Briefs

New Laser-Trimmed Film Resistor Structures for Very High Stability Requirements

J. RAMÍREZ-ANGULO AND RANDALL L. GEIGER

Abstract—**The drift of laser-trimmed film resistors with time and/or temperature limits the effective accuracy attainable from laser-trimmed resistor circuits. This accuracy is dependent on the geometries of the film resistors and on the trimming process. New film resistor structures that practically and significantly improve the effective ultimate accuracy attainable with laser trimmed-film resistors over both time and temperature are proposed. The new structures are evaluated using computer simulations. This technique is substantiated with an example that shows an improvement in resolution of 4 bits when compared to that attainable with conventional bar resistors.**

I. INTRODUCTION

Laser trimming of film resistors is an established process leading to very accurate resistance values with which it is possible to implement high-precision signal processing functions such as instrumentation amplifiers, precision temperature-stable voltage references, etc. [1]-[3].

A major problem that limits the ultimate effective accuracy attainable with film resistors is the amount of absolute and/or relative resistance change that occurs due to aging and temperature variations in the trim structure after trimming. It is desirable to keep these changes as low as possible, in particular, within a predetermined performance window throughout the intended lifetime of the product in which the film resistor is used.

In this brief, new film resistor structures that have the potential for less post-trim drift than is attainable with existing state-of-the-art structures are proposed. The new low-sensitivity structures and their potential for very high stability applications as predicted by computer simulations are discussed using an example in Section III.

II. BACKGROUND INFORMATION

Laser-trimmed film resistors (LTFR's) show different performance than untrimmed resistors. The performance of LTFR's is both trim path and geometry dependent [4]-[6]. The reason why LTFR's show different performance than untrimmed resistors is due to the nonuniform energy distribution in the laser beam (Fig. 1(a)) and nonuniform thermal dissipation characteristics during the trimming process. During trimming, a region along the edge of the laser cut is heated and melted by the laser beam, but the temperature rise is not enough to vaporize the material. This "heat affected zone" (HAZ) is characterized by physical properties that differ from the untrimmed portions of the resistor (Fig. 1(b)). Specifically, changes occur in the sheet resistance, temperature coefficient thermal conductivity, and aging behavior. The overall aging and temperature performance of a laser-trimmed film resistor is determined by both the physical characteristics of the heat *unaffected* material (assumed to be uniform) and of the material that lies in the HAZ. In spite of the fact that the HAZ represents only a small fraction of the total resistor area, its contribution to post-trim drift can be significant in precision applications. This is due to the very large relative current densities or, more precisely, relative power densities along certain portions of the HAZ during normal operation of the resistor. This high relative power density is caused, in part, by current crowding induced in many popular trimming schemes (Fig. 1(c)).

In what follows, a simplified two-zone model for an LTFR is considered [7]. In this model two sheet resistance values characterize the LTFR: a bulk sheet resistance R_s corresponding to untrimmed material and a heat affected zone sheet resistance R_s^{HAZ} that corresponds to the average sheet resistance within the HAZ. Since the HAZ and the heat-unaffected material have different physical characteristics, environmental factors such as temperature variations, aging, and humidity give rise to different changes in the relative resistance in these regions $\Delta R_s/R_s$ and $\Delta R_s^{HAZ}/R_s^{HAZ}$.

The *heat-affected zone sensitivity* [7], denoted S^{HAZ}, is defined as the fraction of the total power that is dissipated in the heat affected zone

$$S^{HAZ} = \frac{P^{HAZ}}{P_s} \tag{1}$$

where P^{HAZ} is the power dissipated in the heat affected zone and P_s is the total power.

As shown in [7], S^{HAZ} can be used to determine approximately the fractional change in the effective resistance of a film resistor $\Delta R/R$ due to the environmental changes in R_s^{HAZ} and R_s according to the simple expression

$$\frac{\Delta R}{R} \simeq \frac{\Delta R_s}{R_s} + S^{HAZ} \cdot \left(\frac{\Delta R_s^{HAZ}}{R_s^{HAZ}} - \frac{\Delta R_s}{R_s}\right). \tag{2}$$

The two terms on the right-hand side of (2) have the following physical interpretation:

1) The first term, $\Delta R_s/R_s$, is a common change for all film resistors in a network. The designer has no control over this term since it is independent of the trimming process. It is a characteristic of the materials and represents the fractional resistance change for an untrimmed resistor.

2) The second term, $S^{HAZ} \cdot \{(\Delta R_s^{HAZ}/R_s^{HAZ}) - (\Delta R_s/R_s)\}$ represents the effect caused by the trimming process. It characterizes the degree of mismatch of the resistance change of a trimmed resistor with respect to that of untrimmed resistors. In this term, the designer has control of only the term S^{HAZ}, since the term in braces is also a characteristic of the film materials. It can be seen that S^{HAZ} is a figure of merit that allows one to evaluate and compare relative performance of LTFR's since it provides a relative measure of the mismatch of a LTFR.

In particular, it follows from (2) that the ratio matching accuracies of two laser-trimmed film resistors fabricated in the same process is

$$\frac{\Delta r}{r} \simeq (S^{HAZ_1} - S^{HAZ_2}) \cdot \left(\frac{\Delta R_s^{HAZ}}{R_s^{HAZ}} - \frac{\Delta R_s}{R_s}\right) \tag{3}$$

where r is the ratio of the two resistors and S^{HAZ_1} and S^{HAZ_2} denote the power dissipation in the HAZ's of each of the two resistors. With conventional trimming strategies, only one of the two resistors is trimmed resulting in a zero value for one of the two S^{HAZ} terms in (3).

The computer program, FIRE [8], was written to analyze and evaluate the performance of LTFR's with arbitrary geometries and trimming cuts. It allows user-enterable trim paths with user-enter-

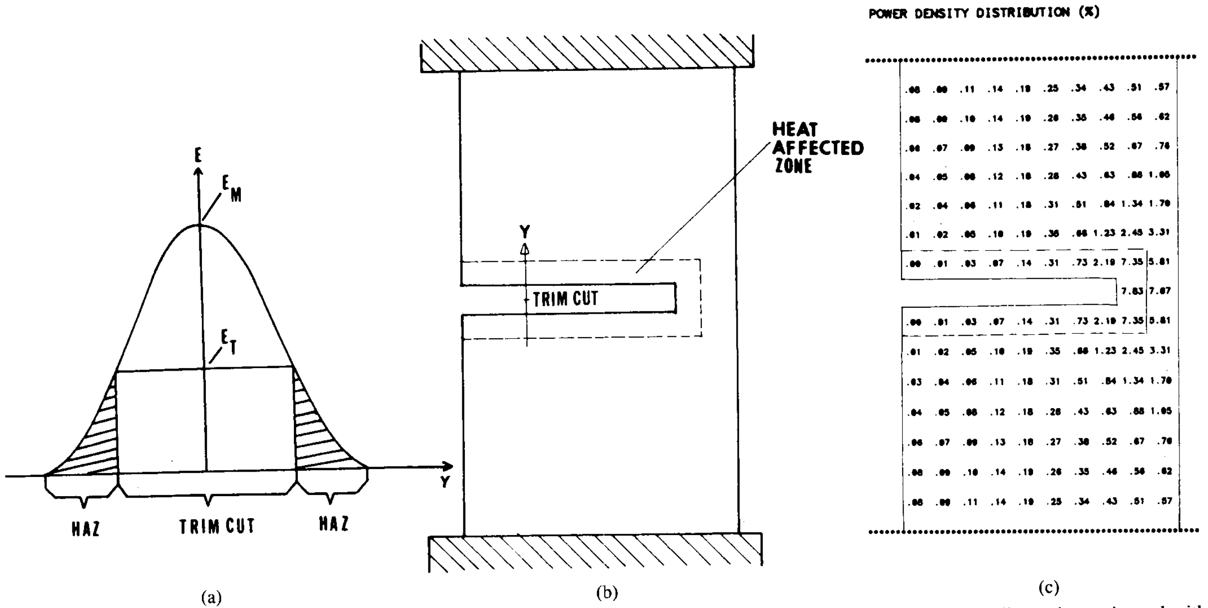
---

Manuscript received August 10, 1987; revised October 13, 1987. This work was supported by Texas Instruments Incorporated.

The authors are with the Department of Electrical Engineering, Texas A&M University, College Station, TX 77843-3128.

IEEE Log Number 8719400.

0018-9388/0400-0516$01.00 © 1988 IEEE



(a) (b) (c)

Fig. 1. (a) Spatial laser beam energy distribution. E_M denotes maximum, and E_T the threshold vaporization energies. (b) Film resistor trimmed with single plunge cut. (c) Relative power density dissipation for resistor of (b).

able characterization of the HAZ surrounding the trim path, and calculates the figure of merit S^{HAZ} used in (2) and (3). A comparison of several commonly used trim geometries and algorithms using FIRE has shown that their performance is comparable. In [8] four resistors with different geometries and/or trim paths were all trimmed to the same value. Simulations showed that S^{HAZ} for all four resistors varied between 11.42 and 15.5 percent. This example included bar and top-hat resistor geometries and different trim cuts: single plunge, multiple plunge, and L cuts Untrimmed and target values of 2 and 4 squares, respectively, were used in all simulations. Extensive simulations have also shown comparable results for conventional bar and top-hat resistors with varying aspect ratios and different target values.

Although the performance of the commonly used film structures and trimming algorithms is comparable, an example of a novel type of structure, denoted "Swiss Cheese Structure," that can offer significant reductions in $\Delta r/r$ is discussed in the following section.

III. SWISS CHEESE RESISTOR STRUCTURES

A. Principle of Design

Fig. 2 illustrates an example of a proposed low-sensitivity trim structure. These structures differ from the typical trim structure only in the addition of trim targets that are void of material (or holes, hence termed "Swiss Cheese Structures").

Individual terms are achieved by performing a laser cut that starts at one edge of the resistor and terminates in a target. The broken lines of Fig. 2 illustrate the specified potential trim paths (two lines are used for depicting each trim path to illustrate typical laser kerfs of approximately 5-μm width). The trim targets are placed so that the change in resistance associated with each trim path to a target is independent of whether any other trim path has been trimmed. To adjust the resistance to the desired target, succesive trims to a combination of targets along the potential trim paths indicated are made. The trimming strategy is to select a set of trim targets so that trimming completely to each target in this set will result in a change in resistance that is slightly less than is needed to meet the required specifications but such that any other set of trim targets that corresponds to a larger change in resistance would result in a change in resistance that exceeds the required specifications. A continuous trim subsequent to the sequence of target trims is then made in a low current density region to achieve the required value of resistance. The trim range and trim resolution are dependent on the number of holes and on the resistor architecture.

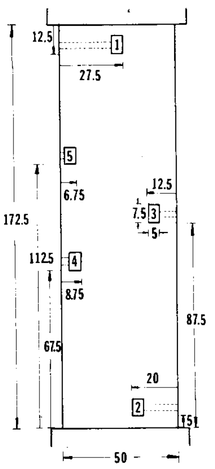


Fig. 2. Low-sensitivity "Swiss Cheese Structure" with 5-bit digital trim resolution and 32-percent tuning range; dimensions are given in micrometers.

It can be readily shown that the trim targets and the film material geometry can be designed in such a manner as to make the total power dissipation in the HAZ arbitrarily small. From a qualitative point of view, Swiss Cheese Structures achieve their reduced sensitivity due to the fact that the major current crowding inherent in any trimming strategy is forced to occur in virgin film material opposite from the laser kerf.

Since the region of highest relative power dissipation is not in the HAZ, it does not contribute to the sensitivity to the HAZ, and thus, from (3), the ratio matching accuracy is improved.

B. Design considerations for Swiss Cheese Structures

One method of achieving independent and cummulative changes for the trim targets is to provide a large vertical separation between the trim targets. The minimum separation between targets is determined by the requirement that the field disturbance zones of adjacent targets do not overlap. The field disturbance zone of a target is defined as the zone over which the current density distribution changes by more than a certain amount θ when a trim is made from the edge to the target along the specified trim path. The value of θ is determined by the number of bits of resolution required. The size of a disturbance zone is dependent on the resistance increment associated with a specific trim target. It is in general larger for targets leading to larger resistance increments. Correspondingly, the distance of a target from the trim edge determines the resistance change associated with that trim target. In general, larger resistance changes require a larger separation between the target and the trim edge. It can be concluded that the size of a Swiss Cheese Structure will be dependent on the desired number of bits of digital trim resolution and on the tuning range.

The structure shown in Fig. 2 was designed using FIRE [8]. It has 5 trim targets, each target provides one bit of digital trim resolution. The structure is designed for a maximum resistance increment (tuning range) of 32 percent in 32 equispaced 1-percent steps. The digital trimming is performed by trimming from either the right or the left edge of the resistor to the corresponding target following the paths specified by the broken lines. The holes numbered from 1 to 5 cause *independent and cummulative* binary weighted increments of 16, 8, 4, 2, and 1 percent, respectively. For instance, trimming simultaneously to targets 1, 3, and 5 results in a resistance increment of 16 percent + 4 percent + 1 percent = 21 percent.

The sensitivity to the HAZ of Swiss Cheese Structures is much lower than that of conventional bar and top-hat resistors because trimming to the targets forces current crowding only in non-heat-affected regions. This improves the S^{HAZ} difference in (3) and thus improves ratio matching accuracy. On the other hand, trimming schemes for conventional bar and top-hat structures induce current crowding at the edges and at the tip of the trim cut that are in the unstable HAZ. Current crowding in this case leads to relative large values for S^{HAZ}.

For conventional structures and trimming strategies, a 30-percent trim increment results typically in a value of 8 percent for S^{HAZ}. Correspondingly, a maximum value for S^{HAZ} of 0.25 percent was calculated for the structure of Fig. 2 with trims made to all 5 targets, which corresponds to the maximum value of S^{HAZ} for this structure.

It can be seen that *the Swiss Cheese Structure is a factor of 30 times less sensitive than a conventional structure for corresponding 30-percent trim increments.* As can be seen from (3), this corresponds to nearly 5 bits of increased ratio accuracy. For instance, a mismatch of 10 ppm/°C in the temperature coefficient of the sheet resistance of the two zones (heat-affected and heat-unaffected material) over a temperature operating range of 100°C results, according to (3), in ratio resolutions of 18 bits for the Swiss Cheese Structure compared to 14 bits for the conventional structure.

IV. CONCLUSIONS

The low-sensitivity properties of the Swiss Cheese Structures show that they have potential to improve significantly the ratio accuracy attainable in precision laser-trimmed circuits over what can be realized with current state-of-the-art techniques. Effective improvements of 4 bits were demonstrated by example at the expense of a minimal increase in film resistor area and trimming complexity. The concept involved in the design of the Swiss Cheese Structures is straightforward and can be extended easily to other trimming ranges and/or increased resolution.

ACKNOWLEDGMENT

The technical collaborations with W. Dietrich and M. Hamlett are gratefully acknowledged.

REFERENCES

[1] *Product Data Book Supplement*, Burr-Brown Corp., Arizona, 1983.

[2] E. J. Swenson, "The evolution of laser processing in semiconductor manufacturing," in *Proc. 26th Midwest Symp. Circuits and Systems* (Puebla, Mexico, Aug. 15-16, 1983), p. 212.

[3] R. Wagner, "IC design for laser trimming," in *Proc. 26th Midwest Symp. Circuits and Systems* (Puebla, Mexico, Aug. 15-16, 1983), pp. 223-226.

[4] A. Kestenbaum, "Trim characteristics of tantalum nitride resistors on silicon," in *Proc. IEEE Int. Symp. Circuits and Systems* (Montreal, Canada, May 7-10, 1984), pp. 1198-1201.

[5] D. V. Smart, "Considerations of laser material interactions for the trimming of thin film resistors," in *Proc. IEEE Int. Circuits and Systems* (Montreal, Canada, May 7-10, 1984), pp. 1185-1188.

[6] R. Dow, M. Mauck, T. Richardson, and E. Swenson, "Reducing post-trim drift of thin-film resistors by optimizing YAG laser output characteristics," *IEEE Trans. Components, Hybrid, Manufact. Technol.*, vol. CHMT-1, pp. 392-397, Dec. 1978.

[7] J. Ramírez-Angulo, R. L. Geiger, and E. Sánchez-Sinencio, "Characterization, evaluation and comparison of laser-trimmed film resistors," *IEEE J. Solid-State Circuits*, vol. SC-22, pp. 1177-1189, Dec. 1987.

[8] J. Ramírez-Angulo, R. L. Geiger and E. Sánchez-Sinencio, "FIRE: A computer program to predict the performance of laser-trimmed film resistors," in *Proc. 36th Electronic Components Conf.* (Seattle, WA, May 5-7, 1986, pp. 405-411.

Recombination Lifetime of Short-Base-Width Devices Using the Pulsed MOS Capacitor Technique

MEHRAN AMINZADEH AND LEONARD FORBES

***Abstract*—Schroder *et al.* [1] have described a simple technique for the determination of recombination lifetime [2] using pulsed MOS capacitors at elevated temperatures. This simplified technique does not consider lateral quasi-neutral bulk generation and the time dependence of the width of the space-charge region in short-base-width devices (i.e., epitaxial wafers). Consequently, calculations using Schroder's technique indicate that the recombination lifetime is a function of device diameter. A simple one-dimensional approach is proposed in which bulk generation in the lateral area of the device is taken into consideration resulting in a fairly uniform recombination lifetime that is independent of the device diameter for short-base-width devices.**

I. INTRODUCTION

Schroder *et al.* [1] have described a simple method for the determination of recombination lifetimes on silicon wafers using the pulsed MOS capacitor technique at elevated temperatures of 70-100°C. This technique relies on the dominance of quasi-neutral bulk generation (diffusion current) over the space charge and surface generation at elevated temperatures. The technique is sum-

---

Manuscript received June 2, 1987; revised October 30, 1987. This work was supported by the Intel Research Council and conducted in cooperation with SEH America.

The authors are with the Department of Electrical and Computer Engineering, Oregon State University, Corvallis, OR 97331.

IEEE Log Number 8719399.