Electrocomponent Science and Technology, 1981, Vol. 8, pp. 47–52
0305-3091/81/0802-0047 $06.50/0

A NEW TYPE OF FILM DRIVER

MASATO MURATA, SHOHEI AKITAKE, HITOSHI YAMAGUCHI, HAJIME SASAKI and SHIRO OTANI

IC Division, Nippon Electric Co., Ltd, 1753 Shimonumabe Nakahara, Kawasaki, Kanagawa, 211 Japan

A new type of film driver (NFD) has been developed using thin film integrated circuits technologies. The realized driver was one-tenth as small as that of a conventional driver in volume. The NFD has employed the tantalum nitride (Ta_2N) thin film resistors with low TCR values in order to achieve high accuracy. The NFD was housed in a hermetically-sealed metal case with a size of 39 × 26 × 6 mm. Resistors of NFD circuits were adjusted by laser trimming. DC levels of the transistor circuits, were adjusted by functional laser trimming. When the developed NFD is operated at medium output voltage of 4 Vp-p for 5 years at circumstance temperature of 40°C, the resistance change of the resistors which control the accuracy of the output voltage is predicted to be less than 0.05%, which corresponds to the drift of the output level within 2 mV.

1. INTRODUCTION

Driver circuits are installed in an LSI tester. The more the scale of the integrated circuits increases, the more the numbers of the pin are needed and the more test items must be added. Each driver supplies accurate voltage to each pin of IC's with high speed. The drivers are positioned near to each pin of IC's, so that small size is required for the driver.

The driver operates at a high electrical power density compared with the conventional driver because of the high circuit density, so that the temperature of the NFD substrate easily reaches a high temperature. However, values of the driver circuits must not change at the operating temperature range in order to achieve a highly accurate driver and therefore the resistors must be quite stable for a long period at the operating temperature as well.

Ta_2N film resistors are one of the choices for the requirements because the resistors show excellent thermal stability, and the TCR values are adjustable to the small values by the heat treatment of as-deposited films in vacuum.[1] However, care must be paid to the stabilization treatment temperature of the resistors to allow minimum drift of resistance values during the assembly process.

For the miniaturization of the NFD, chip transistors, chip diodes and chip ceramic capacitors were selected instead of hermetically sealed discrete components.

2. EXPERIMENTAL

2.1 *The Structure of the NFD*

The NFD supplies accurate voltage to each pin of measured IC's ranging from − 2 V to + 6 V according as the measuring requirements of the IC's. The driver circuits were basically consisted of the differential switching circuits and were driven by Emitter Coupled Logic (ECL). The high level and low level of the output voltage of the driver were set respectively from each of the external driver leads.

As the maximum total power consumption of the NFD was 3.6 watt, good heat conductivity was required for the substrate for high heat dissipation. So 99.5% alumina ceramic with the size of 32 mm × 19 mm and 0.64 mm thickness was chosen as a substrate. The schematic cross section of the developed NFD is shown in Figure 1. The NFD has 12 chip transistors, 6 chip diodes, 10 chip ceramic capacitors and 28 Ta_2N thin film resistors on the substrate. The active elements were mounted onto the substrate by Au-Si eutectic adhesion and then electrical connections between the elements and the circuits were achieved by TC bonding of 25 μm $\emptyset$ Au wires. The capacitors were mounted on the substrate by using silver paste. The substrate was then housed into 42-pin metal stem case and was encapsulated by a metal cap case in nitrogen gas atmosphere by solder sealing technique. The case was

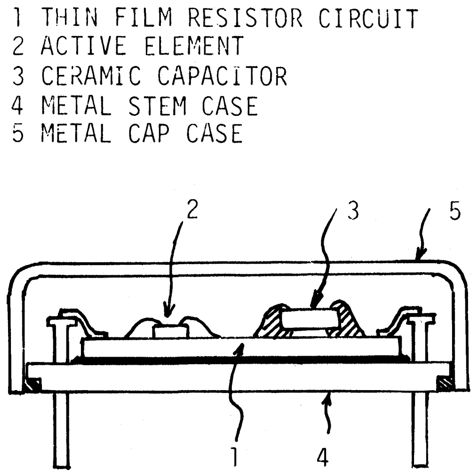

FIGURE 1 Schematic cross section of the NFD.

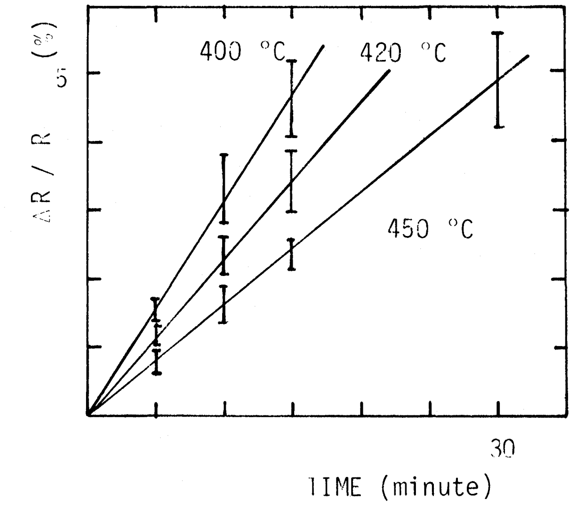

FIGURE 2 Resistance change on the die bonder at 430°C in nitrogen gas atmosphere.

connected to the ground level to reduce the noise or ringing at the high speed switching operation of the NFD.

2.2 *Resistor Stabilization Heat treatment Condition for NFD*

The substrate with resistor circuits were treated at various temperature levels during assembly process as follows.

1) die bonding of active element at 410°C
2) TC bonding at 300°C
3) mounting chip ceramic capacitors at 200°C
4) housing the substrate into the stem at 130°C
5) baking before sealing at 200°C
6) sealing at 220°C

Conventional resistor circuits were stabilized in air at 300°C for 7 hours.[1] The resistance values of such resistors changed more than 3% during the NFD assembly process, though the required resistance accuracy of the NFD was within ± 2% of the specified values, and especially within ± 0.1% for the output resistors.

Thus three temperature levels of 400°C, 420°C and 450°C for 1-hour treatment in air were examined as a resistor stabilization condition to reduce the resistance change during the assembly process.

Figure 2 shows the resistance change of thus produced resistors which were tested on the die bonder for active elements at 430°C in nitrogen gas atmosphere. The tested temperature level and interval were more severe than that of the actual die bonding conditions of 410°C for less than 10 minutes. As most of the resistance change of NFD was caused by this mounting step, it was made clear from Figure 2 that the 1-hour treatment at 450°C was satisfactory for the resistor stabilization treatment which caused only less than 2% change of the resistance values in the test.

Figure 3 shows the resistance change of the Ta_2N films during the stabilization treatment which was carried out prior to the assembly process. At over 500°C, the Ta_2N films were perfectly oxidized. The resistance values of the films changed from 30 to 40% when kept at 450°C for 1 hour, but the change was acceptable for

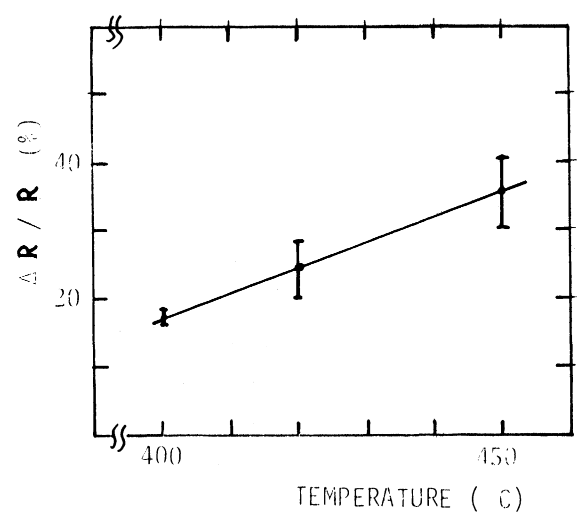

FIGURE 3 Resistance change at heat treatment for 1 hour.

the resistor designing. Therefore the stabilization temperature was determined to 450°C for the NFD resistor fabrication. The actual resistance change of thus produced resistors during the NFD assembly process was quite small, which was only less than 1%.

2.3 Heat treatment of Resistors in Vacuum

The Ta_2N films employed for the NFD resistors were in the so-called "plateau region",[2] and its TCR value was − 90 ppm/°C. The 50-ohm resistor at the output stage of the NFD controlled the accuracy of the output level and consumed the highest electrical power of 1.3 watt at maximum output amplitude. But the resistance value should not change in the operating temperature range in order to supply the specified driver voltage. Thus a low TCR value was required for the resistor.

The low TCR of the Ta_2N films was achieved by heat treatment of the as-deposited films in vacuum at over 500°C. The upper line in Figure 4 shows the TCR values of thus treated films as a function of the heat treatment temperature in vacuum. The lower line shows the TCR values of the vacuum-heat treated films after the stabilization treatment in air at 450°C for 1 hour for the NFD resistor fabrication.

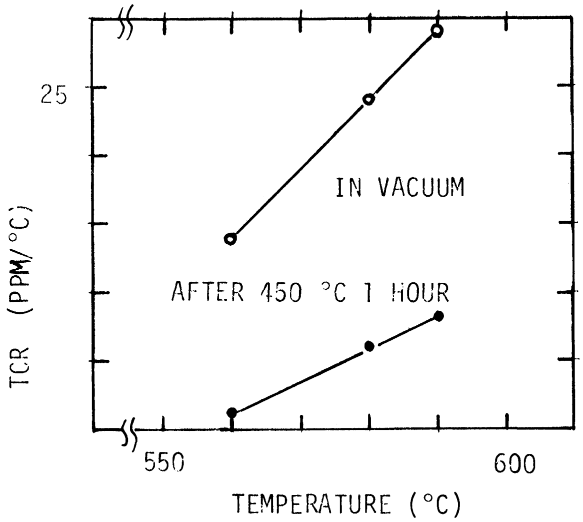

FIGURE 4 Heat treatment in vacuum for 2.5 hours.

It was shown that near zero TCR was obtained when the films were treated in vacuum at 560°C and stabilized in air at 450°C for 1 hour. Therefore the resistor films were prepared in this condition.

2.4 The Effect of Heat Sink

For the heat dissipation of the resistor generated at the output stage, three different heat sinks were examined by measuring the surface temperature of the resistor by an infra-red thermometer. The measurements were carried out at the center of the resistor by applying various electrical power levels for 30 minutes at room temperature of 25°C without air flow. The tested heat sinks were as follows.

a) 5 mm thick foamed styrol board
b) 0.64 mm thick alumina ceramic board
c) 80 mm × 80 mm × 40 mm brass

As shown in Figure 5, when the thermal resistance was defined by the ratio of the temperature rise to the electrical power, it ranged from 11°C/W to 58°C/W, depending on the heat sink.

The surface temperature of the metal case of the actual NFD was also shown in Figure 5 (d) as a function of the total operating electrical power of the circuits, and its thermal resistance was calculated to be about 19°C/W, showing that the metal case was effective for the generated heat dissipation. It was considered that the case was insufficient for practical use without cooling, because the maximum total electrical power was 3.6 W and the substrate temperature at that power reached to more than 95°C. The temperature of less than 85°C was desirable for the NFD to provide high reliability,[4] and this was achieved by cooling the NFD by air flow. In this case, the temperature was 72°C.

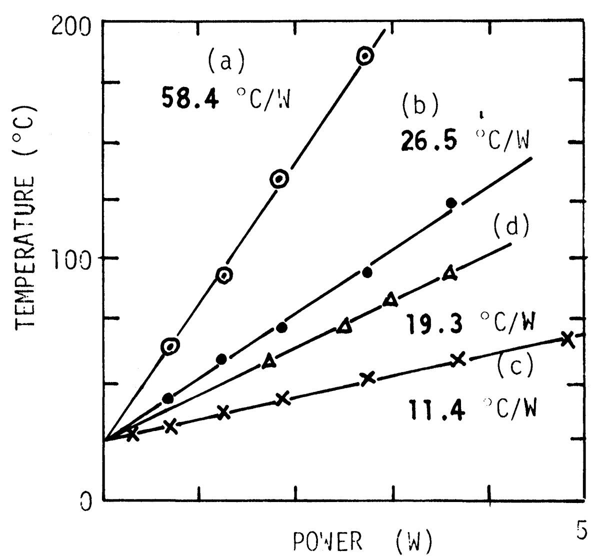

FIGURE 5 Thermal resistance without air flow.

2.5 Resistor Stability against Electrical Power

The heat stability of the output resistor against electrical power was tested for the patterns with the size of $W \times L = 4 \times 4$ mm^2, 3×3 mm^2, 2×2 mm^2 and 1×1 mm^2 respectively. This was because a relatively wide area might be required for obtaining stable resistors against the power. But in this case, some parasitic capacitance which could adversely create the reflected wave might be added in the resistor itself.

The resistors were prepared on the same substrate with the same size of the NFD substrate, and 1 W was applied to each of resistors simultaneously for about 800 hours at room temperature without heat sink. The power density of each resistors was calculated to be 63, 111, 250 and 1,000 mW/mm^2 respectively.

The resistance change was almost the same for all the resistors except that of power density of 1,000 mW/mm^2, as shown in Figure 6. The tremendous resistance change at the high power density might be due to the insufficient heat transfer from the resistors to the substrate.

From these results, the output resistor was designed whose power did not exceed 250 mW/mm^2 even after laser trimming was finished. So the dimension was determined to be 3 mm wide and 2.7 mm long. The laser trimming was carried out in the manner that three quarters of the resistor length was trimmed with the minimum width of 2 mm. In this case, the maximum allowable electrical power was 1.35 W, which was greater than the maximum power of 1.3 W for the NFD output resistor.

2.6 Long Term Stability

The resistors with the resistance values of 50 ohm and 1,000 ohm in NFD circuits were kept at 125°C for 2,000 hours for the life test and the results were shown in Figure 7.

The resistance change of Ta_2N resistors by oven aging is expressed generally by Eq. (1).[3] In the right sic of the equation, the first term corresponds to the resistance change for no trim resistors and the second term must be added when the resistors were trimmed.

$$\Delta R/R = \exp[22.3 - 1.2 \times 10^4/T + 0.46\, ln\, t] + \exp[6.4 - 1.63 \times 10^3/T + 0.14\, ln\, t - ln\, W] \quad (1)$$

where

$\Delta R/R$; resistance change in per cent
T : temperature in °K
t : aging time in hour
W : residual pattern width of laser-trimmed resistors in μm

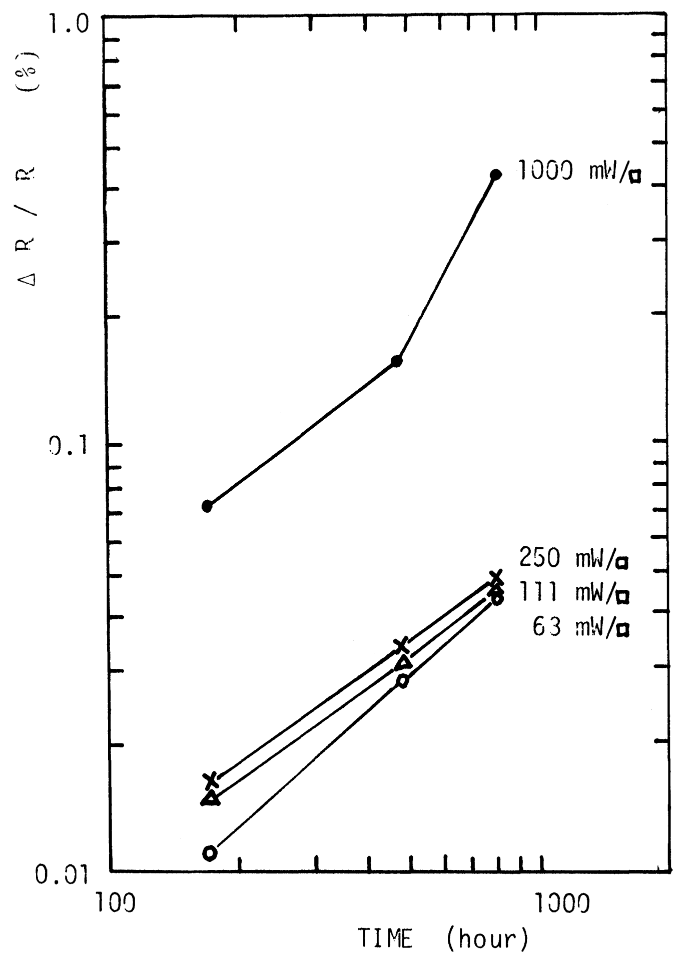

FIGURE 6 Power aging test.

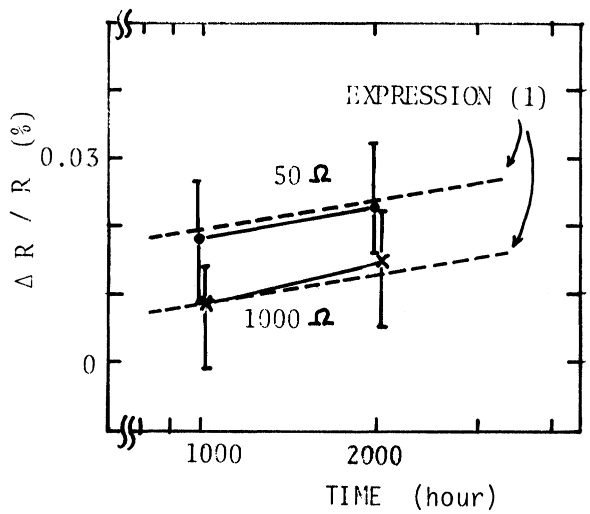

FIGURE 7 High temperature test at 125°C.

The second term of the equation can be neglected for 1,000 ohm resistors because the laser-trimmed pass length is very small. Therefore, the equation includes two terms for 50 ohm resistors and the first term only for 1,000 ohm resistors. Thus calculated values were also shown in Figure 7, and it was made clear that the experimental results and calculation fit well. The completed NFD's were operated for 2,000 hours at 40°C in the condition that the output voltage became 4 Vp-p, and their resistance changes were shown in Figure 8 for 50 ohm and 1,000 ohm resistors. The total power in this case was about 2.5 W.

The calculation was also made to estimate the resistance changes by the test. The temperature rise of resistors by the test was assumed to be 48°C at 2.5 W from Figure 5 (d), and the resultant surface temperature to be 88°C. The calculated values were shown in Figure 8

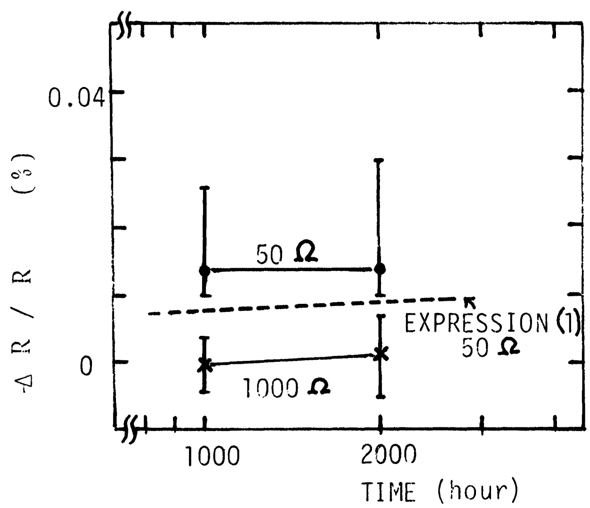

FIGURE 8 Bias test at 40°C.

as a broken line where 2,500 μm was employed for W in Eq. (1).

The discrepancy between the experimental results and the calculation for 50 ohm resistors was observed and this migh be caused because the actual temperature of the resistors was higher than 88°C. The calculated temperature from the experimental results and Eq. (1) was about 110°C.

From these results, the resistance changes of NFD circuits were predicted to be + 0.03% when the NFD's were operated for 5 years at 40°C with 4 Vp-p output voltage. The change of + 0.05% corresponds to the drift of output voltage by 2 mV in the driver. Therefore, it is clear that developed NFD's are quite stable in the test.

2.7 *Switching Characteristics*

Figure 9 shows the switching characteristics of the developed NFD measured through an attenuation of 1/10. The measurements were carried out by open termination with a 50 ohm line cable. The cable length was selected to be 20 cm.

The rise time was longer than the fall time. The reason for this might be explained by the switching characteristics of the transistor at the output stage. The transition frequency of the transistor depended greatly on its collector current, indicating 0.1 GHz at 1 mA and 3 GHz at 100 mA. When the output level went high, the collector current started to reduce gradually, resulting the longer rise time of the NFD. On the contrary, when the output level went low, the current increased rapidly, causing the shorter fall time.

As the output resistor was prepared with a relatively wide area, a parasitic capacitance, which was calculated to be 1 pF, was induced between the resistor and the

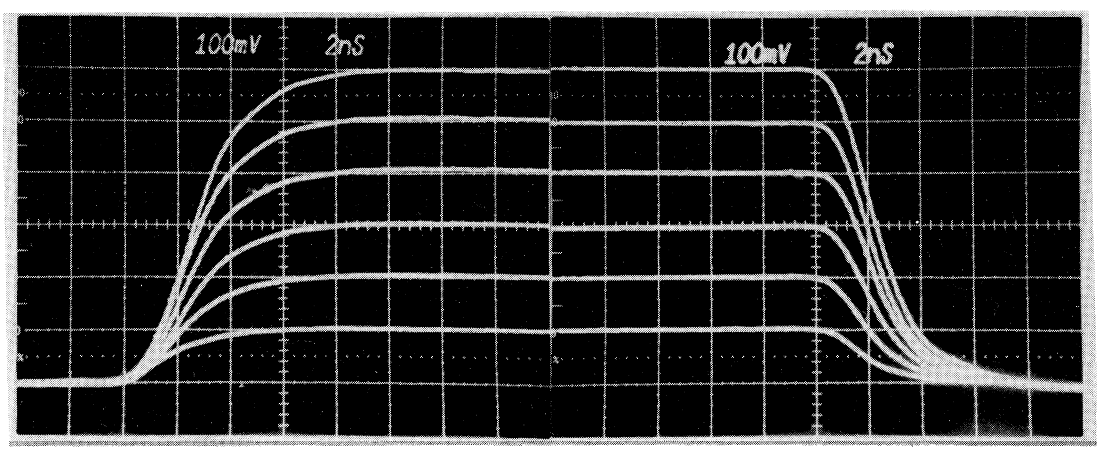

FIGURE 9 Switching characteristics of the NFD.

metal case through the substrate. In order to compensate the reflected wave created by the parasitic capacitance, a small thin film inductor was added between emitters of the differential transistors at the output stage.

CONCLUSION

A new type of film driver has been developed which gave one-tenth as small as that of conventional drivers in volume. It was made clear that chip type active elements, chip capacitors and Ta2N film resistors were effective for miniaturization of the driver. The developed drivers have been quite stable even in operation for a long period at high electrical power, supplying accurate output voltage to each pin of IC's.

REFERENCES

1. A. Sato, Y. Oda and Y. Hishinuma, *Proc. of Electronic Comp. Conf.*, pp. 58 (1970).
2. D. A. McLeen, N. Schwartz and E. D. Tidd, *Proceedings of the IEEE*, pp. 1450 (December, 1964).
3. H. Kurosawa *et al.*, *National meeting of the Institute of Electronics and Communication Engineers of Japan*, pp. 154, Vol. 1, (March, 1978).
4. H. Maruyama, S. Sugamori, T. Sudo and Y. Ichimiya, *Proceedings of the IEEE Test Conference*, pp. 369 (1979).