이오드 전극간의 플라즈마 불안정성에 관한 연구

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A STUDY OF PLASMA INSTABILITY IN A CESIATED THERMIONIC DIODE

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Abstract

Oscillations with radio-frequencies are observed in a cesiated variable spacing thermionic diode having a parallel-plane geometry under certain conditions. The emitter is operated over the temperature range from 1300 to 2000 K and collector from 300 to 1050 K. The cesium vapor pressures are in the range of 10^{-3} to 3 torr. The interelectrode gap is between 1 mm to 0.08 mm. The oscillations are only observed in two nonoverlapping regimes. The low temperature oscillations (1300 to 1550 K) are inversely proportional to both the cesium vapor pressure and the square of the interelectrode gap. The high temperature oscillations is inversely proportional to the interelectrode gap. However, all these observed oscillations are frequencies of the plasma ion oscillation.

1. INTRODUCTION

Frequency studies of the thermionic energy conversion (TEC) alternation current (AC) output become increasingly attractive because the indirect conversion of relatively low voltage direct current (DC) output into AC requires a large additional heat rejection weight, which is a major problem for TEC in space nuclear power applications. The AC converter was discovered in 1960 by several workers [1]. The determination of current oscillation phenomenon has been one of the most important aspects of TEC because space power systems need self-modulated frequencies for communication purposes. Because the DC and AC power output occurs simultaneously, the AC output can be used for the power oscillator which can then transmit a signal for a very long distance.

The AC output occurs due to the electron and cesium ion interaction that results in plasma instability inside the diode gap under certain conditions. An AC output measurement system has been designed and fabricated to conduct the plasma instability studies. The oscillation regimes are investigated in the present paper using a spectrum analyzer as a function of emitter temperature, cesium vapor pressure, and interelectrode gap. The dependency of observed oscillations on the temperature, the pressure, and the interelctrode gap are then studied and compared with the theory [2]. The objective of the present paper is to report how the interelectrode gap and the cesium vapor pressure affect a thermionic converter's output frequency at two different emitter temperature regimes.

2. EXPERIMENTAL

A variable spacing ceisum thermionic diode was built by Electro-Optical System, Inc. (EOS) for the study of power output optimization. The diode is in the form of a guard-ringed parallel-plane geometry in which a polycrystalline rhenium emitter of 2 cm^2 area faces a radiation cooled polycrystalline rhenium collector of 1.9 cm^2 area [3]. Then, the test station was fabricated for the present research [4]. The test vehicle was designed to control the interelectrode gap in the range of 0.02 mm to 1 mm with an accuracy of $\pm$ 0.015 mm. Emitter temperatures are varied from 1300 K to 2200 K, collector temperatures from 300 K to 1100 K, and cesium reservoir temperatures from 300 K to 600 K. The liquid cesium reservoir is positioned far from the electrodes so that the low cesium reservoir temperature can be achieved by controlling a shielded resistance cesium heater.

The measurement of spacing is very crucial in this work. The gap calibration is performed before each experiment. In order to calibrated the interelectrode gap precisely, it is necessary to check the electrode continuity at the terminal outputs using an ohmmeter. Emitter temperature was measured with a micro-optical disappearing filament pyrometer. The pyrometer was focused on a cylindrical cavity (hohlraum) that was drilled radially into the emitter. The hole had a length to diameter ratio of 10 to 1. It was estimated that emitter temperature was accurate to $\pm$ 7 K due to error of the observor's eye. The temperatures of collector and cesium reservoir were sensed by sheathed alumel-chromel (type K) thermocouples with an accuracy of $\pm$ 5 K.

The AC components were detected across a resistor (30 Ω) with a pair of double probes that were fed the signal to the input of a spectrum analyzer (Hewlett Packard, 140T/8553B/8552B). The following oscillation parameters were determined in this research:

temperature, spacing, pressure, and oscillation frequency. On the CRT of the spectrum analyzer, the x-axis represented the frequency. The y-axis was the amplitude, which was set in the log mode (log 10dB/division). The maximum peak signal on the display was considered as zero and then the x-axis scale was counted to determine the frequency. The maximum signal peak was called as "the zero frequency" throughout this work. The harmonic peaks of noise signals (1.47 MHz, 3 MHz) were excluded from the evaluation. An oscilloscope camera was used to take pictures of the graphic portion of the display on the spectrum analyzer.

3. RESULTS AND DISCUSSION

Oscillations were observed only under certain conditions of cesium reservoir and emitter temperature because the electron and ion emission had a "S" shape dependency property [5]. The dependency of frequency on the diode's parameters in two nonoverlapping regimes was investigated. Two nonoverlapping regimes were observed as follows: First, high emitter temperature (above 1900 K) and low cesium vapor pressure (less than 0.01 torr). Second, low emitter temperature (1300 to 1550 K) and high cesium vapor pressure (0.01 to 3 torr).

3.1. Low Temperature Oscillations

At a spacing of 1 mm the current oscillations were only observed when the collector temperature were between 423 K and 503 K, and the cesium reservoir temperature was in the range of 427 K to 506 K. The corresponding ceisum vapor pressures were $1x10^{-2}$ torr to $2.45x10^{-1}$ torr. The frequencies ranged from 200 kHz to 500 kHz. At a cesium vapor pressure of $1x10^{-2}$ torr, a frequency of 400 kHz was developed. The spectrum gradually moved to the zero frequency with increasing cesium vapor pressure and then disappeared at a ceisum vapor pressure of $2.45x10^{-1}$ torr. The frequency of the spectrum moved to zero frequency with cesium vapor pressure and then sank to zero frequency at a certain cesium pressure. The output spectrum at an emitter temperature of 1440 K and a cesium reservoir temperature of 490 K is illustrated in Fig. 1. Similarly, observations were also carried out down to the spacing of 0.13 mm. The results were plotted by a least squares fit method as shown in Fig. 2. It is experimentally evident in this work that the frequency decreased linearly with cesium vapor pressure at a fixed spacing and emitter temperature. As the spacing was greater, the slope of the curve was steeper. Also, the dependency of frequency on the emitter temperature was investigated and illustrated in Fig. 3. It indicated that the frequency was proportional to the square root of the emitter temperature, and higher emitter temperatures at a fixed spacing resulted in higher frequencies at low cesium vapor pressure. Oscillations did not occur above an emitter temperature of 1550 K. Finally, Fig. 4 showed the overall comparison of the maximum frequency over the interelectrode gap at different emitter temperatures with a cesium vapor pressure 0.14 torr. The frequency was inversely proportional to the square of the interelectrode gap when the spacing was greater than 0.13 mm. The drift instability as a result of a displacement of the electron distribution with respect to the ion distribution and the two-beam instability (equilibrium stream and pertubation stream) may explain the low emitter oscillations.The volume ionization was a key collision process in the low emitter temperature regime because the luminous bands and bunches were experimentally observed.

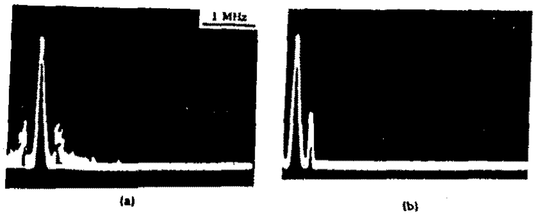

Fig. 1. The output signal at spacing 1 mm, emitter temperature 1440 K, and cesium reservoir temperature 490 K: (a) output signal and (b) 300 kHz standard signal. (Vertical scale: log 20dB/div., Horizontal scale: 1 MHz/div.)

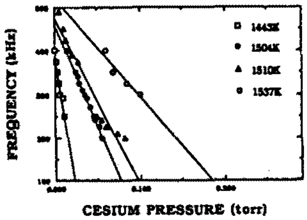

Fig. 2. The variation of frequency with cesium vapor pressures at spacing 1 mm and indicated emitter temperatures.

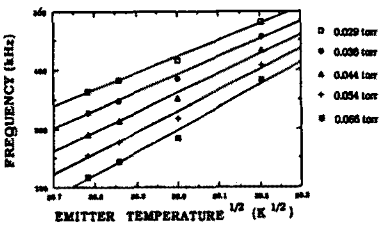

Fig. 3. The variation of frequency with emitter temperatures at spacing 1 mm and indicated cesium pressures.

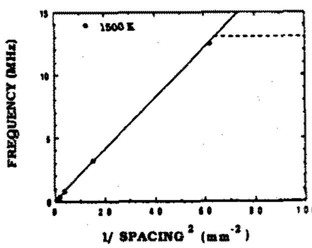

Fig. 4. The dependence of frequency on spacing at emitter temperature 1500 K and cesium pressure 0.14 torr. (solid line: theory, dotted line: experimental data)

3.2 High Temperature Oscillations

At emitter temperatures, above 1900 K, and at a spacing of 1 mm, frequencies were in the range of 200 kHz to 1 MHz. Oscillations were attenuated when the cesium reservoir temperature was 463 K, which meant that the signal frequency was attenuated to the original frequency without movements. The output signal is illustrated in Fig. 5. Coulomb collisions were evident because the present work's spectrum was quite broad and its amplitude were small. This suggests that a virtual emitter due to the Pierce instability forms between the electrodes [6]. Since the mass of cesium ions are 1000 times heavier than the electron, it is possible to re-examine the DC states of a physical system for a time period that is significant only for the motion of electrons, but is insignificant for ions. The temporary DC state breaks up as soon as the ions begin to move, and then the ion-electron systems result in oscillations that are characteristic of the motion of the ions. The virtual emitter formation is the principle mechanism for the high emitter temperature oscillations. As described earlier in sec. 3.1., the same evaluation was applied to the high temperature oscillation. The variation of frequency with increasing cesium vapor pressure was studied. The cesium vapor pressure did not cause the significant change of the oscillation frequency. The emitter temperature also had the same trend as that of the cesium reservoir temperature. However, it was found that the frequency was inversely proportional to the interelectrode gap when the gap was greater than 0.08 mm. It is illustrated in Fig. 6.

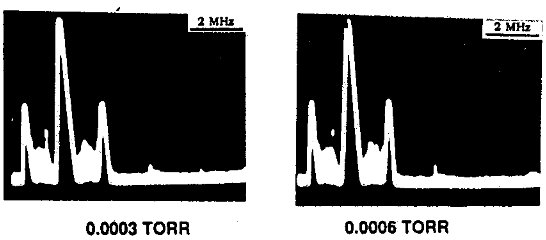

Fig. 5. The spectrum showing oscillations at spacing 1 mm, emitter temperature 1925 K, collector temperature 643 K: (a) cesium reservoir temperature 367 K and (b) 375 K. (Vertical scale: log 20dB/div., Horizontal scale: 2 MHz/div.)

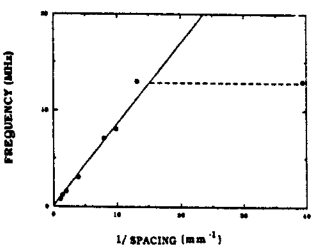

Fig. 6. The dependence of frequency on the spacing in a high emitter temperature. (solid line: theory, dotted line: experimental data)

4. CONCLUSIONS

At low emitter temperature (1300 to 1550 K), the characteristic of the relationship, $f \propto T^{1/2} / (d^2 \times P_{Cs})$, was found experimentally in the present study when the spacing was greater than 0.13 mm. However, at high emitter temperature (above 1900 K), the dependency of frequency on the spacing, $f \propto 1/d$, was only experimentally observed when the spacing was greater 0.08 mm. However, no correlation was found when the spacing was less than 0.08 mm due to the occurrence of DC power output.

From two nonoverlapping experimental conditions, two different collision phenomena were observed: (1) volume processes due to collisions between plasma and neutral atoms which gave rise to the resonance oscillations and (2) Coulomb collisions (correlation and exchange effect) which resulted in relaxation-type oscillation and broad frequency ranges. And all these observed oscillations were frequencies of the plasma ion oscillation as reported by Tonks [7].

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