Measurement and Modeling of Size and Proximity Effects in Conductor Linewidths (Summary) *

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Abstract

'l'he widths of refractory-gate metal lines were measured as a function of design width W_i and design spacing S_j using an electrical test structure, the Cross-Quad-Bridge. The data are characterized, besides by a constant linewidth aberration AW, by a characteristic size effect width W_c and a characteristic proximity effect spacing SC. With both characteristic dimensions $|W_c| \approx |S_c| \approx 0.3 \mu m$, the effects on a design with $W_1 \approx S_1 \approx 1.2 \mu m$ are about $(W_c/W_1)^2 \approx 6\%$ each,

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As widths and lateral separations of conducting lines drop into the near-pm range and new etching techniques like plasma etching are applied, two new linewidth aberration effects, in addition to the long-known constant over- or underetching, become apparent. The first is a size effect, e.g., narrow lines may be etched more than wide lines; the second is a proximity effect, e.g., the inner edges of two lines which are closely separated from each other but widely separated from other lines may be etched less than the outer edges. The effective width of such a paired line, W_{ij}, is modeled to first order as

$$W_{ij} = W_i + \Delta W + sign(W_c)\frac{W_c^2}{W_i} + sign(S_c)\frac{S_c^2}{S_j} \tag{1}$$

with

W_i = designed linewidth
S_j = designed spacing from single adjacent line
A W = constant linewidth aberration
W_c = characteristic width of size effect
S_c = characteristic spacing of proximity effect.

The Cross-Quad-Bridge Resistor, shown in Fig. 1, is used to extract A W, $W.$, S_c, and the sheet resistance R_s of conducting lines. It consists (left to right) of a van-der-Pauw cross and four bridges with the following parameters:

Design width	Design spacing	Effective width
$W_1 =$ w“	S_2 –+ 00	W_{12}
$W_1 =$ w“	$S_1 = S_0$	W_{11}
$W_2 =$ 3W”	$S_1 = S_0$	W_{21}
$W_2 =$ 3W”	$S_2 \rightarrow \infty$	W_{22}

Herein W_0 and SO denote the minimum dimensions for line width or spacing, respectively, which are allowed by the design rules; and spacing $\rightarrow$ oo should be interpreted as much larger than So. A similar structure with five bridges was proposed in Ref. [1]. The sheet resistance, R,, is determined in the usual way from resistance measurements on the van-der-Pauw cross, see e.g., Ref. [2]. For the determination of the effective bridge widths, the bridge voltages $V_{4,6}$, $V_{5,7}$, $V_{8,10}$, and 17$_{9,1}$1 are measured while a bridge current 1,12 = $\pm I_b$ is forced. Then the effective bridge widths are derived from the averaged magnitudes of the bridge voltages according to

$$W_{12} = R_s L_b I_b / \langle V_{4,6} \rangle \tag{2}$$

$$W_{11} = R_s L_b I_b / \langle V_{5,7} \rangle \tag{3}$$

$$W_{21} = R_s L_b I_b / \langle V_{8,10} \rangle \quad (4)$$

$$W_{22} = R_s L_b I_b / \langle V_{9,11} \rangle. \quad (5)$$

The parameters $\Delta W, W_c$, and S_c are extracted from the following inear system by least squares fitting of the coefficients a, b, and c:

$$\begin{bmatrix} W_{12} - W_0 \\ W_{11} - W_0 \\ W_{21} - 3W_0 \\ W_{22} - 3W_0 \end{bmatrix} = a \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} + \frac{b}{W_0} \begin{bmatrix} 1 \\ 1 \\ 1/3 \\ 1/3 \end{bmatrix} + \frac{c}{S_0} \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix} \quad (6)$$

with AW = C L, $W_c = sign(b)\sqrt{|b|}$, and $S_c = sign(c)\sqrt{|c|}$.

RESULTS: Cross-Quad-Bridge Resistors were designed for GaAs MESFET gate metals with an enlarged cross width of 25 μm and bridge dimensions L_b = 100 μm, W_0 = 1,2 μm and S_0 = 1.5 μm. Processes A and B had refractory metal gates defined by dry etching.

Table 1 shows in the three upper Mocks typical results for the measured and fitted linewidths, W_{ij} and J'_{ij}; the fitted coefficients a, b, c and the absolute values ϵ of the residuals; and the extracted model parameters. The last two blocks list the various contributions to the measured linewidth ***for the minimum design rules*** in ***absolute*** terms and ***relative*** to the design linewidth. For Process B only the fitted data were available.

In Fig. *2* the measured linewidth aberrations, $W_{ij} - W_i$, and the fitted model plane have been plotted over the (reciprocal) design plane $(1/W_i, 1/S_j)$ for Process A.

The constant linewidth aberration indicates in both cases overetch effects. Narrower lines show an additional overetch in Process A and an underetch in B. Lines in closer proximity arc etched less, which probably means that the narrower spacing is not cleared as well. The size effect and the proximit y effect both make significant contributions to the total linewidth aberrations.

REFERENCES

[1] l). J. Hannaman, U. Lieneweg, M. G. Buehler, and L. Mantalas, "Cross-Quint-Bridge Resistor," JPL New Technology Report NPO-1 8106 (1990); NASA Tech Briefs 15(6), 28 (1991)

[2] M. G, Buehler and C. W. Hershey, "The Split-Cross-Bridge Resistor for measuring the sheet resistance, linewidth, and line spacing of conducting layers," IEEE Trans. Electron Dev. ED-33, 1572 (1986)

Table 1: Cross-Quad-13 ridge results for two processes

		Process A	Process B
W_{12} (F_{12})	[μm]	0.684 (0.670)	(0.652)
W_{11} (F_{11})	[μm]	0.721 (0.735)	(0.699)
W_{21} (F_{21})	[μm]	3.202 (3.188)	(3$065)
W_{22} (F_{22})	[pm]	3.108 (3.122)	(3.018)
a	[μm]	-0.452 ± 0.035	--0.599
b	[μm²]	-0.095 ± 0.051	0.061
c	[μm²]	0.098 ± 0.021	0.071
ϵ	[μm]	0.014	*
A W	[μm]	-0,452 ± 0.035	-0.599
W_c	[μm]	-0.307 ± 0.026	0.247
S_c	[μm]	0.314 ± 0.021	0.266
F_{11} – w"	[μm]	-0.465	-0.501
a	[μm]	-0.452	-0.599
$b/W.$	[μm]	--0.079	0.051
c/S_0	[μm]	0.066	0.047
$F_{11}/W_0 - 1$	[%]	-38.8	-41.8
A W/W_0	[%]	-37.7	-49.9
$sign(W_c)W_c^2/W_0^2$	[%]	-6.6	4.2
$sign(S_c)S_c^2/S_0W_0$	[%]	5.5	3.9

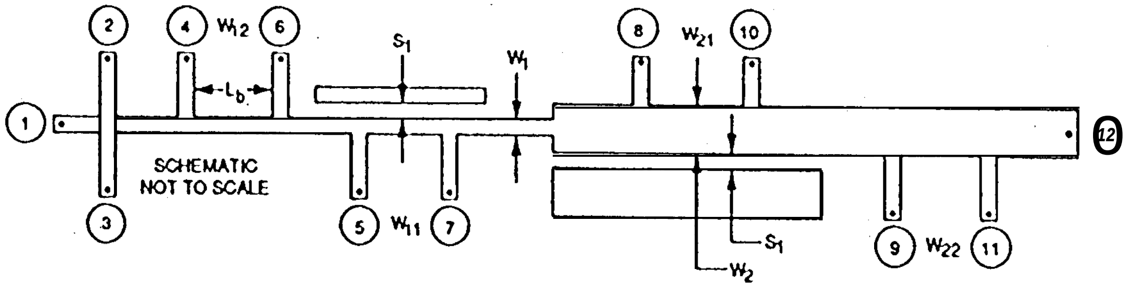

Figure 1: Layout of Cross-Quad-Bridge Resistor. All four bridges have same length L_b.

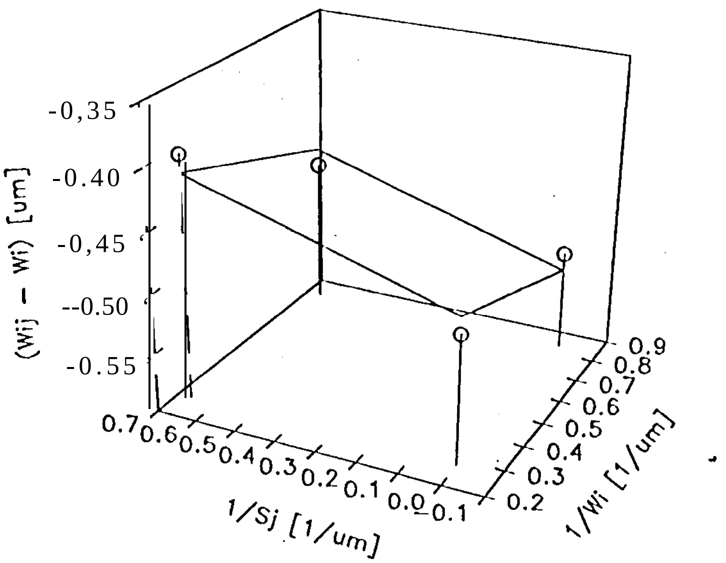

Figure 2: Experimental points (spheres) and fitted model (plane) for aberrations from designed linewidths as function of reciprocal design linewidths and spacings of Process A