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By

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Abstract : Electron temperature in the sporadic E layer was measured with a Glass-sealed Langmuir probe at mid latitude station in Japan in the framework of the SEEK (Sporadic E Experiment over Kyushu) - 2 campaign which was conducted in August 2002, Important findings are twofold (1) Ne and Te vary in the opposite sense in the height range of 100-108 km and Te in the Es layer is lower than that of ambient plasma, (2) Te in these height ranges is higher than the possible range of neutral temperature. These findings strongly suggest either that the heat source that elevates Te much higher than possible Tn is still missing at around 100 km, though the most strong candidate is vibrationally excited molecular nitrogen, or that the physical parameter values which are used for the current theory on electron temperature are not proper.

Introduction

It is very difficult to measure electron temperature (Te) inside sporadic E (Es) because sounding rockets go through thin density layer(s) where electron density changes very fast. To obtain Te in the nighttime Es together with that outside Es from a Langmuir probe is especially difficult or almost impossible when electron density (Ne) is not high enough and the amplifier of the instrument cannot have enough gain. This occurs in most of the cases. In addition to these, v- i characteristic curves of Langmuir probe is distorted by the spinning of the rocket and/or by the irregular electron density structure if the probe sweep bias is not fast enough. To get accurate v-i characteristic curves in the rapidly changing media need a well-designed instrument. For these reasons, only few Te data exist so far. Schutz and Smith (1976) reported Te of 520 K inside Es layers at the heights of 108.5 km and 114.5 km. Te outside ES was 550 K at 106.5 km and 111.5 km, which means that Te inside Es was about 30 K lower than the ambient plasma. This result was obtained by simply averaging 29 points of Te values, which were obtained in the height range of 105 km -125 km. No detailed analysis of the rocket attitude was conducted. Szuszczewicz and Holmes (1977) reported Te inside Es in the height range of 105 -107 km both for up leg and down leg. In the up leg, electron density starts increasing at the height of 106.0 km, and reaches a peak at the height of 106.71 Km, and decreases. Te at the peak

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density was 345 K, and Te at the height of 107.5 Km was 380 K. For down leg, maximum height of electron density was 106.2 km. Below the maximum Ne located at the height of 105.7 km, Te was 345 K and above the maximum electron density at the height of 106.5 km Te was 500K. Thus Te inside Es is 140 K lower than outside Es. Two other papers reported on Te inside Es. Aubry et al (1966) showed two Es events. One case is that Te inside Es was 1/2 that of ambient. Another case is that Te is two times higher than ambient. Andreyeva et al (1971) reported two cases; one case shows Te inside Es is equal to that outside Es, and other case shows Te that is 10 % lower than ambient.

Gleeson and Axford (1967) conducted theoretical discussion by taking the heating of internal gravity wave into account. Te in the midst of Es, which was located at the height of 115 Km, was calculated to be about 90 K lower than that of ambient.

As described above, Te data inside Es is still very scarce and no clear conclusion on Te inside Es has been drawn in spite of the long history of sounding rockets.

The S-310-31 rocket was launched at 23:24 JST on August 3 in 2002 to study the QP echo associated with sporadic E from Kagoshima Space Center (131°05'E, 31°15'N). The second rocket S-310-32 was launched 15 minutes after the first rocket. Adjusted solar radio flux and Kp index (sum) were 172.7 and 22, respectively.

A Langmuir probe was installed in the rocket S-31-31. A cylindrical stainless steel electrode of 3 mm in diameter and 20 cm long was used. The electrode, which was installed in the glass tube, was baked at the temperature of 160 C on the ground during the evacuation at the pressure of 10^{-7} Torr inside the glass tube (Oyama and Hirao, 1978). The glass tube was sealed after three days of the evacuation.

The glass tube was broken 2 sec after the nose cone was opened 60 second after the launch, and 1 sec after the glass tube was broken, the electrode was ejected perpendicularly to the rocket spin. Simultaneously the glass tube was removed by a centrifugal force of the rocket spin.

Probe voltage of triangular shape was swept from 0 V to 2.5 V and then from 2.5 V to 0 V within 0.25 sec, which means that one v - i characteristic curve was obtained every 0.125sec. The use of the triangular wave allows us to check the hysteresis of the v - i curve (Oyama,1976). The hysteresis appears when the electrode is contaminated. The spin rate of the rocket was reduced from 2.2 Hz to 0.7 Hz by a yo-yo despinner 55 sec after the launch. Accordingly one v- i characteristic curve was obtained during about 30 degrees of rocket spin. A current amplifier picked up the probe current and the voltage-converted current was amplified with three amplifiers (output voltage of 5 V corresponds to 1 microampere (low gain output), 0.1 microamperes (middle gain output), and 0.01 microamperes (high gain output), respectively). The output voltages of three amplifiers have offset voltage of 0.5 V in order to measure ion current (zero current corresponds to 0.5V). The circuit was calibrated every 30 sec by connecting 40 mega ohm resistance to the input of the amplifier right after disconnecting the wire to the electrode. 8 bits A/D converter converted output voltage with the sampling frequency of 3200 Hz. During the period of 78-108 sec after the launch, output voltage from the middle gain amplifier was converted by 12 bits with sampling frequency of 6400 Hz and stored in the memory. The data, which is thus stored in the memory, was transmitted to the ground 193 sec after the launch when the rocket reached around the apogee. The retrieval of the data completed at 313 seconds after the launch. V-i characteristic curve thus obtained are analyzed by taking the attitude and spin phase into account. Te and Ne were carefully processed with respect to the spin phase and the moving direction of the rocket. The probe current is influenced strongly by the angle between the electrode and the direction of geomagnetic field, whilst variation of Te with respect to the spin phase was not detectable for this experiment.

Fig.1 shows the ion current of the v-i characteristic curves at the probe voltage of 0 V. The voltage where the probe current is zero (floating potential) is between 1 V and 1.5V with respect to the rocket body except inside Es. Therefore 0 V of the sweep voltage is well in the ion saturation regime of the v-i characteristic curves.

In the height region between 100-110 km, an Es layer was found. The first maximum of 1.5×10^{-1} μA is located at the height of 103.5 km. At the height of 105.5 km the second maximum of 9×10^{-2} μA is found. Finally at the height of 107 km,a thin layer of 8×10^{-8} μA was found. After the rocket went through the Es layer between 100-110 km, the ion current gradually reduced, reached its minimum at 123 km and again gradually turned to increase. At the height of 128 km the current dropped from $4\text{x}10^{-4}$ μA to 1.8×10^{-4} μA and suddenly jumped to 10^{-3} μA at the height of 129 km and then dropped to 4×10^{-4} μA. This peculiar behavior might be the key observation to study the formation mechanism of the Es layer, as we will discuss in the separate paper. A small peak is seen at the height of 142 km. This small peak can be seen more clearly in electron current (which is not shown here) of the v-i characteristic curve. Features similar to the ones at the heights of 100,110,123 and 142 km seen during the up leg are seen at 98 - 108, 120 and 141 km during the down leg

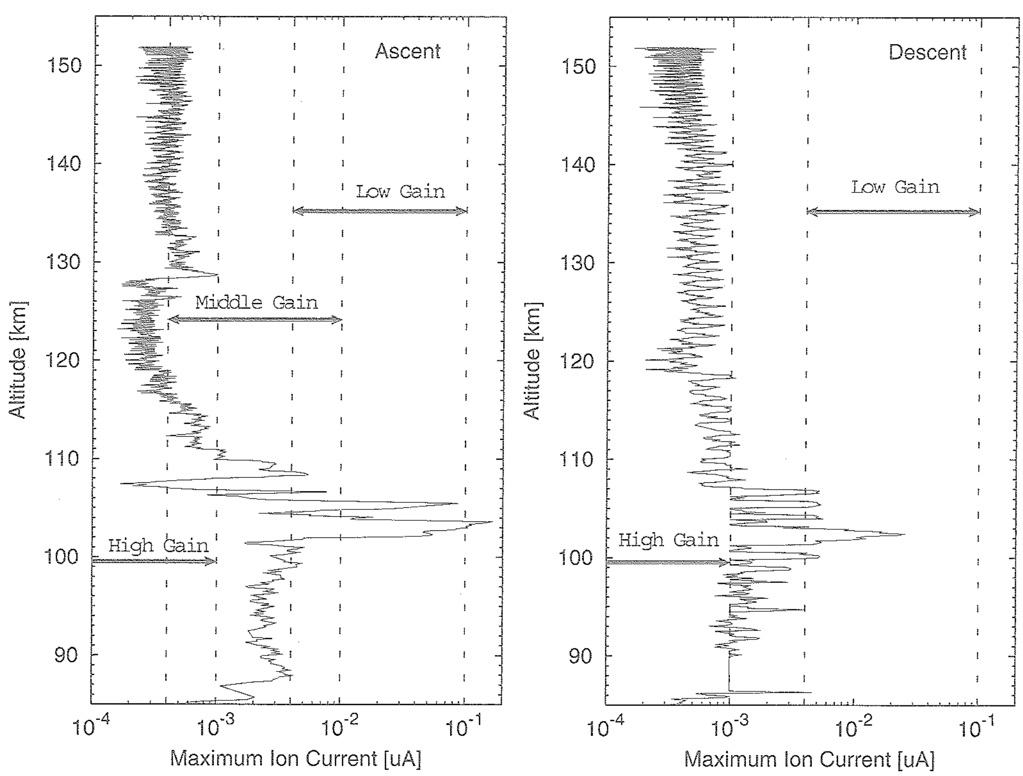

Fig.1 Height profile of the ion current from the v- i characteristic curve for up leg (left) and down leg (right) of the rocket trajectory.

The height range of 100-110 km is expanded in Fig.2 where Te is plotted together with Ne. Te was calculated from the semilog. plot of the electron current measured with a cylindrical Langmuir probe. The accuracy of Te is about 50-100K. Ne was obtained with a fixed biased spherical Langmuir probe. The electron current at the probe voltage of 4.5 V was normalized by the upper hybrid resonance of the gyro-plasma probe (Oya, 1969) at the maximum density height of 103.5 km. The impedance probe is considered to give reliable absolute values for Ne larger than 10^3 els /cc. One can see that Te is well anti-correlated with Ne, even for small changes.

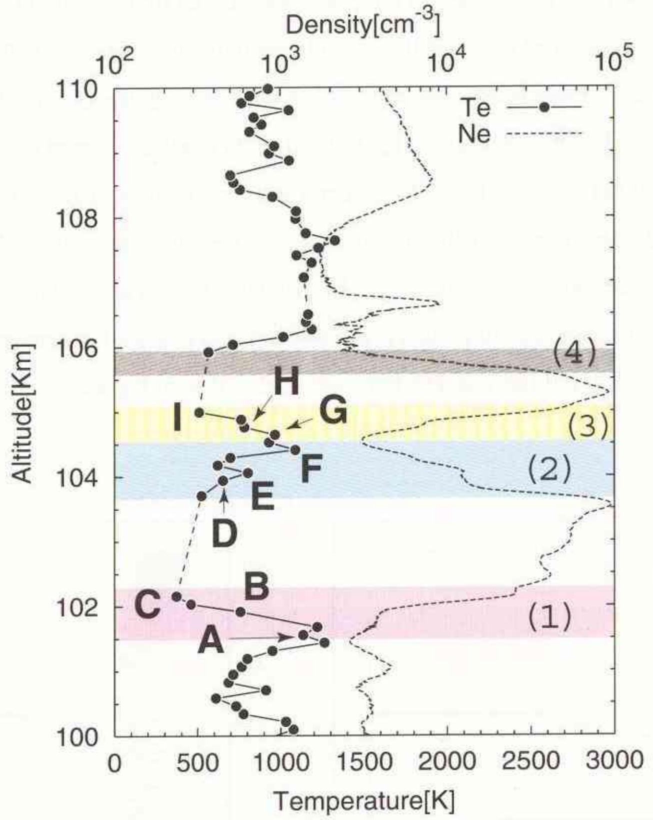

Fig.2 Te (black circles) and Ne (solid line) in the height range of 100-110 km. A, B, C, D, E, F, G, and I indicate the heights where v-i characteristics curves and semilog. plotted electron current curves shown in Fig, 3 were measured.

The first and second peaks of Ne at the height of 103.5 km and 105.3 km are 105 els/cc and 9×10^4 els/cc, respectively. Just below the first peak, Ne is 4×10^3 els/cc at the height of 101.5 km. Ne between two density peaks, at the height of 104.5 km is 3×10^3 els/cc. Te is 1000 K at the height of 101.5 km and 300K at the height of 102 km. Above the first Ne peak, Te is 500K . Between the first and second Ne peaks Te is 1000K.

The reliability of the Te measurement is illustrated in Fig.3 a, b, and c. In Fig.3a, v-i characteristic curves in the height range of 101.5 - 102.2 km are shown in the left part of the figure and the electron current is plotted versus probe voltage in the right part of the figure. The rocket went into the Es layer in the order of curves A, B, and then C. The change of the slope is clearly seen for the semilog. plotted curves. Te reduced as Ne increased from A to C. We could not get the full v-i curve at point C, because the rocket potential went down to negative to the extent that probe bias cannot cover voltage range sufficient to get the full v-i curve. Above the height marked C, the rocket potential further went negative and therefore the v-i curve showed only ion saturation region and Te was not available.

In Fig.3b, three similar curves in the height range of 103.7 km to 104.4 km where Ne decreased from the maximum to the minimum are shown. The slope of the semilog. plotted electron curve decreases with height from D to F. At the height F, Te takes the highest value among the three curves. This means that Te increases as Ne decreases.

Fig.3c shows the height range from 104.4 km to 105 km where Ne started to increase from its minimum value toward the peak value. Although Te did not decrease in the order of increasing Ne (compare the slope of the semilog. plotted curve, G and H), Te was surely lower at higher Ne. Above the height I, the rocket potential again became negative far below the probe sweep voltage and v-i curve was not available.

The magnitude of this rocket potential can only be explained by the huge ion mass of more than 1000 ,which might be either cluster ions or charged dust particles. The metal ions such as Mg^+ cannot explain the present floating potential.

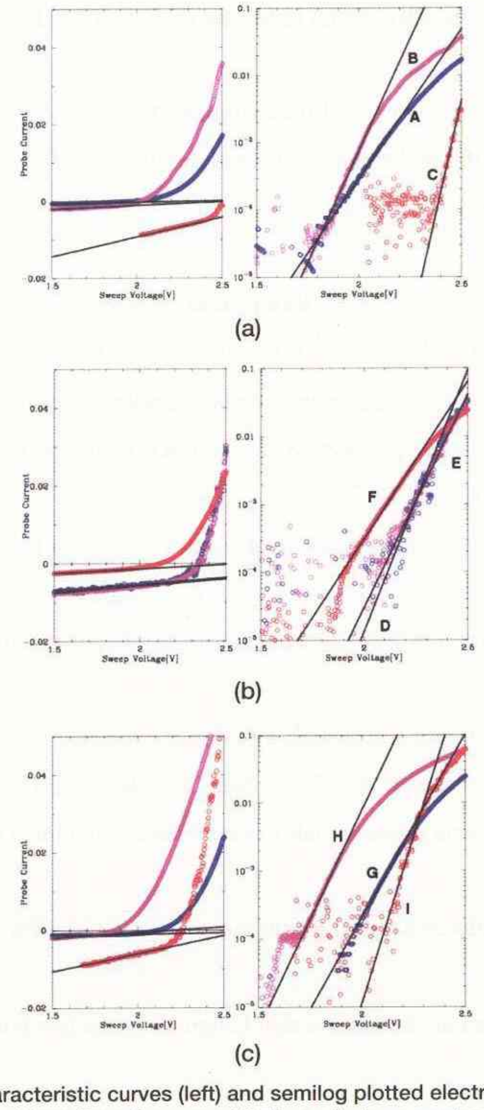

Fig.3. V- i characteristic curves (left) and semilog plotted electron currents (right) obtained from the v-i curves at 9 places that are marked in Fig.2.

Concluding remarks

Electron temperature in the lower E region in the presence of Es was obtained after careful analysis of rocket attitude and spin phase. We believe that the data, which is obtained with a glass- sealed Langmuir probe, is one of the most reliable data measured so far. From this measurement, two important findings are made:

1.Te in the height range of 100 - 110 km has an average value of 800K, which is still much higher than the possible range of neutral temperature (about 250 K) at these heights.

2. Electron density varies in anti- correlation with Te. When electron density is high, electron temperature is low. This feature was observed most clearly inside Es, that is, Te is lower than that outside Es. It is noted that this feature was seen in all altitude ranges in the nighttime ionosphere where no direct solar EUV exists.

We now strongly believe that some heat source is still missing (Oyama and Hirao, 1980) that can elevate electron temperature above the neutral temperature, or that the current theory on Te uses wrong parameter values such as suggested by Jane et al (1981) on the electron temperature in the equatorial electrojet. The heating of electrons by vibrationaly excited nitrogen molecule is still a strong candidate (Oyama, 1983; Kurihara et al., 2003).

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