Stress and Other Challenges with Evaporated Ni-Cr Thin Film Resistors Used in the Manufacture of ASICs

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Keywords: thin film resistor, resistivity, Ni-Cr, TaN, stress

SUMMARY:

This paper studied the change in the characteristics of the Ni-Cr thin film resistors developed at the Sunnyvale facility of Skyworks Solutions,(formerly known as NDI-Alpha Industries), with the number of depositions from the same source melt, as well as the effects of sputter etch cleaning, oxygen plasma etch, HCl dip and regular annealing.

HISTORY:

The Ni-Cr thin film resistors are used as an alternative to TaN resistors, due to the lower TCR[(1)] and higher stability against baking and plasma attacks of Ni-Cr. It is also possible to do in situ process monitoring during evaporation.

The difference between the composition of the evaporated Ni-Cr films and composition of the source material has been reported in earlier studies[(2)]. Since chromium has a higher vapor pressure than nickel, the actual films contain more Cr, making the source get richer in nickel, after each run. During the period of process development and the earlier days of lower volume production levels, there were quite frequent source material additions to the "melt" in the evaporators, as well as quite frequent replacement of the melts with the newly made ones. Therefore, the issue of compositional change of the melt and the resulting change in the composition of the films that were deposited in the later runs, came up very seldom, if ever.

PROBLEM:

Only after the production volume increased to "hundreds of wafers per week", and the evaporators started running multiple daily runs, did we start noticing that the thickness of the deposited films was decreasing for the same resistance target value of the resistors, with the later runs from the same starting melt. The source melt becoming richer in nickel (and more conductive) would have to be deposited thinner, for the same process specifications.

The thinner Ni-rich films were also much more susceptible to attack during the subsequent "acid cleaning steps" of the wafers with dilute HCl dip, leading to the formation of "mouse-bite" defects on the wafers. (See figs.-1 and -2 below, of actual and intentionally produced mouse-bite defects on some Ni-Cr resistors.)

Stoichiometric changes in the film also affect the compressive stress in the film, changing from higher stress levels to lower, as the melt and the film become richer in nickel. Obviously the films with greater stress will also have greater tendency of peeling-off of the wafers. However, the stress effects are much less serious compared to the acid attack, at least within the compositional changes we have been experiencing.

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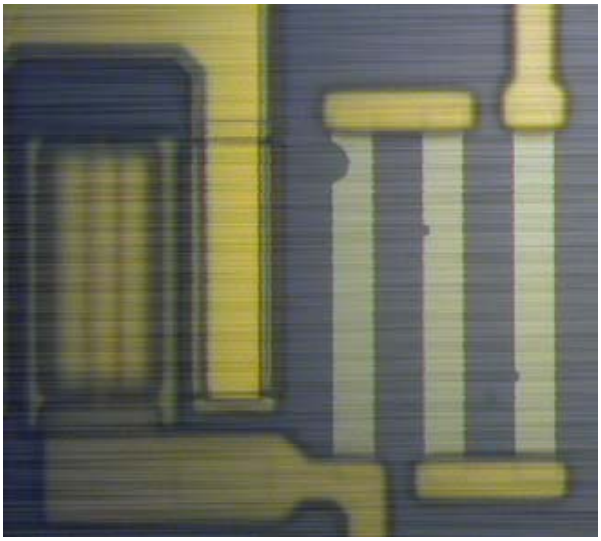

Figure-1: After two consecutive acid dips

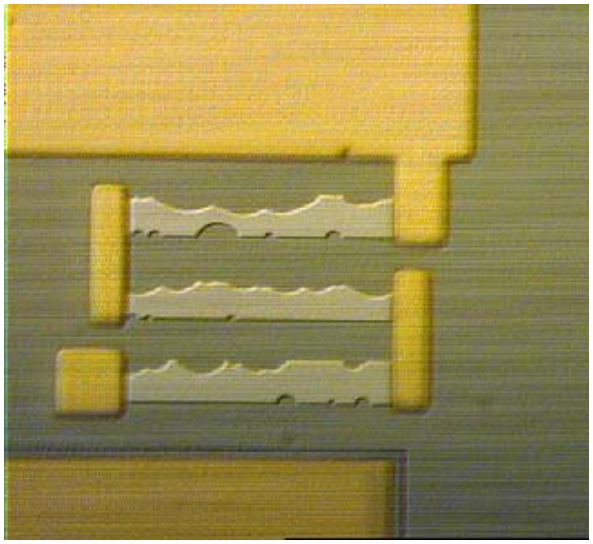

Figure-2: After four consecutive acid dips

SOLUTION:

We determined that the films deposited from the newly made Ni-Cr melt (presumably with exactly 80%-20% proportions) in the earlier runs did not have any problems with the acid attack, despite their higher film stress. The mouse-bites appeared always with the later depositions, as the source-melt and the resistor films got richer in nickel.

Therefore, the corrective action was to limit the number of depositions from the same starting source melt, and to reduce the duration of the acid dip, without risking the effectiveness of the cleaning process.

EXPERIMENTAL RESULTS:

1- TYPICAL PROCESS DATA: (from the snapshots of the process at different time periods)

Ni-Cr RESISTORS:

Resistivity (ohm/sq.)	Thickness (Å)	Power (kW)	Stress (e9 dyne/cm^2)
20	580-700	8	5.5-13.5
50	190-240	8	5.0-11.0
TaN RESISTORS:			
20	850-1050	15	3.0-7.1
50	500- 610	10	3.9-7.6

Note 1: The thickness values are as read from the crystal deposition monitors of the evaporators- all CHA's.
Note 2: The stress values are negative (compressive).
Note 3: TaN resistors were deposited in PE-4450 Sputter station.

2- RESISTOR DAMAGE DATA (Only Ni-Cr Resistors[3]):

Several silicon test wafers selected among the process monitor wafers were measured using the 4-point probe before starting the experiments, and after each one of the intentional damage test steps, given below: (The plasma damage tests to Wafer-1 and Wafer-2 was done using YES downstream plasma asher, while the remaining wafers were all done in the Branson-IPC barrel etcher.) All numerical results are the median values measured on five locations on each wafer.

The HCl dip was for 30 seconds in a 1:10 HCl:DI mixture, and bake was done in convection ovens for 40 minutes, at 250 C.

The test results led to the following conclusions:

1- The actual change in the sheet resistance values (these are silicon process monitor wafers) is within 3% in the worst case, 2- The damage is much less for the thicker films (20 ohm/sq), and 3- Downstream plasma asher has practically no effect.

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Wafer Number	Initial Rs	After de-scum	After HCl Dip	After Bake
1	45.9	46.1	46.1	46.1
2	45.9	46.0	46.3	46.1
3	46.0	47.6	47.6	47.4
4	45.9	47.7	47.5	47.1
5	24.8	24.9	25.0	25.3
6	19.5	19.7	19.8	19.7

3- SPUTTER-ETCH DAMAGE (Ni-Cr Resistors only)**:**

The following data show the change in the sheet resistance values of nominally 50 ohm/sq silicon monitor wafers, after a 30 sec de-scum in YES downstream asher, followed by 500 W sputter etch in PE-4450 sputter station, in a nitrogen/argon atmosphere, for the given durations.

Resistance (ohm/sq)	**2-minutes**	**3-minutes**	**4-minutes**
Before Etch	46.9	46.6	47.0
After Etch	56.9	64.9	76.5

Conclusion: The increase in the sheet resistance corresponds to an approximate 20 Å/min etch rate for the nominally 50 ohm/sq wafers (assuming the resistivity of the Ni-Cr film to be about 1.1 µohm.cm), for the etch durations studied. The same study on the 20 ohm/sq resistors had a relatively smaller change in the actual resistance values; even after a 4-minute sputter etch, the initial value of 22.2 ohm/sq increased to 26.6 ohm/sq, but taking the thicker film thickness values into consideration, it translates into a similar etch rate.

STRESS VARIATION: (Ni-Cr films from the same evaporator, and all 20 ohm/sq, nominal)

The data below are the stress measurements done on the silicon process monitor wafers, from consecutive production runs, starting with a new source melt, and continuing after adding new source material to the melt.

Deposition Number	DATE	Sheet Resistance	Film Thickness	Film Stress
0	10/04/02	19.5	606	No data
			(New starting melt)	
1	10/07/02	19.6	603	No data
		(No stress measurement was done)		
2	10/07/02	19.8	596	10.10 e9
3	10/07/02	20.3	592	9.10 e9
4	10/08/02	20.4	591	8.85 e9
5	10/11/02	19.8	585	8.35 e9
6	10/11/02	19.7	588	7.61 e9
7	10/14/02	20.2	587	6.65 e9
8	10/14/02	20.4	570	6.17 e9
9	10/14/02	19.5	581	6.77 e9
10	10/14/02	19.6	568	7.00 e9
11	10/14/02	19.8	551	5.60 e9
	(At this point, added new Ni-Cr pellets)			
0	10/15/02	20.5	598	10.80 e9
1	10/15/02	20.0	595	8.90 e9
2	10/15/02	20.0	578	7.84 e9
3	10/15/02	20.0	577	7.29 e9

The following week, after adding new source pellets, and running several more depositions, an additional data point: (No stress measurements during the first 5 depositions)

6	10/21/02	19.7	559	6.03 e9

Conclusion: Film thickness and stress change quite monotonously with the number of depositions from a new source melt. (After these results, the deposition process was modified to limit the number of runs from the same source to 8, or the film thickness to be above 550Å, whichever comes first.)

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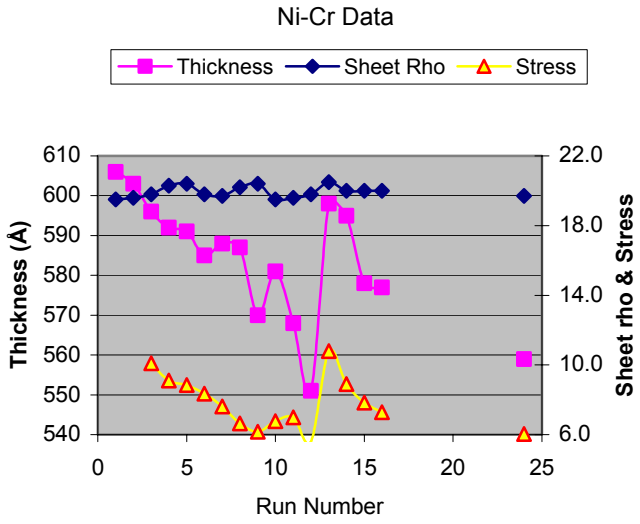

ACKNOWLEDGMENTS:

The authors wish to acknowledge the valuable contributions by Mr. Gary Hu, Dr. Yun Chung and Dr. Chang Hua, to the discussions held on the subject.

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[2] Kopf, R.F., et. al., Lucent Technologies, Murray Hill, NJ. , The Elec. Chem. Soc., SOTAPOCS XXXV, San Francisco, 1999

[3] See also the paper by the Newbury Park Campus of Skyworks, Inc., on the same subject, but emphasizing the TaN work.