Resistor trimming geometry; past, present and future

2016 IOP Conf. Ser.: Mater. Sci. Eng. 104 012002

(http://iopscience.iop.org/1757-899X/104/1/012002)

IOP Conf. Series: Materials Science and Engineering **104** (2015) 012002 doi:10.1088/1757-899X/104/1/012002

Resistor trimming geometry; past, present and future

M Alafogianni, R Penlington, M Birkett,

[1]Faculty or Engineering and Environment
Northumbria University, Newcatle upon Tyne, NE1 8ST, UK

E-mail: maria.alafogianni@northumbria.ac.uk

Abstract. This paper explores the key developments in thin film resistive trimming geometry for use in the fabrication of discrete precision resistors. Firstly an introduction to the laser trimming process is given with respect to well established trim geometries such as the plunge, 'L' and serpentine cuts. The effect of these trim patterns on key electrical properties of resistance tolerance and temperature co-efficient of resistance (TCR) of the thin films is then discussed before the performance of more recent geometries such as the three-contact and random trim approaches are reviewed. In addition to the properties of the standard trim patterns, the concept of the heat affected zone (HAZ) and ablation energy and the effect of introducing a 'fine' trim in areas of low current density to improve device performance are also studied. It is shown how trimming geometry and laser parameters can be systematically controlled to produce thin film resistors of the required properties for varying applications such as high precision, long term stability and high power pulse performance.

1. Introduction

For thin film resistors it is generally impossible to deposit batches of product with resistance tolerances better than about ±10% [1-3]. This is due to problems in attaining uniform sheet resistance, but mainly due to dimensional variation of the individual resistor elements in the batch, a problem which is amplified as the resistor size decreases [3, 4].

Thus, it is normal to fabricate the resistor film to a lower resistance value than required and then adjust it by removing or 'trimming' away sections of the film material to increase the resistance to its target value in order precision of less than 10% to be succeeded [5, 6].

There are many different trimming methods which can be used to adjust the value of the resistor such as anodisation, heat trimming, electrical trimming, mechanical trimming, chemical trimming and laser trimming [1, 2]. However, laser trimming is by far the most effective and popular method and is still a subject of continuing theoretical and experimental research and optimisation [7-24].

This paper discusses the laser trimming process of thin film resistors with regard to both conventional and well established trim patterns and the influence of their geometry on key electrical performance properties such as resistor tolerance and temperature co-efficient of resistance (TCR). The concept of the heat affected zone (HAZ) bordering the kerf is also introduced and some recent trim patterns design to reduce its effects are discussed.

2. Laser trimming

2.1. Laser trimming process

The laser uses a light beam of a few µm in diameter to remove the resistive film from the ceramic substrate in a very short time period of less than 1 ms. The high intensity light pulse is then absorbed by the material causing it to heat and vaporise. This process depends on the intensity of the laser pulse, or the power level, the focus of the pulse as well as the properties of the material being ablated [1].

The laser beam is scanned across the resistor to produce a continuous kerf, changing the resistance value of the film as it progresses. The accuracy of the adjustment of the resistance value is dependent on the properties of the laser beam itself, the shape of the cut and also the speed at which the measurement system can switch the laser beam off between pulses once the target resistance value is reached [1, 12-13].

There are two main types of laser used for the adjustment of resistive films; the pulsed carbon dioxide (CO2) and the neodymium: yttrium-aluminium-garnet (Nd: YAG) laser. As for the CO2, it has a long pulse width with high energy per pulse, which causes vaporisation of the film [1]. However, the long pulse width can also cause damage to the substrate and the material at the edge of the kerf, the heat affected zone (HAZ) [17]. On the other hand, the YAG laser uses an acousto-optic Q-switch for a two way optical switching of the laser beam. This system is able to produce short pulses of high peak power at a wavelength of 1064nm, to rapidly vaporise the film, whilst minimizing heat flow and damage to the material surrounding the kerf [1]. Additional reductions in the HAZ can be succeeded by lasers operating in the green region of the visible spectrum due to the decrease in laser spot size resulting from the shorter wavelength of 532nm [14].

2.2. Conventional trimming geometries

There are various different laser trim patterns which can be used for the adjustment of surface mount bar shape resistors as shown in Figure 1. The influence of the width and length of the cutting line, the number of cuts is really important concerning the device geometry [25]. The plunge cut (Figure 1a) is the simplest and economical cut consisting of a single kerf orthogonal to the current flow through the resistive element but its overall tolerance accuracy can be less than other methods [5,15-16].

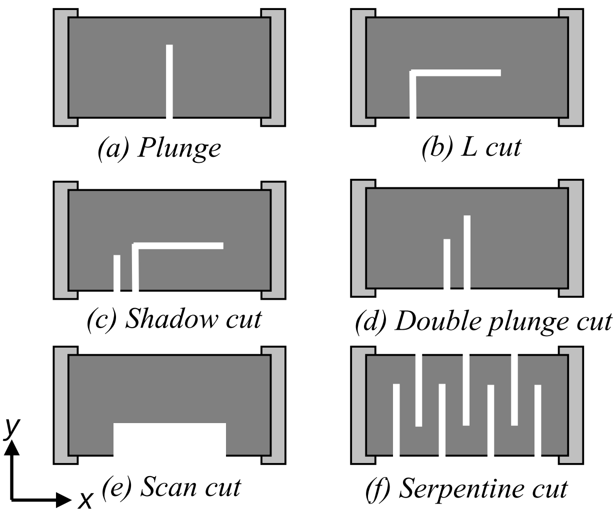

Figure 1. Commonly used laser trim kerf shapes [15]

The 'L' cut (Figure 1b) is perhaps the most frequently employed method due to its superior stability and tolerance accuracy. With this type of cut the resistance increases rapidly as the kerf is cut perpendicular to the current flow (y direction), which is called transverse cutting. Then, more gradually when it turns through 90º and cuts parallel to the current flow (x direction), which is called longitudinal cutting, until target value is reached i.e. in an area of equal current density, see Figure 2. [26, 27]

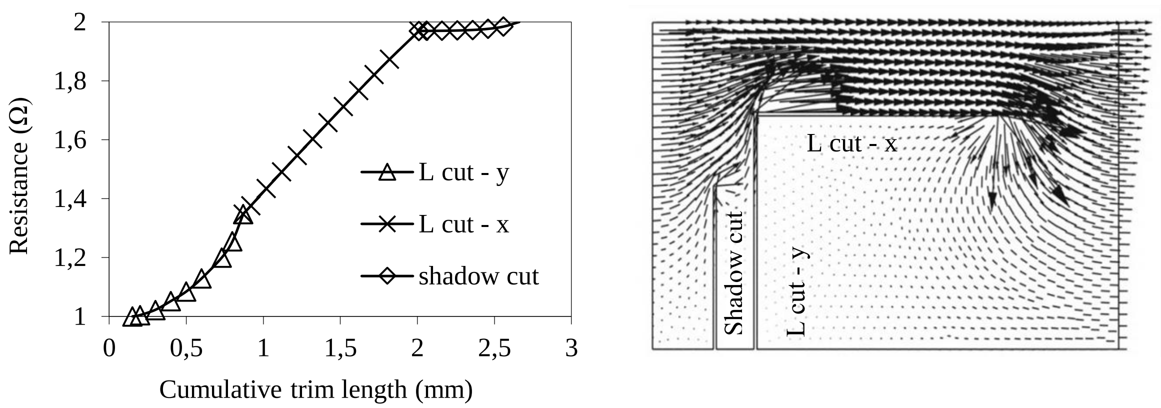

Figure 2. Typical plots of resistance increase with kerf length and corresponding model of current density for the 'L' cut and shadow cut [15].

The stability of the resistor can be maximised according to the variations on the x and y lengths. It is worth noting that when the y leg is as short as possible leaving maximum resistor line width remaining, the optimum performance is achieved. However, the trim time is increased and there is also the risk of trimming into the resistor termination with the extended x leg. Thus, with the 'L' cut, there is the opportunity to find a balance between trim speed and tolerance and stability accuracy but it is slightly more expensive than the plunge cut due to the additional time required to perform this cut [12-13, 23].

A shadow cut (Figure 1c) consists of an additional plunge to the side of an 'L' cut or plunge cut (double plunge (Figure 1d)). As a result, tighter resistance tolerances can be achieved as the kerf is cut in an area of low current density in the 'shadow' of the first cut, see Figure 3. The additional trimming time needed makes this type of cut quite expensive [5, 15].

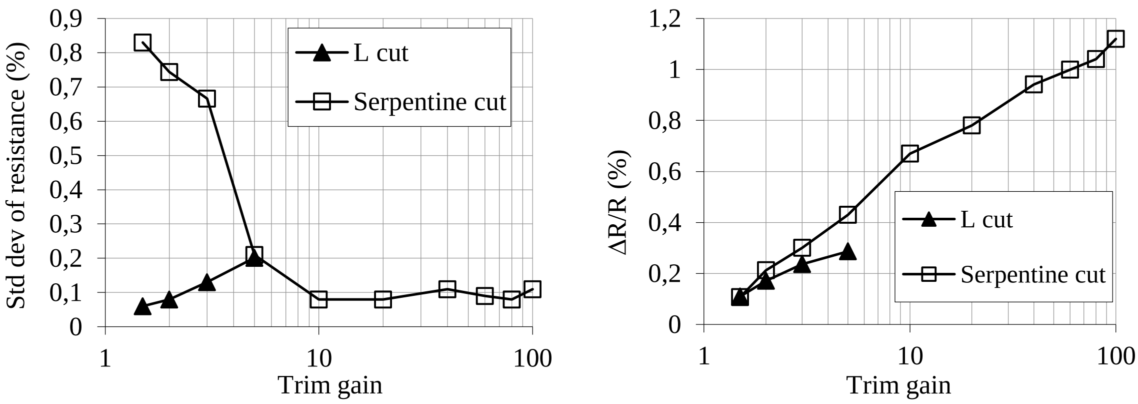

Figure 3. Variation in standard deviation of resistance and resistance stability with increasing trim gain for CuAlMo TFR's trimmed with both 'L' cut and serpentine cut [15].

A serpentine cut (Figure 1e) consists of multiple cuts made in areas of high current density which effectively increase the geometric length of the resistor and thus its resistance value. It has the ability to give a large resistance gain. As a result, the tolerance accuracy of the resistor is improved as shown in Figure 4. This type of cut can be employed when the pre-value resistance is much lower than the target value. However, a long trim length can lead to stability problems due to the large amount of HAZ surrounding it. In addition to this, when the resistance gain is very large, the TCR increases and causes instabilities due to the amount of material which has been raised to temperatures in excess of the zero TCR heat treatment temperature without being vaporised. [28, 29]

However, a solution to this issue would be a two stage serpentine trim to be employed when precision thin film resistors are required. During the first trim stage, the majority of the trimming is performed in order the resistor to be adjusted to around -1% from its target value. Then, the device is stabilised, typically overnight at around 200ºC to relieve stresses built up in the HAZ [15]. Predicting the resistance change that occurs during this stabilisation operation is not possible. As a consequence, the second stage of the process, which is called fine trim, is required for the accurate adjustment of the resistor to target value. It usually consists of one or two plunges in the shadow of the first serpentine as shown in Figure 4. However, this type of cut can be very time consuming and expensive, but the increasing availability of auto substrate handling equipment can help reducing the labour cost involved [15, 16].

The scan cut (Figure 1f) is the most commonly used due to its stability [28] and especially when the device is required for high frequency applications to minimise creation of capacitive reactance components of an RC circuit. It also finds use in high voltage situations as the likelihood of voltage breakdown across the trim kerf is greatly reduced. This type of cut is very time consuming to perform and is not cost effective for general use [15, 28].

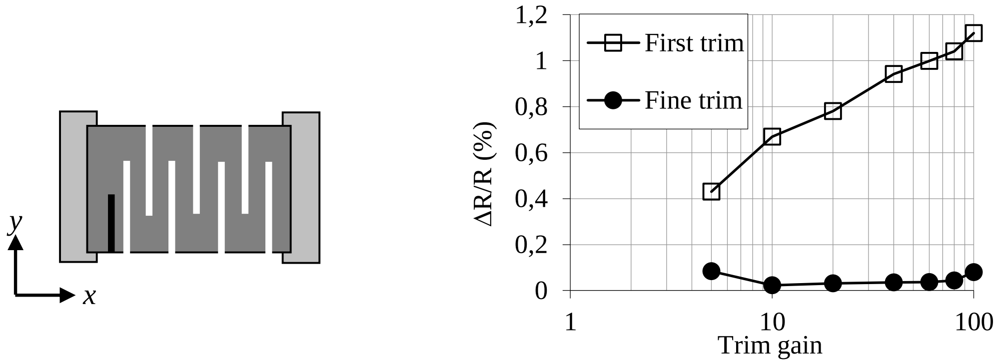

Figure 4. Two stage serpentine trim pattern and corresponding variation in resistance stability with increasing trim gain for CuAlMo TFR’s trimmed with both first and fine trims [15].

2.3. The heat affected zone (HAZ)

A major cause of post-trim drift in laser trimmed resistors is due to the HAZ bordering the kerf [15, 29] and it would be beneficial to consider this area in more detail. It is worth commenting that the energy profile of the beam has a Gaussian distribution due to the fact that a Q-switched YAG laser is adjusted to operate in single traverse electromagnetic (TEM_{00}) mode. This profile can be translated into a Gaussian temperature profile as far as the thin films are concerned and it is shown in Figure 5.

It is noted that the central part of the profile has sufficient intensity to cause vaporisation of the thin film. As for the areas of film adjacent to the kerf, the energy absorbed from the laser beam is less than the threshold required for vaporisation. Thus, this region of the film becomes a heat affected zone and can considerably cause more changes and variations in the resistance than areas of film that are not irradiated by the laser beam [20, 21].

This aging effect is caused due to the fact that the film which was stabilised prior to the adjustment process and it has now been re-exposed along the edges of the laser kerf. The changes in the resistance are related to changes in the structural properties of the film material because of the rapid heating and cooling during the trimming process such as the sheet resistance and TCR [29-31].

It is worthwhile thinking that the length of the kerf and the effect of the HAZ in the trimmed resistors are important parameters that can determine the overall stability of the resistor [22]. These parameters can be optimised by varying the shape of the continuous trim and the properties of the laser beam itself.

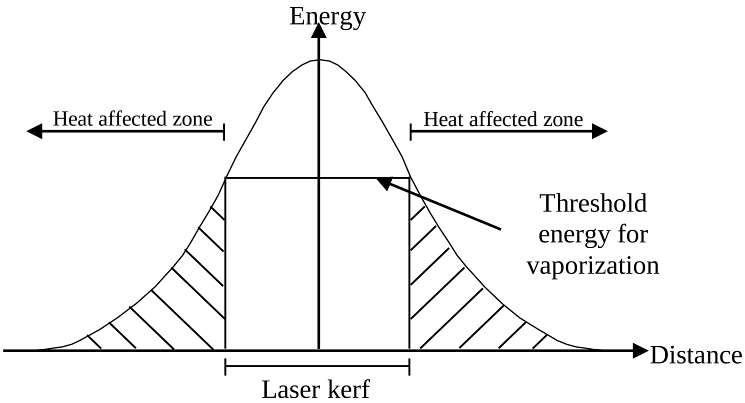

Figure 5. The fundamental mode laser beam profile as a Gaussian distribution [15, 29-31].

2.4. Alternative trimming geometries

An alternative trimming method in order to avoid the issues associated with the HAZ is link cutting [13]. This process can be applied by opening up shorting bars in loop and ladder type patterns to increase the resistance in discrete steps. Once the trimming bars are opened the current is redirected around the new longer path and any current crowding in the trimmed area or HAZ is eliminated. Although this method can provide a solution to the issues caused by the aging effects, a greater chip area is required compared to the conventional bar design. Moreover, as the resistance is adjusted in discrete steps a very large number of links may be required [13].

However, there have been methods applying the link cutting approach to bar resistors. The Swiss cheese pattern can be thought as the most popular cut using the benefits of the link cutting approach. This method forces current crowding only in non-heat affected areas [29-31].

Another study proposed a type of laser trimming performing an L-cut in a ‘top hat’ shape thin film resistor, avoiding excessive crowding of the current lines after trimming [27]. A more recent study has focused on the effect of replacing the two contact bar resistor with a three contact distributed structure and then trimming the resistor by narrow cuts in a variety of shapes around the additional contact and it can be shown in Figure 6(a) [17]. In addition to this, another approach proposed for designing resistors was the random trimming. This method is performed by cutting a hole in a random point that was combined with a single plunge cut as shown in Figure 6(b). First, the single plunge is applied in order to offer rough adjustment and wide trim range fast and then random trim spots and voids helped to get closer to the target resistance [5].

Both of these methods have shown encouraging results and it was found that the resistance could be increased more controllably than an L-cut [5,6], but the additional trimming time and materials required were negative factors concerning satisfying improvements in the production of thin film resistors.

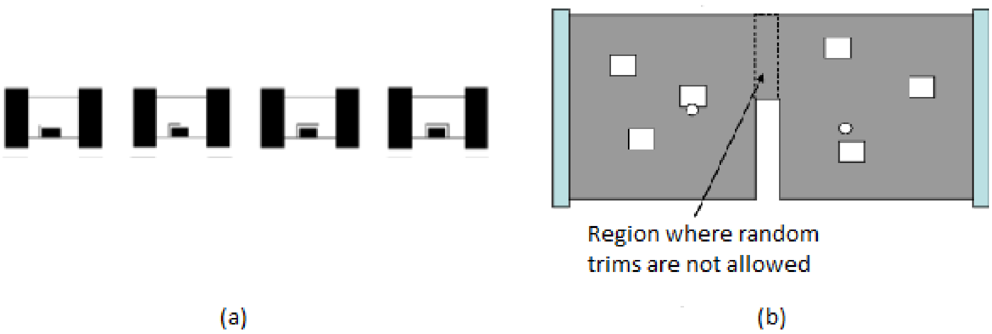

Figure 6. (a) Illustration of laser cut length used in three-contact resistors with rectangular additional contact [17], (b) Random trimming with single plunge cut [5].

3. Conclusions

This paper introduced the laser trimming process which can be thought as the most precise and reliable method in order to adjust the resistance value of bar-shaped thin film resistors. The advantages and disadvantages of common trim patterns were discussed and the effect of the HAZ on the performance of the resistors was also introduced. It is worth noting that trimming geometries play an important role on the characteristics of the resistors such as stability and tolerance accuracy. Moreover, trim pattern design has an effect on the resistance distribution and long term resistance performance of thin film resistors. It was also noted that the L-cut is the most commonly used trim pattern due to its expected tolerance which is less than 1% as well as its stability.

In addition to this, recent studies have focused on alternative trimming geometries and were presented in this paper such as the three-contact geometry and the random trim approach besides their positive results. However, these approaches, besides their promising results, did not appear to fulfil the improvements in the resistor performance reported due to the additional trimming time and materials needed. Therefore computer modelling of laser trim patterns could help in predicting and optimizing the resistor design process by designing new trim strategies. Within these limits, the maximum trim speed, overall performance and quality characteristics could be achieved. Thus, further research could focus on the possibility of improving the trimmed structures taking into account the factors that affect the performance of the resistors such as TCR and HAZ.

4. References

[1] Elshabini-Riad A and Barlow F 1998 *Thin Film Technology Handbook* (New York: McGraw-Hill) chapter 3 1-19
[2] Elshabini-Riad A and Bhutta I 1993 Lightly trimming the hybrids *Circuits and Devices* 30-4
[3] Fjeldsted K and Gottfried L 2004 Optimal designs for embedded passives laser trim *Circuitree* **7** 10-4
[4] Maissel L and Glang R 1970 *Handbook of Thin Film Technology* (New York: McGraw-Hill) 18-24.
[5] Sandborn P and Sandborn P 2008 A random trimming approach for obtaining high-precision embedded resistors *IEEE T. Adv. Packaging* **31** 76-81
[6] Sandborn P and Sandborn P 2006 Using embedded resistor emulation and trimming to demonstrate measurement methods and associated engineering model development *Int. J. Eng. Educ.* **22** 1-7
[7] Meunier M, Gagnon Y, Lacourse A, Ducharme M, Rioux S and Savaria Y 2007 Precision resistor laser trimming for analog microelectronics *IEEE Leos. Ann. Mtg*.1
[8] Meier M, Bertsch D, Onda N, Etter M, Gutsche M, Dommann A, Romano V and Nicolet N 2006 Laser trimming of amorphous Ta42Si13N45 thin films with ultrashort pulses *Microelectron Eng.* **83** 2234-7
[9] Antonov Y 2006 Use of laser trimming for the development of a project for accuracy-normalization of the resistance of resistors in hybrid integrated circuits *J. Commun. Technol. El+* **51** 1351-5
[10] Lullo G, Castiglia A, Carini G and Arnone C 2004 Chalcogenide thin films for direct resistors fabrication and trimming. *Mat. Sci. Semicon. Proc*.**7** 337-41

[11] Schultze V and Fischer A 1989 Laser trimming of NiCr thin film resistors I: Thin film resistors without a protective layer Thin Solid Films 182 23-33
[12] Schmidt H and Couch B 1989 Predicting the effect of high speed laser trimming on resistor stability *Electronic Components and Technology Conf.* (Houston:IEEE)
[13] Shier J 1988 A finite mesh technique for laser trimming of thin film resistors *IEEE J. Solid-St. Circ.* **23** 1005-9
[14] Gu B,Couch B,Oh J,Chase P 2003 Comparative study on laser trimming with different wavelengths *Proc. of the Int. Symp. on Microelectronics* pp672-5
[15] Birkett M and Penlington R 2013 Laser Trim Pattern Optimization for CuAlMo Thin-Film Resistors. *IEEE T. Compon. Hybr.* **3** 523-9
[16] Birkett M and Penlington R 2012 Laser Trimmming of CuAlMo Thin-Film Resistors:Effect of laser processing parameters *J. of Electronic Materials* **41** 2169-77
[17] Wroński M, Kamiński S, Miś E and Dziedzic A 2005 New trim configurations for laser trimmed thick-film resistors—theoretical analysis, numerical simulation and experimental verification *Microelectron Reliab.* **45** 1941-8
[18] Gofuku E, Ohnawa T, Kohara M and Nunoshita M 1993 Resistance adjustment with short pulse Nd:YAG laser for ruo2 based thick-film resistors based in polyamide film *IEEE T. Compon. Hybr.* **16** 592-7
[19] Kurihara Y,Yamada K, Kanai K and Endoh T 1990 Laser trimming of thick film resistors on aluminum nitride substrates. *IEEE T. Compon. Hybr.* **13** 596-602
[20] Kestenbaum A and Baer T 1980 Photoexcitation Effects During Laser Trimming of Thin-Film Resistors on Silicon *IEEE T. Compon. Hyb.* **3** 166-71
[21] Kestenbaum A and Baer T 1980 Trimming behavior and post-trim characteristics of Ta2N resistors on silicon *IEEE T. Compon. Hybr.* **CHMT-3** 637-46
[22] Dow R, Mauck M, Richardson T and Swenson E 1978 Reducing post trim drift of thin film resistors by optimising yag laser output characteristics *IEEE T. Compon. Hyb.* **1** 392-7
[23] Bulger G 1975 Stability analysis of laser trimmed thin film resistors *IEEE T. Parts Hyb. Pac.* **PHP-11** 172-7
[24] Fehlhaber P. 1971 Laser trimming of silicon-chromium thin film resistors. *Solid State Technol.* 1971 33-6
[25] Liou B 2011 Use of laser trimming for the fabrication of high precise n-p compensation-doped polycrystalline silicon thin film resistors. *J. Comput. Theor. Nanos.* **8** 2291-98
[26] Wang Z,Yan X,Sun Y and Zhao,X 2010 The influence of laser spot on resistance of chip resistors *Symp. of Photonics and Optoelectronics*
[27] Manolescu A and Manolescu A M 2007 Laser trimming modeling of thin film integrated resistors Int Semiconductor Conf. 473-6
[28] Deluca P. 2002 A review of thirty-five years of laser trimming with a look to the future. Proceedings of the IEEE. **90** 1614-19
[29] Ramirez-Angulo J and Geiger R 1988 New laser trimmed film resistor structures for very high stability requirements *IEEE T Electron Dev* **35** 516-8
[30] Ramirez-Angulo J, Geiger R and Sanchez-Sinencio E 1987 Characterisation, evaluation and comparison of laser-trimmed film resistors *IEEE J Solid-St Circ* **22** 1177-89
[31] Ramirez-Angulo J, Geiger R and Sanchez-Sinencio E 1986 A circuit analysis approach to the performance evaluation of laser-trimmed film resistors *Proc. of the Int. Symp. on Circuits and Systems (IEEE)* 1201-5