Effects of Vacuum Conditions on Low Frequency Noise in Silicon Field Emission Devices

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The effects of pressure on emission current noise have been studied. Field emission currents from silicon devices were observed over a range of pressures. The current fluctuations were analyzed in both the time and frequency domain. Signal to noise ratios between 0.9 and 6.9 were observed. These values appear to be more dependent on operation time than on pressures. Spectral density coefficients of low frequency measurements range from -1.37 to -1.81. Some pressure dependence is suggested in the lower pressure ranges. At higher pressures emission currents seem to be reduced and the current is cut off completely above a threshold pressure which is somewhere in the 10s of Torr.

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INTRODUCTION

Vacuum microelectronic devices are quickly becoming established as a viable technology for flat panel displays and other electron gun device applications. Consequently, it is increasingly necessary to understand aspects of device noise and lifetime. Factors associated with device lifetime include tip destruction due to ion bombardment, excessive emission current, and contamination of the emitter tips. One very important method of investigating these phenomenon is through the study of the environment in which the emitters are operating, for instance, by attaching a residual gas analyzer to a system and studying the outgassing of phosphors or the emitters themselves.[1] Another method is to study the device noise under various conditions, for example, different system pressures, and to relate these data to specific events, i.e. noise. Furthermore, as device applications become more diverse, an understanding of the noise characteristics of individual tips is becoming important. Knowledge of such characteristics is vital to the design of any vacuum microelectronic device.

One of the most predominant types of noise is 1/f noise which can be described by

$$S(f) = \frac{C}{f^{\gamma}} \tag{1}$$

where S(f) is the noise power, dependent on the bandwidth, γ is the spectral density index, and the value of C is dependent on the magnitude of the measured voltage or current.[2,3] In this study we examined the low frequency emission current fluctuations from silicon field emission devices under different vacuum conditions. Initial measurements have been performed using array devices evaluated under a vacuum of $2\text{x}10^{-6}$ Torr. These data are compared with data obtained from arrays tested under better and worse vacuum conditions. In addition to 1/f noise, the extent of fluctuation was observed. Variation of current with time, independent of frequency, was measured and the signal to noise ratio determined. By comparing these two factors, as well as general observations, insight on the effects of the operating vacuum on silicon field emitters should be gained.

EXPERIMENTAL PROCEDURE

Noise measurements were done using 50x50 arrays of gold gated silicon field emission devices fabricated using the method previously described.[4] The gate and cathode were controlled using a semiconductor parameter analyzer which was able to source the voltages and monitor the currents. The devices were tested under DC conditions at fixed gate voltages. Field emission electrons were collected using a metallic anode located approximately 3 mm from the gate/cathode structure. Electrical contact to the anode was made via a feed-through at the opposite end of the vacuum chamber from the gate and cathode leads. Anode biasing was done using two methods. The first was by directly connecting the parameter analyzer to the anode. This allowed measurement of the anode current at each sample interval. Since the sample interval of the parameter analyzer was limited to 2ms, another biasing scheme was needed to obtain higher frequency measurements. This was carried out by setting a DC bias for the anode at 100 V using a power supply. A digitizing oscilloscope was then capacitively coupled to the anode allowing direct measurement of the noise fluctuations.

Measurements were done at pressures of $2x10^{-2}$, $2x10^{-4}$, $2x10^{-5}$, $2x10^{-6}$, and $<10^{-8}$ Torr. The measurements at $<10^{-8}$ Torr were done in a separate chamber. The other measurements were done in the same chamber starting with the base pressure of $2x10^{-6}$ Torr and using the gate valve on the ion pump to control the pressure. Neither the devices nor the chambers were baked out prior to the study.

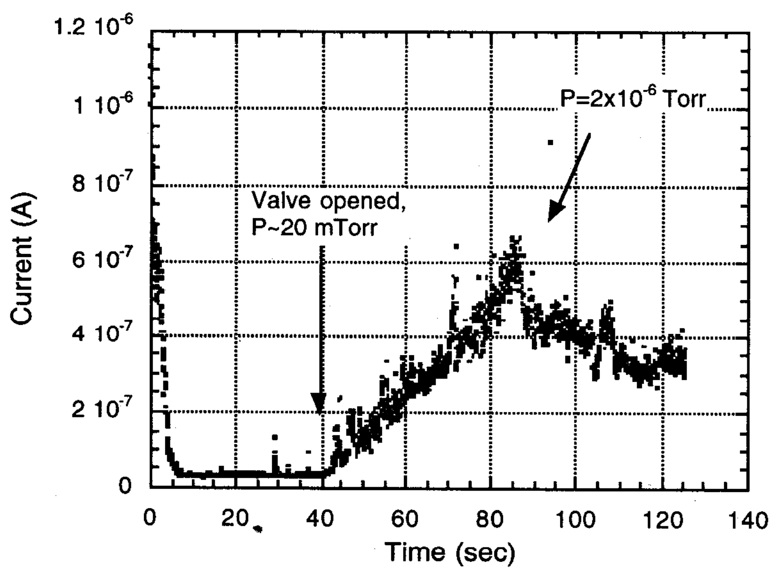

Figure 1: The change of current with change in pressure.

RESULTS AND DISCUSSION

Currents measured from the devices ranged from about 0.5 to 4 μA depending on the bias and most likely the number of tips on the device that were emitting. Current - time measurements were made at a several different pressures. During the measurements, two observations about the current behavior were made. First, the devices were turned on by immediately switching the gate voltage to the bias value. When this was done, the emission current initially started out at a high value, then dropped to a lower level in a few seconds. Second, as the pressure is raised into the millitorr range there is a threshold where emission stops completely. In some cases plasmas were observed before this threshold was reached. Once the pressure was brought back down into the range of operation the emission current resumed. This phenomenon was observed for both anode and gate currents, suggesting that a large portion of the field emission current is being collect by the gate. Figure 1 shows a plot of current -vs- time where the chamber pressure was initially set above the stable emission threshold by closing the high-vacuum valve. The pressure was then lowered after 40 seconds by opening the valve. As the pressure dropped the emission current rose, when the pressure stabilized, so did the emission current.

Figure 2 shows a current - time plot at a single pressure measured from when the device was turned on. Several of these measurement were made at various pressures and the average current, standard current deviation, and noise power - frequency response was calculated for each. A signal to noise ratio was calculated by

$$S/N = \text{Average current}/2*\text{Standard Deviation} \qquad (2)$$

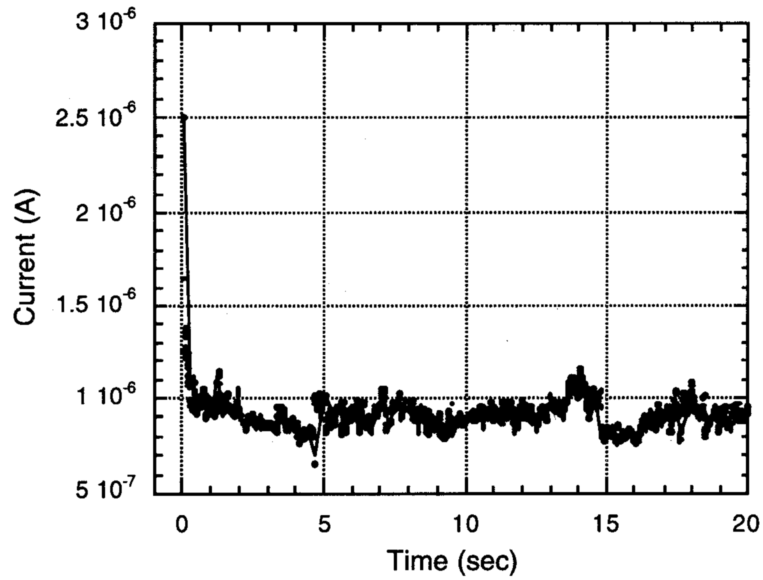

Figure 2: Typical current - time data measured at $2x10^{-6}$ Torr. Note the initial high current.

In general, there was no significant difference in the S/N ratio at pressures between $2x10^{-6}$ and $2x10^{-4}$. However, it was found that if the emission was given time to stabilize, this ratio became higher though the overall current was lower. At lower pressures this effect was less noticeable, and better S/N ratios were found at higher emission currents. In all cases the signal to noise ratio was never greater than 6.9. Table 1 summarizes this information. It is difficult to make any conclusion about the exact cause of the stabilization phenomenon. However, since the process is repeatable and is less noticeable in better vacuum, the mechanism of this phenomenon may be contaminant desorption.

Table 1: Average current, signal to noise ratio, maximum, and minimum currents from 50x50 arrays at different pressures.

Pressure (Torr)	Average I (μA)	S/N	Max I (μA)	Min I (μA)	Comment
$2x10^{-4}$	1.07	2.3968	4.36	0.816	
$2x10^{-4}$	0.96	2.1526	3.88	7.84	
$2x10^{-4}$	0.92	6.5097	1.19	6.17	after 30 sec.
$2x10^{-5}$	1.29	2.1311	5.65	1.00	
$2x10^{-5}$	1.27	2.1675	4.74	0.90	
$2x10^{-5}$	0.83	6.9703	1.11	0.68	after 30 sec.
$2x10^{-6}$	1.36	2.0893	4.86	0.86	
$2x10^{-6}$	1.22	2.5574	1.93	0.62	
$2x10^{-6}$	0.70	6.8561	1.00	0.61	after 30 sec.
$<10^{-8}$	2.92	3.2678	4.40	1.88	
$<10^{-8}$	3.31	4.0878	4.89	2.41	
$<10^{-8}$	3.23	3.9800	5.11	2.35	

Flicker noise was analyzed by converting current - time data to noise power - frequency data using FFT calculations. Figure 3 shows the frequency space data at four different pressures. The straight lines represent curves fit to the noise equation, (1), and the spectral densities from these fits are shown in Table 2. The spectral density for the low pressure data is much lower than the others. There is a trend towards increasing γ until $2x10^{-4}$ Torr is reached, at which point it starts to lower once again. At this time, the reason for this is not known, however, since measurements were done at constant gate voltage rather than constant anode current, it may be that the change in γ is related to a drop in emission current at higher pressures.

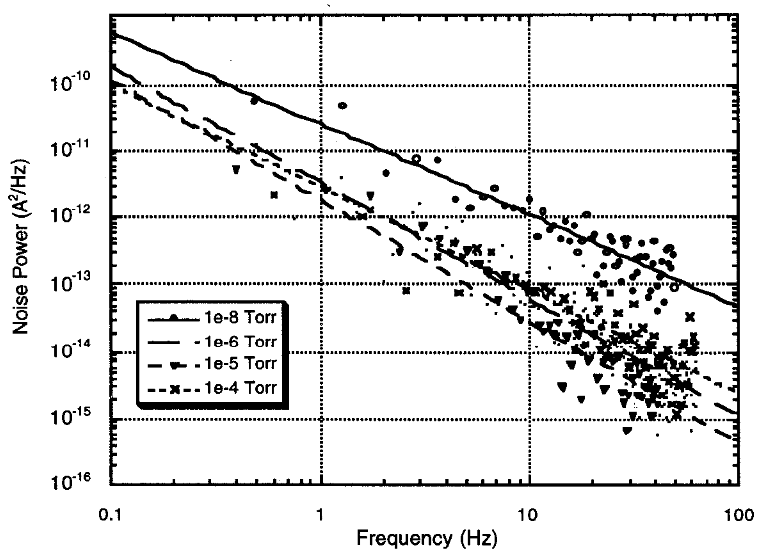

Figure 3: Low frequency noise at various pressures.

Table 2: Calculated spectral density at different pressures.

Pressure (Torr)	Spectral Density
$1x10^{-8}$	-1.3669
$1x10^{-6}$	-1.7366
$1x10^{-5}$	-1.8093
$1x10^{-4}$	-1.5364

SUMMARY

The effects of pressure on field emission noise are being studied. There is some indication that there are measurable effects on flicker noise due to changes in pressure. Signal to noise ratios measured at pressures from $2x10^{-6}$ to the current cutoff threshold are similar and seem to improve over time at the expense of overall current. At pressures near $1x10^{-8}$ the signal to noise ratio appears to be more consistent, though still quite low. Measurement of these effects are continuing. This study will be expanded to single emitter devices since array devices suffer from uncertainties, particularly the lack of knowledge of precisely how many emitters are working. Results from this study are intended to provide information on the vacuum levels necessary for reliable behavior of silicon field emission devices.

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