Development of resistors with TaxNy deposited by RF sputtering using laser-writing technique

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Abstract

In this work Ta_xNy thin films were used to manufacture resistors by direct laser writing. The 150 nm thick films were deposited by RF sputtering on polished alumina substrates, exhibiting sheet resistances around 30 Ω/sq. Resistors were defined on the Ta_xN_y films using a focused UV laser beam. Device resistance, calculated from its dimensions and resistivity, was 160 Ω, while the actual measured value was 277 Ω. This discrepancy was attributed to a laser annealing effect near the ablated areas altering the film structure and/or composition.

Keywords: RF sputtering, Ta_xN_y, laser-writer, resistor.

1. Introduction

Multi-chip modules (MCMs) have gained importance in the area of microelectronic technology, due to the possibility of reducing the size of complex electronic designs with these modules (ALMEIDA, 1995). Deposited MCMs (MCM-Ds) are capable of producing high density connections, joining several active and passive components into a single module (System in Package and System Integration) (ALMEIDA, 1995). In fact, this technology has been used by companies like AMD in the graphic processor units of some of their graphics cards (AMD, 2020). Multi-chip modules are widely used to support multiple functions in semiconductor-based products.

CTI Renato Archer (DIMES - Assembly, Packaging and Systems Integration Division) has been researching and producing MCM-Ds for some time now, using thin film technologies. Among the thin films used in MCM-Ds, the tantalum nitride (Ta_xN_y) films are prominent due to the outstanding properties of this material, the main one being the low noise/signal ratio, fundamental in devices with nanometric dimensions (ALMEIDA, 1995). Tantalum nitride can be used to develop thin film resistors for MCM-Ds (RADHAKRISHNAN, 1999; STRAVEV, 1997; WU, 2007). The films present high stability, resistivity, hardness and are chemically inert. Tantalum nitride can also be applied as diffusion barrier in metal–semiconductor contacts (RIEKKINEN, 2002; STRAVEV, 1997; WU, 2007) or wear and corrosion-resistant material (RIEKKINEN, 2002). For this reason, tantalum nitride has been widely used in the mechanical and microelectronics industries (ALMEIDA, 1995). The material has been prepared by several researchers, covering a wide range of resistivities, varying from 169 to 3985 μΩ.cm according to the processing conditions (RADHAKRISHNAN, 1999; RIEKKINEN, 2002; STRAVEV, 1997; WU, 2007).

In a previous work, Adamo et al. (ADAMO, 2014) developed a microfabrication route for Ta_xN_y resistors on MCM-D substrates. First tantalum nitride, titanium-tungsten and gold were deposited by sputtering on alumina substrates. Then, photolithography and etch were performed, in order to define the resistor pads, and finally another step of photolithography and etch were completed to define the bridge or resistor (ADAMO, 2014). In this work, Ta_xN_y thin films were also used to manufacture resistors, but unlike previous works, a laser ablation method was applied to define the geometry of the devices. The procedure is simple and flexible, allowing easy changes in design and resistance values.

2. Experimental Procedure

Thin Ta_xN_y films were deposited on polished 99.9% Al_2O_3 substrates using a custom-built RF sputtering system with 2 in. diameter TaN targets. Film thicknesses were monitored during deposition through a quartz oscillator. Resistivity and sheet resistance were measured with a four-point probe setup (Jandel 2018, RM3000+ Test Unit.). The resistors were defined by ablating the Ta_xN_y films with a frequency tripled Nd:YVO4 focused UV laser beam (Spectra Physics, Pulseo 355-20), and computer-controlled translation stages in a XYZ configuration. Device resistances were assessed from current x voltage measurements performed using two probes.

3. Result and Discussion

Film thickness was 150 nm and its sheet resistance was 29.6 Ω/sq. These measurements were performed in a continuous film (not on resistors or any other devices), leading to a resistivity of 444 μΩ·cm. The values are in agreement with typical results found in the literature (NIE. 2001; RADHAKRISHNAN, 1999; RIEKKINEN, 2002; STRAVEV, 1997; WU, 2007).

Figure 1 shows a resistor patterned using direct laser writing. Using the dimensions, geometry and sheet resistance values, the expected device resistance was calculated to be 160.3 Ω. The actual, experimentally determined value, calculated from the IxV measurements was 277 Ω, which falls within the range reported by other authors (NIE. 2001; RADHAKRISHNAN, 1999; RIEKKINEN, 2002; STRAVEV, 1997; WU, 2007). The difference between measured and calculated resistances can be attributed to the laser altering the Ta_xN_y film at the borders of the ablated line, causing a change in the sheet resistance value, which in turn alters the resistance.

From Figure 1 was possible to noted in the image that the resistor has been well defined by ablation of the Ta_xN_y film (thin black line), but the neighboring regions all around the device and contact pads exhibited a darker color when compared to the original film.

The other possibility to explain this difference is due to the resistor length parameter (L), this parameter is inversely proportional to the area (LIMA, 2011). Figure 1 shows that the resistor has a length of 0.61 cm, however, in the electrical measurement the value of L is not that. The electrical contacts, pads, are not defined by gold, material used as electrical contact. In this way, parameter L assumes the distance between the test leads, as shown in Figure 1.

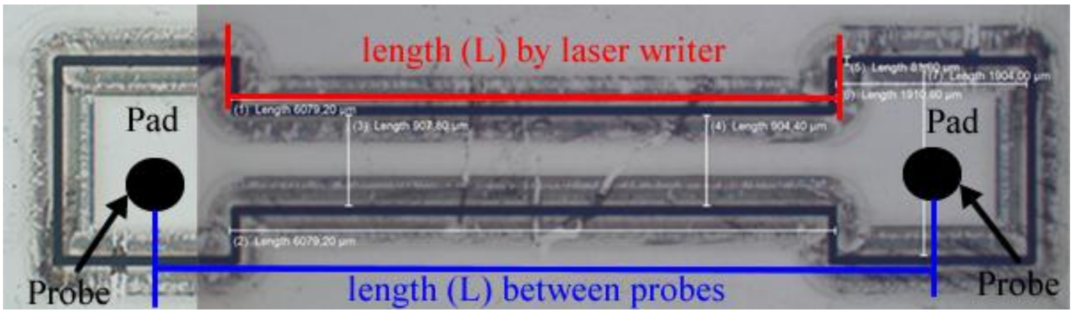
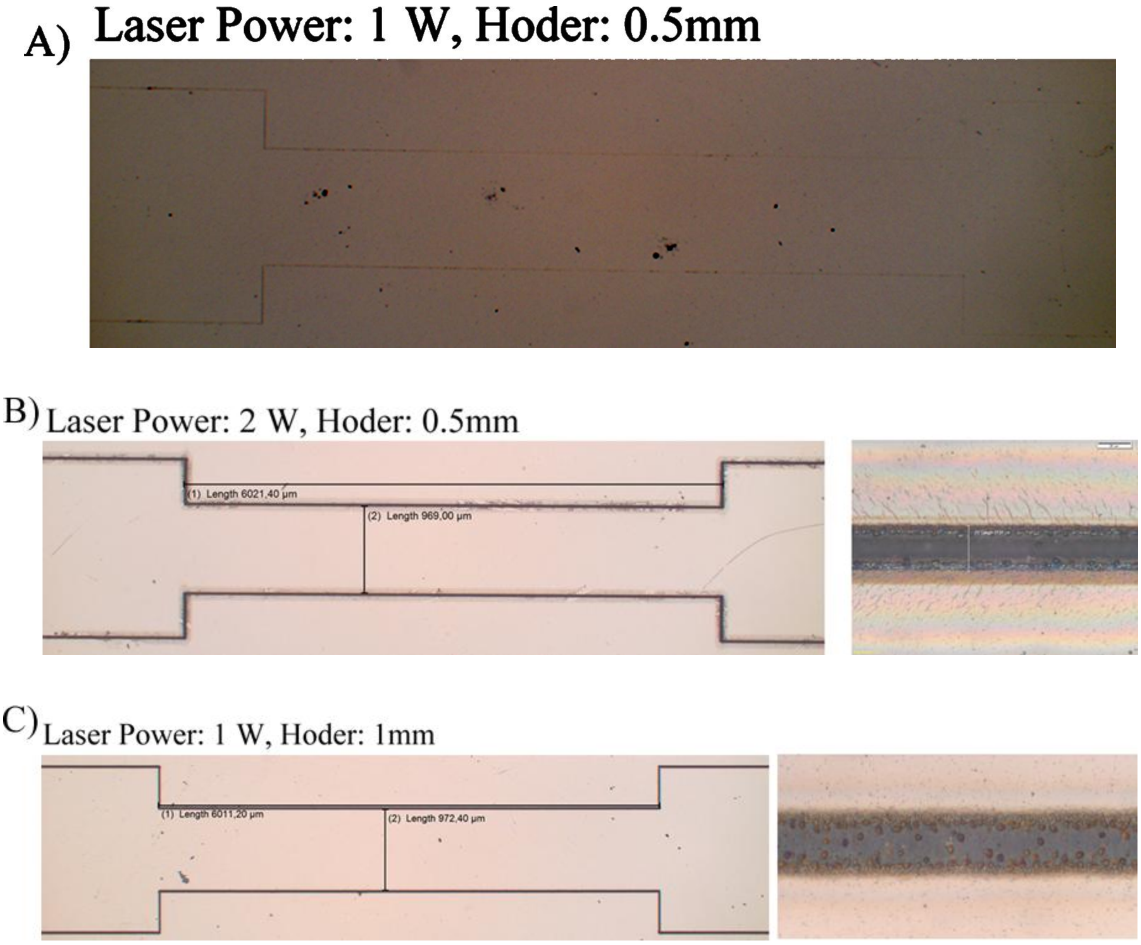


Figure 1: Resistor patterned by laser writing, showing a heat-affected darker region around the laser-ablated path (black line).

The laser beam energy profile is Gaussian shaped, making it capable to ablate the Ta_xN_y film at the center of the beam spot. However, as the intensity of the beam gradually falls towards the laser spot perimeter, the illumination is only able to anneal the material, modifying its local composition (most probably through nitrogen loss and/or oxidation). In this way, the effective cross-section for current conduction is smaller than the nominal value.

As a solution to this problem, the laser could be equipped with a pin hole with a drilled in the center. This would allow to block the edges of the laser, allowing only the central part to pass through. Thus, it was necessary to carry out a study to determine which pin hole and power are the most suitable for the Ta_xN_y film. This study consists of varying the laser power (1W and 2W) and the pin hole diameter (0.5 mm and 1 mm). For this test, the 150 nm Ta_xN_y film was used, deposited by RF sputtering using the TaN target. Figure 2 shows the result of this study. For the test with 1W power and the 0.5 mm diameter pin hole (Figure 2A), it was not possible to corrode the Ta_xN_y film. By increasing the power to 2W and keeping the pin hole 0.5 mm, it was possible to corrode the Ta_xN_y film and form the resistor, as shown in Figure 2B. However, it can be noted that the edges of the film are still damaged. By increasing the pin hole diameter to 1 mm and decreasing the laser power to 1W, it was possible to corrode the Ta_xN_y film (Figure 2C) with an improvement in relation to the damage of the film when compared to the two previous cases. By increasing the laser power to 2W and keeping the pin hole at 1 mm, it can be noted that it is still possible to corrode the Ta_xN_y film, forming the resistor (Figure 2D) and obtaining minimal damage to the film. This last setting is the least damaging to the edges of the Ta_xN_y film, causing little or no change in the values of R_S and R.



D) Laser Power: 2 W, Hoder: 1mm

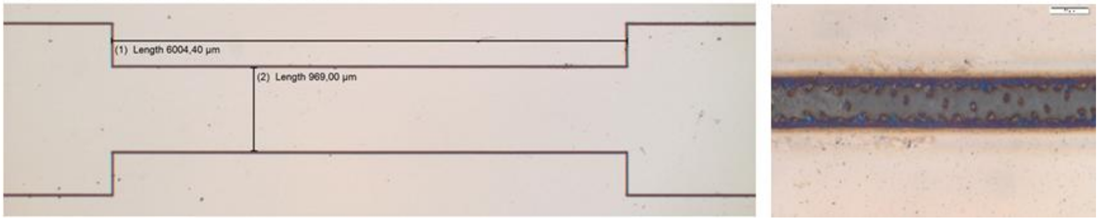


Figure 2: Results of the study using the laser-writing technique. Variation of power (W) and pin hole (mm). Samples with 150 nm thick TaxNy film deposited sputtering RF using the TaN target. A) Laser power 1W and pin hole 0.5 mm; B) 2W laser power and 0.5 mm pin hole; C) Laser power 1W and pin hole 1 mm; D) 2W laser power and 1 mm pin hole.

With the best parameter characterized, the next step is to develop the Transfer Length Method device (TLM). This device consists of making resistors in series by varying the length (*L*). By extracting the resistance values of each resistor, it is possible to determine the linearity of the TLM device, which must be proportional to the relationship between length and width (*L/W*) of the resistors. Figure 3 shows the TLM device manufactured using the 150 nm thick Ta_xN_y film deposited by RF sputtering using the TaN target. This device was manufactured using the laser writing technique with a power of 2W and the pin hole with a diameter of 1 mm. It can be seen from Figure 3 that even using the parameters that resulted in the best writing (Figure 2D), in this device the laser power ended up cracking the Ta_xN_y film. Therefore, it is already expected that the value of R_S and R have been changed, generating a difference between the measured and calculated resistance values.

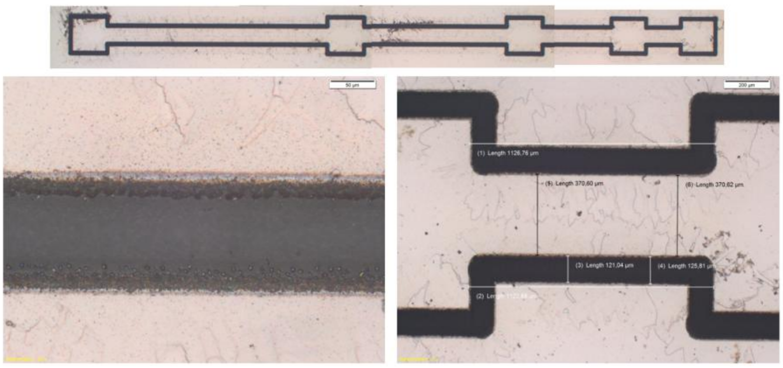


Figura 3: TLM device developed using laser writing with 2W power and 1 mm pin hole. TLM manufactured using the 150 nm thick Ta_xN_y film deposited by RF sputtering using the TaN target.

Table 1 shows the values of length (*L*), width (*W*), relationship between length and width (*L/W*) and the resistivity (*R*) of the resistors that make up the TLM device. From the results presented in Table 1, it can be noted that the TLM did not show a linearity. As previously discussed, this may have happened due to the variation of the R_S and the device does not have the pads defined, changing the value of *L*. Both values change the value of the resistance (*R*).

Dimension (mm)		(L/W)	R (Ω)
L	W		
1.1		3	194
2.1		5.7	245
4.1	0.37	11	497
6.1		16.5	1177

Table 1: Values of length (*L*), width (*W*), relationship between length and width (*L/W*) and the resistance (*R*) of the resistors that make up the TLM device.

4. Conclusions

It was possible to develop resistors and TLM devices using laser writing. The best parameters for laser writing were 1W or 2W and with a pin hole with a diameter of 1 mm. These settings allow to corrode the Ta_xN_y film, forming the resistor, and do not damage the edges of the device, causing little change in the sheet resistance (R_S) and resistivity (R) values. However, both devices showed differences between the measured and calculated resistance values. This may have occurred due to the variation of R_S during the film, due to the modification caused by the laser or due to the regions of pads that are not defined, making the length of the resistor (L) to be between the probes and not by the pads, defined by laser writing.

Acknowledgments

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