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Theoretical and experimental studies were performed to investigate the feasibility for the formation of fusible links by using thin Aluminum films. The results of this research indicate that, by using the Aluminum films of 100 to 200 angstroms in thickness, it is possible to obtain links with fusing currents on the order of 10 milliamperes. These values may be acceptable for the fabrication of large area MOS-gated power devices.



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# FUSIBLE LINK TECHNOLOGY
# FOR
# POWER SEMICONDUCTOR DEVICES

**Final Report**

**Prasad Venkatraman**
**B. Jayant Baliga**



**Contract No. : DAAL03-90-G-0215**
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# FINAL REPORT SUMMARY

This final report describes theoretical and experimental studies performed to investigate the feasibility for the formation of fusible links by using thin Aluminum films. The results of this research indicate that, by using the Aluminum films of 100 to 200 angstroms in thickness, it is possible to obtain links with fusing currents on the order of 10 milliamperes. These values may be acceptable for the fabrication of large area MOS-gated power devices.

This work was performed by Graduate Student Prasad Venkataraman towards the fulfillment of his Ph.D. degree under the guidance of Professor B. Jayant Baliga.

# CONTENTS

# 1 INTRODUCTION

Fusible links are links made of a low melting point metal (such as aluminium), which can be opened by electrical methods or lasers. They have been used in integrated circuits (especially memory chips) to disconnect faulty portions of the chip from the rest of the chip. Their use has significantly enhanced the yield of memory chips.

It is proposed that fusible links also be used in power MOS-gated devices to improve the yield. The main cause for reduction in the yield of these devices is a short between the gate and the source, which causes a leakage current into the gate when the device is in the off-state. This problem can be overcome by partitioning the MOS device into segments consisting of a smaller number of cells and connecting the gates of these segments through the fusible links. Now, if a faulty cell is present in any of the segments, the leakage current flowing into the gate of that segment will blow the fuse, thus disconnecting the faulty segment from the rest of the device. The device will still continue to function with only a small reduction in its current carrying capability. Since the fuse is connected in series with the gate, it is important that the fuse have a small resistance, so that the RC delay does not adversely affect the switching characteristics of the device. Also, the technology for fabricating the fuses must be compatible with the process used to fabricate the power MOS devices. Hence, aluminium was chosen as the fuse material since it has a low resistivity and it is also used in the MOS process.

In this project, we have fabricated fusible links that can be opened by passing a small current (of the order of a few milliamperes) through them. The fuses were made of aluminium. A thermal analysis of the fuses was first carried out to determine the fuse dimensions required to obtain a fusing current of a few milliamps. Based on this analysis, a mask set was designed and fuses of 100 Å and 200 Å thickness and widths ranging from 1 to 6 microns were fabricated. The fusing currents obtained were found to be reasonably close to those predicted by the thermal analysis.

This report describes the analysis, design and fabrication of the fusible links, as well as the experimental results obtained on the fusing currents. Problems encountered during the fabrication are also discussed.

# 2 THERMAL ANALYSIS OF FUSIBLE LINKS

In order to fabricate the fusible links, it was necessary to have a good idea of the fuse dimensions required. This is because the fusing current depends on the dimensions of the fuse. Fuses that are very thick and wide will require excessive currents for fusing. For this purpose, a thermal analysis of the fuses was carried out. This section describes the thermal analysis and gives the results of the analysis.

## 2.1 Thermal Analysis

In this section, the thermal analysis carried out on the fuses is described. The structure shown in Fig 2.1 was analyzed. The structure consists of an oxide layer on silicon. The fuse metal is deposited on the oxide. The oxide and silicon are assumed to have thermal resistances $R_{\theta,ox}$ and $R_{\theta,si}$, corresponding to thermal resistivities of $\theta_{ox}$ and $\theta_{si}$ respectively. The heat flux is assumed to flow perpendicular to the metal into the oxide. The current required to maintain a temperature difference of $\Delta$T is calculated.

The temperature difference $\Delta$T is given by

$$\Delta T = PR_{\theta} \tag{2.1}$$

where P is the power dissipated in the metal. If W and L are the width and length of the fuse respectively, then

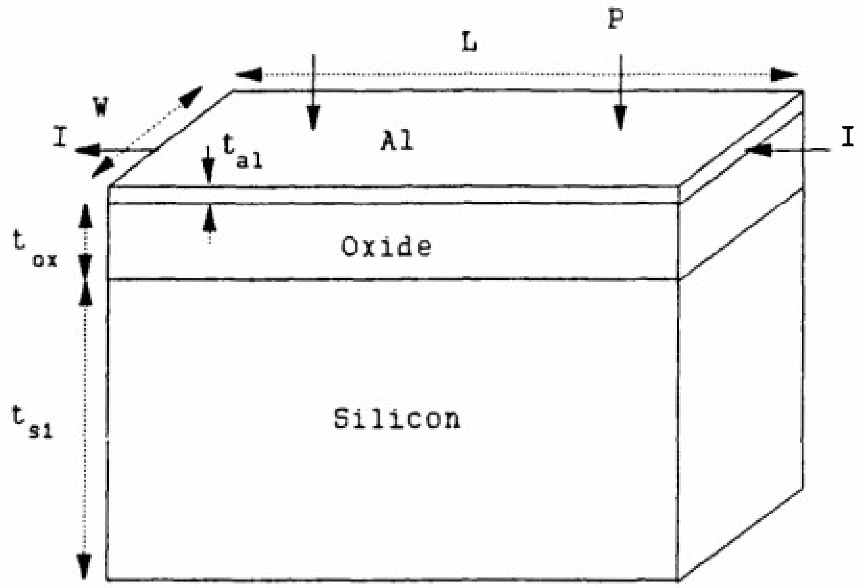


**Figure 2.1 Fuse Structure for Thermal Analysis**

$$R_{\theta,ox} = \frac{t_{ox}}{\theta_{ox} W L} \tag{2.2}$$

$$R_{\theta,si} = \frac{t_{si}}{\theta_{si} W L} \tag{2.3}$$

The total thermal resistance is given by

$$R_\theta = \left(\frac{t_{ox}}{\theta_{ox}} + \frac{t_{si}}{\theta_{si}}\right)\frac{1}{WL} \tag{2.4}$$

Power P is given by

$$P = I^2 R_{Al} \tag{2.5}$$

where I is the current in the fuse and $R_{Al}$ is the electrical resistance of the fuse, given by

$$R_{Al} = \rho_{Al}\frac{L}{Wt_{Al}} \tag{2.6}$$

From Eq. 2.1, 2.4 and 2.6, we get

$$\Delta T = \frac{I^2\rho_{Al}}{W^2 t_{Al}}\left(\frac{t_{ox}}{\theta_{ox}} + \frac{t_{si}}{\theta_{si}}\right) \tag{2.7}$$

Rearranging, we get

$$I = \frac{W\sqrt{t_{Al}}\sqrt{\Delta T}}{\sqrt{\rho_{Al}}\left(\frac{t_{ox}}{\theta_{ox}} + \frac{t_{si}}{\theta_{si}}\right)^{\frac{1}{2}}} \tag{2.8}$$

The fusing current corresponds to a temperature rise $\Delta T$ at which the melting point of aluminium (661°C) is reached.

## 2.2 Results of Thermal Analysis

From Eq. 2.8, we note that there are several parameters that can be varied to adjust the fusing current. In particular, we note that the fusing current decreases if

(a) The width of the fuse, (W) is decreased.

(b) The thickness of the fuse, ($t_{Al}$) is decreased.

(c) The thickness of the oxide layer, ($t_{ox}$) is increased.

(d) The thickness of the silicon substrate, ($t_{si}$) is increased.

We note that the fusing current is independent of the length of the fuse. We can also reduce the fusing current by selecting a fuse material that has a higher resistivity and a lower melting point.

Table 2.1 shows the fusing currents for various fuse widths and thicknesses. The thickness of the silicon and oxide layers were taken as $500\mu$ and $1\mu$ respectively. Plots of the fusing current versus fuse width are shown in Fig. 2.2.

From Table 2.1, we see that for fuse thicknesses of 1000 Å and 500 Å, the fusing currents are very high unless we use fuses of very small width, i.e., 1 or 2 $\mu$. To get low fusing currents, it is necessary to use fuses of 100 to 200 Å thickness.

**Table 2-1 Fusing Currents for Various Fuse Widths and Thicknesses.**

| $t_{si}(\mu)$ | $t_{ox}(\mu)$ | $t_{al}(Å)$ | w ($\mu$) | i (mA) |
|---|---|---|---|---|
| 500 | 1 | 1000 | 5 | 111.1 |
| | | | 3 | 66.7 |
| | | | 2 | 44.5 |
| | | | 1 | 22.2 |
| 500 | 1 | 500 | 5 | 78.6 |
| | | | 3 | 47.2 |
| | | | 2 | 31.4 |
| | | | 1 | 15.7 |
| 500 | 1 | 200 | 5 | 49.7 |
| | | | 3 | 29.8 |
| | | | 2 | 19.9 |
| | | | 1 | 9.9 |
| 500 | 1 | 100 | 5 | 35.1 |
| | | | 3 | 21.1 |
| | | | 2 | 14.1 |
| | | | 1 | 7.0 |

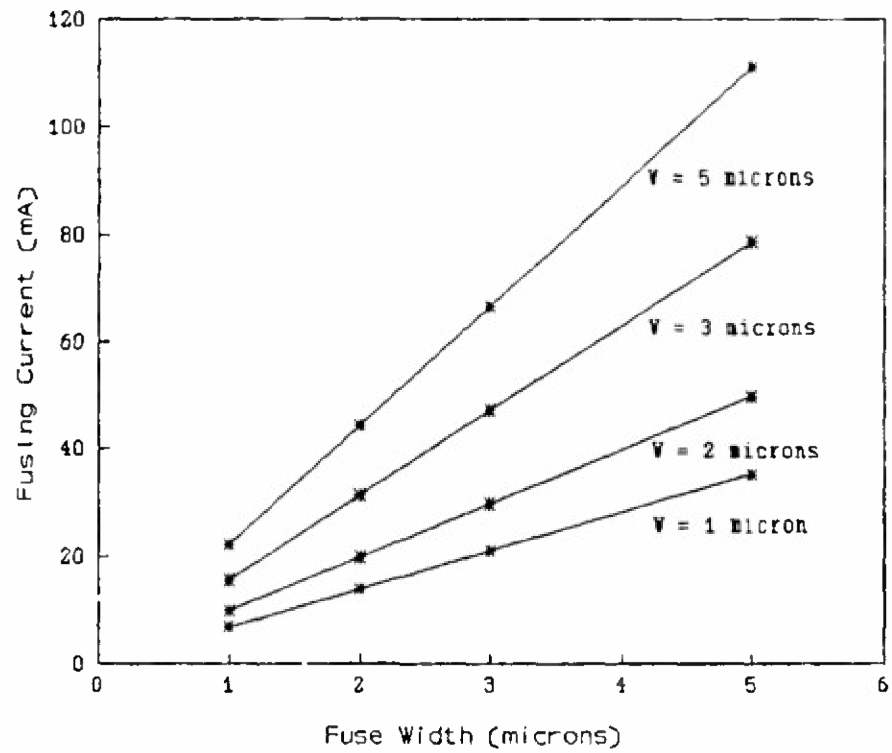


**Figure 2.2 Fusing Current vs. Fuse Width**

## 2.3 Summary

A thermal analysis of the fusible links has been carried out. Based on this we have found that fuses of 100 to 200 Å thickness are necessary to obtain fusing currents of a few milliamperes. The fusing current was found to increase as the square root of the fuse metal thickness and linearly with fuse width.

# 3 DESIGN AND PROCESSING OF FUSIBLE LINKS

This section describes the mask design and the processing for the fusible links. Problems encountered during the processing are also discussed.

## 3.1 Design of Fusible Links

Four different types of fuse structures were designed as shown in Fig. 3.1. In the structures of Figs. 3.1(a) and 3.1(b), a polysilicon layer was deposited on the thermal oxide and patterned. The polysilicon was then covered with CVD oxide and contact windows opened before depositing metal. In structures of Figs. 3.1(a) and 3.1(c), a thick metal layer was used for the pads, while for the other two structures, no thick metal was used.

Mask design was done using MAGIC. Four masks were designed. The first mask was used to pattern the polysilicon layer. The second mask was used to open contacts to the polysilicon. The third and fourth masks were used to pattern the thick metal layer and the fuse metal layer respectively.

## 3.2 Fabrication of Fusible Links

The fabrication of the fusible links was done at the NCSU microelectronics laboratory. The deposition of the thick aluminium and the fuse aluminium was done at the Microelectronics Center of North Carolina. N-type <100> wafers were used for

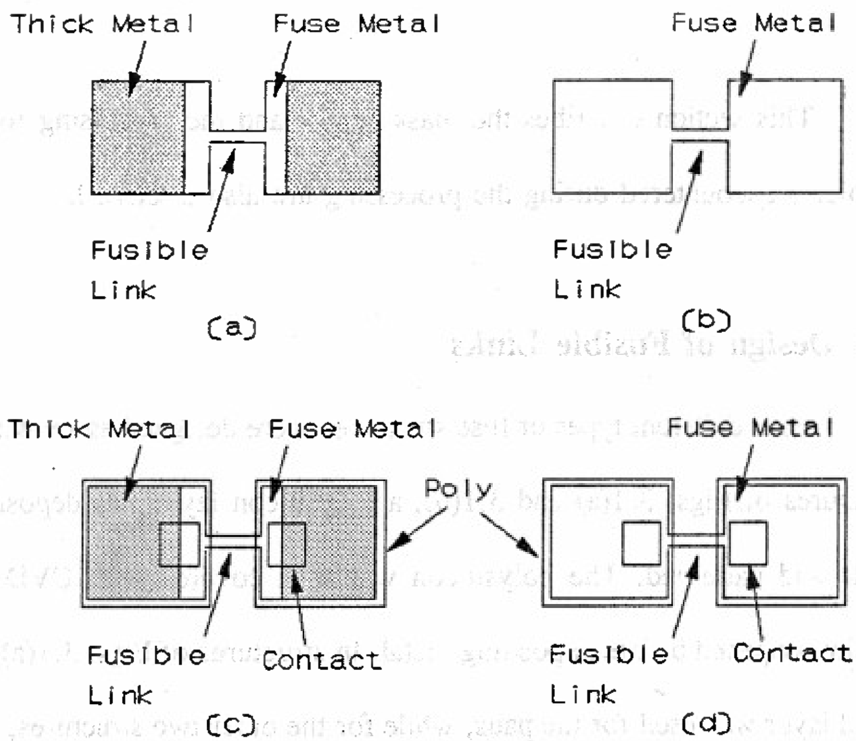


**Figure 3.1 Fusible Link Structures**

fabricating the fuses. After pre-diffusion cleaning, wet oxide was grown at 1050°C for 190 minutes. The oxide thickness was approximately 1$\mu$. Next, approximately 6000 Å of polysilicon was deposited on some of the wafers and doped using $POCl_3$. The first mask was then used to pattern the polysilicon. Next, approximately 5000 Å of CVD oxide was deposited on the polysilicon and contact windows opened using the second mask. The next step was to deposit 1$\mu$ of Aluminium on all the wafers (including those without the polysilicon) and pattern it. The fuse metal Aluminium was then deposited and patterned. During the etching of the fuse metal, the thick Aluminium layer was also exposed to the etchant. However, since the fuse metal thickness is much less than that of the thick Aluminium, the amount of thick metal etched away is very small.

Two runs were carried out. In the first run, fuses of 1000 Å, 500 Å, 250 Å, and 100 Å thickness were fabricated. In the second run, only fuses of 200 Å and 100 Å were fabricated.

## 3.3 Problems Encountered During Fabrication

The problems encountered in processing involved the fuse metal layer. In the first run, etching of the fuse metal layer was carried out using Aluminium etch ($H_3PO_4$(79%), $CH_3COOH$(5%), $HNO_3$(5%), $H_2O$(11%)) at 45°C. However, this gave a very high etch rate and most of the exposed thick aluminium was also etched away. In the second run however, care was taken to do the etching at room temperature. This gave much greater control over the etching rate and no significant etching of the thick aluminium took place.

Another problem encountered was during the stripping of photoresist after patterning the fuse aluminium layer. The photoresist was stripped using accustrip. Accustrip reacts slightly with aluminium, leading to a slight reduction in the thickness of the aluminium. In this case, since the thickness of the fuse aluminium layer is only 100 or 200 Å, the reduction in thickness can be significant. As a result, the thickness of the fuses fabricated were slightly less than 100 or 200 Å. One way to solve this problem is to use acetone instead of accustrip to strip the resist. However, acetone will leave an organic residue on the wafer. Another option is to leave the wafers in accustrip for just enough time to remove the photoresist.

## 3.4 Yield

During fabrication, it was found that the 1 and 2 micron wide fuses were broken during the lithography. Hence, the yield of the 1 and 2 micron wide fuses was very poor (less than 50%). This was due to the limitation in the equipment used for photolithography. With better equipment, it should be possible to get higher yields for 1 and 2 micron wide fuses.

For the 200 Å thick fuses, the yield was found to be very high (nearly 100%) for the fusible link structures without the polysilicon layer (i.e., Figs. 3.1(a) and 3.1(b)). The yield for the structures with the polysilicon layer was lower. This can be attributed to the etching of the fuse metal layer around the edges of the contacts to the polysilicon.

For the 100 Å thick fuses, yields close to 100% were obtained for the structure of Fig. 3.1(b). For the structure shown in Fig. 3.1(a), the yield was poor. This could be due to poor step coverage of the fuse metal layer over the thick metal pad. This problem was not observed with the 200 Å thick fuses. This can be solved by minimizing the height of the step or by using a thicker fuse metal layer. For the structures with the polysilicon layer, the yield was again poor.

## 3.5 Summary

A description of the design and fabrication of fusible links was given. Some problems encountered in fabrication were discussed. The yields obtained were also discussed.

# 4 EXPERIMENTAL RESULTS

The fusible links were tested to determine the fusing current and the resistance of the fuses. This section describes the testing procedure and tabulates the results obtained.

## 4.1 Testing Procedure

To determine the fusing current, a dc voltage was applied between the ends of the fuses. The voltage was ramped up and the current through the fuse monitored. When the fuse was opened, the current dropped to zero instantaneously. Hence, the value of the current just before it dropped to zero gave the fusing current. A similar procedure was used to measure the fuse resistance, except that the current was kept at values much below the fusing current in order to prevent the heating effects from modifying the resistance. The voltage applied and the corresponding current were noted down and the resistance was obtained.

## 4.2 Fusing Current Measurement

The fusing currents were measured as described in the previous section. Contrary to what the thermal analysis predicted, the fusing current showed a small variation with fuse length. Shorter fuses required a higher current to fuse. This is attributed to removal of heat from the ends of the fuse. This effect is not accounted for in the one-dimensional analysis reported in Section 2. Also, the currents required for fusing were found to be slightly lower than those predicted by the thermal analysis.

For the 200 Å fuses, the fusing currents were found to range from 30 mA to 37 mA for 5$\mu$ wide fuses and from 16 mA to 21 mA for 3$\mu$ wide fuses. Table 4.1 gives the average values of the fusing currents for the 200 Å fuses. For the 100 Å fuses, the fusing currents were found to range from 13 mA to 16 mA for 5$\mu$ wide fuses and from 6 mA to 9 mA for 3$\mu$ wide fuses. Table 4.2 gives the average values of the fusing currents for the 100 Å thick fuses.

**Table 4.1 Fusing Currents for 200 Å Fuses.**

| W ($\mu$) | L ($\mu$) | I (mA) |
|---|---|---|
| 5 | 50 | 30.3 |
| | 20 | 31.3 |
| | 10 | 32.6 |
| | 5 | 34.5 |
| | 3 | 37.1 |
| 3 | 50 | 16.1 |
| | 20 | 17.3 |
| | 10 | 18.0 |
| | 5 | 19.5 |
| | 3 | 21.9 |
| 4 | 10 | 25.3 |
| | 5 | 26.9 |

**Table 4.2 Fusing Currents for 100 Å Fuses.**

| W (μ) | L (μ) | I (mA) |
|---|---|---|
| 5 | 50 | 13.0 |
| | 20 | 13.7 |
| | 10 | 13.0 |
| | 5 | 15.4 |
| | 3 | 16.4 |
| 3 | 50 | 6.7 |
| | 20 | 7.8 |
| | 10 | 8.3 |
| | 5 | 8.9 |
| | 3 | 9.8 |
| 4 | 5 | 12.3 |

Figures 4.1 and 4.2 show plots of the fusing current for the 200 Å and the 100 Å fuses respectively.

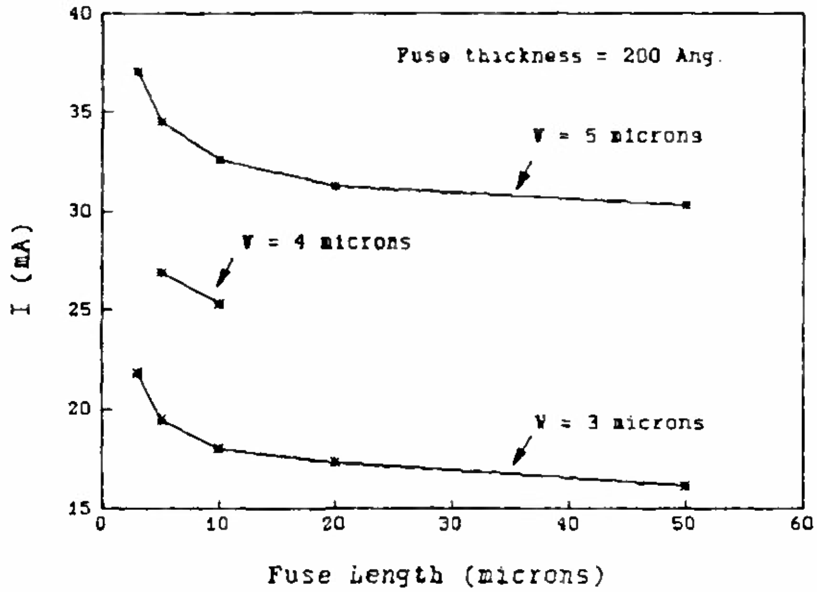


**Figure 4.1 Fusing Currents for 200 Å fuses.**

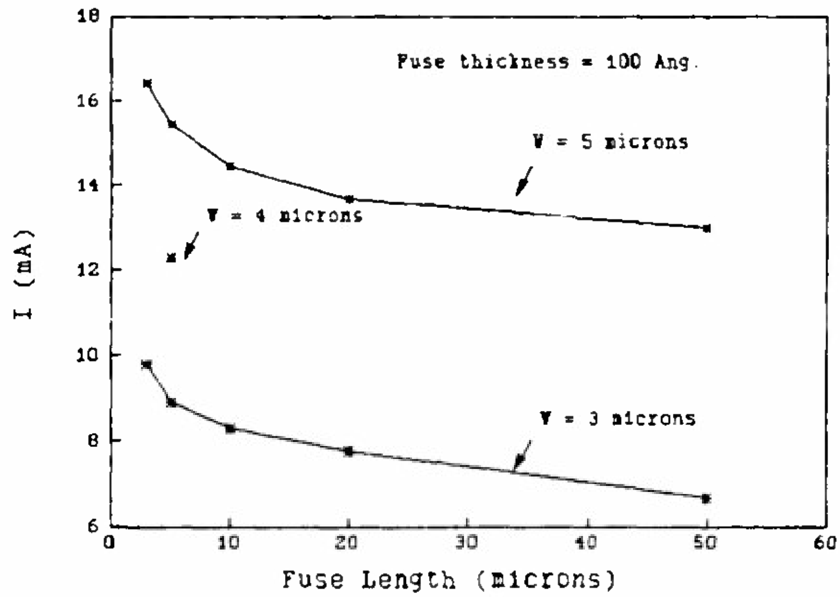


**Figure 4.2 Fusing Currents for 100 Å Fuses.**

## 4.3 Resistance Measurement

The fuse resistance was measured by applying a small voltage across the fuse and measuring the current through the fuse. The current used were much lower than those required for fusing.

The measured fuse resistances are plotted in Figs. 4.3 and 4.4. The measured values of resistance are found to be much higher than the values calculated using the bulk resistivity of aluminium. For instance, for a 100 Å thick fuse with a width of $3\mu$ and length of $10\mu$, the calculated value of resistance is 10 ohms. However, it can be seen from Fig. 4.4 that the measured value is around 200 ohms. The reason for this could be that the resistivity of aluminium in thin films is much higher than its bulk resistivity. It can also been seen from Figs. 4.3 and 4.4 that the resistance does not vary linearly with the length of the fuse. This could be due to the additional resistance contributed by the pads connected to the ends of the fuse. The higher resistivity for the thin aluminium films is the reason that the measured fusing currents are lower than the theoretically calculated values.

## 4.4 Summary

The fusible links were tested to determine the fusing current and the resistance. The fusing current was found to agree reasonably well with the values predicted by the thermal analysis.

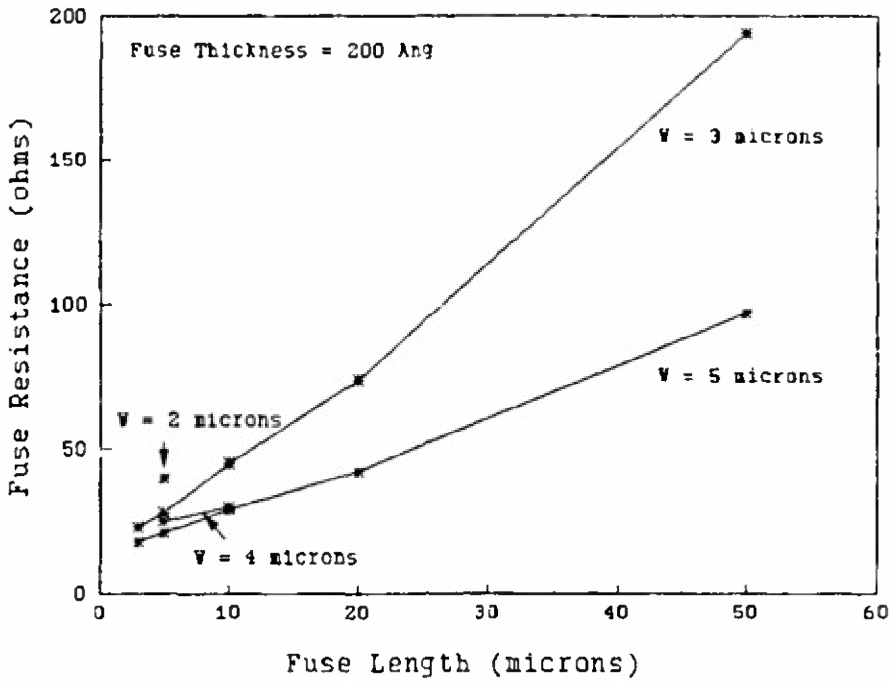


**Figure 4.3 Resistance of 200 Å Fuses.**

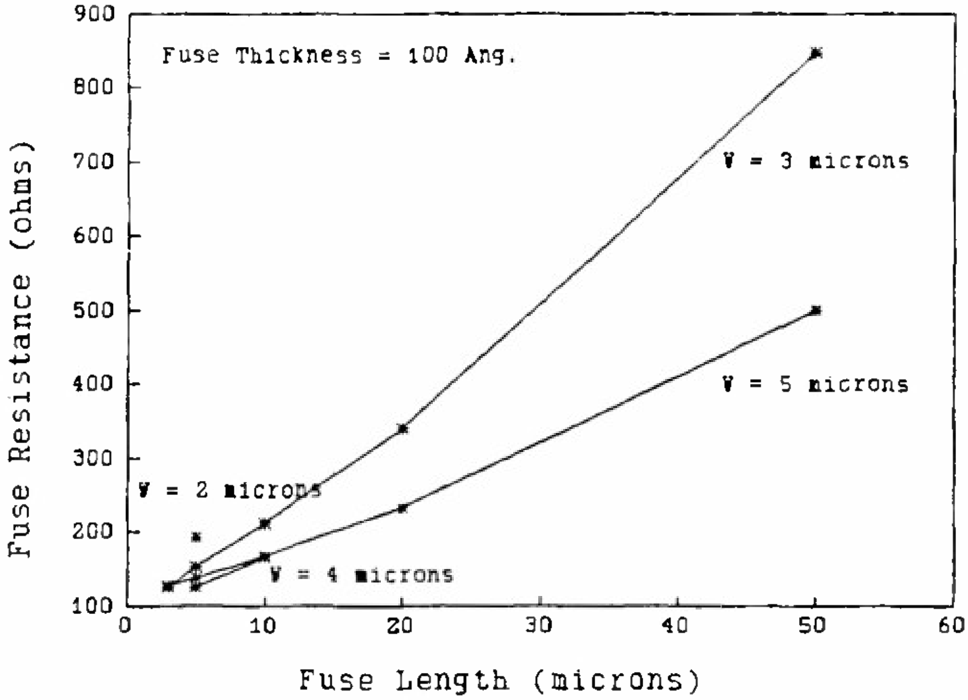


**Figure 4.4 Resistance of 100 Å Fuses.**

# 5 CONCLUSION

In this projcct, a thermal analysis of the fusible links was done. From this analysis, it was found that 100 to 200 Å thick fusible links were necessary to obtain fusing currents of a few milliampcres. The fusible links were fabricated using a four mask process. Testing was done to determine the fusing current and the resistance of the fusible links. It was found that the measured values of the fusing currents were close to the values predicted by the thermal analysis, after taking into account a measured increase in the resistivity of thin aluminium films. These results indicate that it is possible to use fuses to improve the yield of MOS-gated power devices. Further work is required to integrate the fabrication of the fuses with the power device.