A New Test Structure for the Electrical Measurement of the Width of Short Features with Arbitrarily Wide Voltage Taps

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Abstract—Accurate determination of the linewidth of a narrow conducting film for VLSI applications using electrical test structure metrology has required that the length of the line be many times its width to minimize geometric error due to the finite width of the voltage taps. However, long lines obscure important local effects such as nonuniformities in the film. Shorter lines highlight such effects. This paper describes a method of measuring the width of a short line having taps of arbitrary width. The effect of the taps is measured and used in the extraction of the linewidth allowing the determination of local linewidth variations with confidence.

I. BACKGROUND

THE width of a line of a thin conducting material measured using a cross-bridge resistor [1]–[4] (Fig. 1) is given by

$$W_b = \frac{R_s L_b}{R_b} \quad (1)$$

where R_s and R_b are the sheet resistance and bridge resistance, respectively, and L_b is the bridge length. However, (1) presumes zero-width voltage taps; the linewidth corrected for current shunting at the finite-width voltage taps is given by

$$W_{bt} = \frac{W_b}{1 - E} \quad (2)$$

where the correction E is given by [5]

$$E = \left(\frac{2W_b}{\pi L_b} \right) \left[\left(\frac{D}{W_b} \right) \tan^{-1} \left(\frac{D}{2W_b} \right) - \ln \left(1 + \left(\frac{D}{2W_b} \right)^2 \right) \right] \quad (3)$$

where D is the width of the voltage taps. Since the only values available to calculate E using (3) are the design values, it has long been recognized that W_{bt} may be no closer to the actual linewidth than W_b (i.e., the lines of the test structure almost certainly will not be fabricated with exact width, placement, and perfect 90° corners). Thus, (3)

has been used to develop design guidelines which minimize E so the actual correction is negligible for features fabricated within a given tolerance. However, these guidelines introduce the potentially undesirable constraints that $L_b \gg W_b$ and $W_b \geq D$ [1], [3], [4]. The method described in the present work shows how these constraints may be removed allowing the measurement of the width of short bridges using a new test structure design and measurement procedure.

II. PRINCIPAL FEATURES OF THE NEW LINEWIDTH TEST STRUCTURE

The proposed new linewidth test structure (Fig. 2) consists of a van der Pauw cross and three bridge resistors. This test structure embodies the salient features of the structures used in the proof-of-concept experiment described later in this paper. The bridge of length L replaces the conventional (long) bridge. The two bridges of length L_1 are used to measure the effect of finite-width voltage taps on the electrical length of the bridge resistor by using voltage taps not connected to pads (“dummy” taps) to emulate the effect of active voltage taps [6]. All voltage taps cross the current-carrying line and are tapped from a single side to minimize the uncertainty introduced by asymmetric corner rounding [7]. Since the geometric error is measured and used to correct the extracted linewidth, there are no suggested design rules for the width and length of the bridge or the width of the taps other than those required by the process. Otherwise, the new test structure conforms to established rules for cross-bridge resistor design [2].

III. LINEWIDTH EXTRACTION PROCEDURE

Sheet resistance is extracted from the van der Pauw cross as described in [1]–[4]. Then, a fixed current I_b is forced between pads 4 and 1 as the voltages V_{56} , V_{67} , and V_{78} are recorded. The current is reversed and the voltages again are measured, and the magnitudes are averaged. The change in the electrical length, δL , of a segment of line due to a single tap is

$$\delta L = L1 \left(\frac{V_{56} - V_{67}}{nV_{56} + (V_{56} - V_{67})} \right) \quad (4)$$

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Fig. 1. The basic cross-bridge resistor test structure.

Fig. 2. Proposed short bridge resistor test structure.

where n is the number of "dummy" taps. For the bridge segment between taps 7 and 8 the electrical length is $L_e = L_b - \delta L$. Thus, the width of the line segment with $R_b = V_{78}/I_b$ is

$$W_b = \frac{R_s L_e}{R_b}. \quad (5)$$

IV. EXAMPLE OF APPLICATION AND MEASUREMENT RESULTS

The validation of the design shown in Fig. 2 is based on results obtained using Kelvin-tapped, bridge resistor test structures and nearby van der Pauw crosses. The structures were fabricated in chrome on quartz using an optical stepper reticle. The bridge widths (design) were 1 and 2 μm and the lengths 12 and 165 μm . Measurements were made at four sites near the center of the mask. The extracted sheet resistance was $18.60 \pm 0.13 \Omega/\square$. The δL values, the "ideal" geometric errors from (3), and the uncorrected and corrected linewidths of representative bridges are listed in Table I.

To highlight the importance of using the subject technique, the systematic errors of the linewidths of the 12- μm bridge, expressed as a percent difference from those of the adjacent 165- μm bridge, were calculated and are shown in Table II. As expected, the data show that evaluating the linewidth using (1) for the 12- μm -long bridge significantly overestimates the actual linewidth. However, through use of the δL method embodied in (5) these errors are essentially eliminated, with the remaining differences less than 1% of the width. Further, since the average error for the corrected linewidths is within one standard deviation of zero, it is possible that there is no significant systematic error remaining in the measurement.

To evaluate the source of the remaining differences, optical linewidth measurements of the 12- and 165- μm -long bridges at a single mask site were made using the NIST Automated Linewidth Measurement System [8]. These measurements revealed linewidth variations of up to 0.04 μm within a

TABLE I
REPRESENTATIVE VALUES OF W_b , CALCULATED USING (1) AND THE δL -CORRECTED (5), FOR $L = 165 \mu\text{m}$ AND $L = 12 \mu\text{m}$. ALSO SHOWN IS THE MEASURED VALUE OF δL FOR EACH TEST SITE.

As-Drawn W_b, D (μm)	δL Measured (μm)	Linewidth, W_b			
		(for $L = 165 \mu\text{m}$)		(for $L = 12 \mu\text{m}$)	
		(1) (μm)	(5) (μm)	(1) (μm)	(5) (μm)
1, 1	0.64	1.102	1.097	1.143	1.088
	0.65	1.103	1.099	1.147	1.089
	0.77	1.089	1.084	1.147	1.079
	0.54	1.133	1.130	1.175	1.137
2, 2	0.64	2.056	2.048	2.151	2.042
	0.61	2.048	2.040	2.144	2.041
	0.69	2.041	2.033	2.140	2.026
	0.67	2.049	2.041	2.158	2.048

TABLE II
PERCENT DIFFERENCE OF THE WIDTH OF THE 12- μm -LONG BRIDGE FROM THAT OF THE ADJACENT 165- μm -LONG BRIDGE AS EXPECTED FROM (3) AND AS MEASURED USING (1) AND (5) AT FOUR SITES

As-Drawn W, D (μm)	Expected (1) (%)	Uncorrected (1) (%)	δL Correction Applied (5) (%)
1, 1	-1.2	-4.4	0.9
	-1.2	-4.3	0.9
	-1.2	-5.7	0.5
	-1.2	-5.0	-0.6
2, 2	-2.4	-4.9	0.3
	-2.4	-5.0	-0.0
	-2.4	-5.4	0.3
	-2.4	-5.8	-0.3
Average error after correction: 0.2 ± 0.5			

single structure. This suggests that these differences between the measured widths of the 12- and 165- μm -long lines calculated using (5) are due to physical variations in the widths of the lines rather than artifacts introduced by the measurement technique.

V. CONCLUSIONS

A powerful new method for measuring the linewidth of a single short line with arbitrary width voltage taps has been developed. This method allows the determination of the local nonuniformity of lines having lengths of the order of the gate widths of MOS transistors used in VLSI.

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