Evaporation Boats - Investigations on the Electrical Properties

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ABSTRACT

The basic electrical properties of ceramic evaporation boats are described.

The influence of various parameters on the correlation between cold resistivity and resistivity at operating temperature and the relation to the microstructure of the boats is discussed. Derived from these results considerations for the optimization of boat performance are presented and specification criteria are proposed.

INTRODUCTION

The electrical properties of ceramic evaporation boats are crucial for their performance during the metallizing process. In recent years, we have investigated the various parameters affecting the resistivity of boats at room temperature and operating temperature. First results of our study were presented at the SVC meeting in 1991 [1]. This paper deals more specifically with the influence of raw materials, chemical composition and microstructure on the correlation between cold and hot resistivity.

The preparation for test specimens and the measurement set up have also been described earlier [1].

CORRELATION BETWEEN COLD AND HOT RESISTIVITY

1. Theoretical background

The cold resistivity of a ceramic evaporation boat is basically determined by the ratio of TiB_2 (electrical conductor) and BN/A1N (electrical insulators). Consequently, the temperature dependence of the boat resistivity should be equal to that of TiB_2, if TiB_2 is the only electrical conductor.

With regard to resistivity, pure TiB_2 behaves like a metal. The resistivity of metals depends on the temperature and follows the relation:

$$R_{HT} = R_{RT} (1 + \alpha \Delta T)$$

α = temperature coefficent of resistivity

The coefficient α is defined as the slope of the resistivity curve divided by the room temperature resistivity . That means that the slope of the curve must be steeper for higher values of cold resistivity and less steeper for lower values.

Taking into account the temperature coefficient of resistivity for pure TiB_2, one expects that the ratio of hot and cold resistivity for ceramic evaporation boats is always constant and that it is nearly 5, as for TiB_2 (for T = 1500 °C).

But our first measurements showed different results:

- Although TiB_2 is the only electrically conductive constituent in evaporation boats, the temperature dependence of the boat's resistivity was different to that of pure TiB_2.
- Even for almost identical values of cold resistivity, the resistivities at operating temperature for different chemical compositions showed large variations.

Since we knew - as a result of our previous studies - that the cold resistivity alone was not sufficient for predicting the hot resistivity properties, it was the goal of further investigations to determine the reasons for the observed differences.

2. Measurements of samples with identical chemical composition

Measurements were taken with different samples of the same chemical composition but with different TiB_2 powder qualities. Typical results are shown in figure 1.

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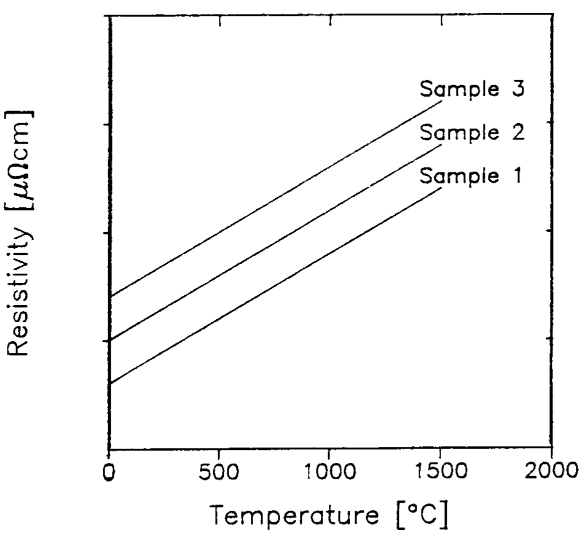
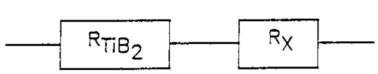


Fig. 1: Resistivity of identical boat compositions with different TiB_2-qualities vs temperature

Contrary to theoretical expectations, all curves are parallel to each other. Therefore we developed a model that allowed us to describe the differences between theory and practical results. The model is based on the following consideration.

In addition to the resistivity of TiB_2 (= R_{TiB2}) which is dependent on temperature, there exists another resistivity (= R_x) in a ceramic evaporation boat that is independent of temperature. The equivalent circuit diagram of the resistivity of a boat can consequently be described by two resistivities in series



It is important to mention that based on this model, the parallelism of all curves can only be explained if R_x is different for all measured test samples.

In order to confirm our model and to find out the parameters that affect R_x, we investigated the influence of the raw materials and process conditions. The nature of the temperature independent resistivity, R_x, is not yet fully understood. According to our results, process conditions such as temperature, pressure and cycle time affect R_x in addition to the following characteristics of the raw materials:

- morphology of TiB_2 and BN
- grain size distribution of TiB_2 and BN
- sintering aids

The imbedding of the resulting electrically conductive TiB_2-network in the insulating matrix of BN also has to be taken into account.

Many models have been discussed in previous literature [2]. The transition between insulating and conducting behaviour in a two phase component depends on grain size, the three dimensional arrangement and the network of both constituents.

Another model explaining the nature of R_x is that a single phase metallic conductor is doped with certain elements (forming an “alloy”) that affect its conductivity. This model was discussed by Matthiessen for metals [3].

Based on our results the presence of a temperature independent resistance R_x is probable. According to our present knowledge, R_x can be caused by “defects” in the network of the conductive phase (i.e. TiB_2) and/or by lattice “defects” of TiB_2. Further studies must be made with regard to this point.

3. Measurements of samples with different chemical compositions

Measurements were taken from different lots of various chemical compositions but with identical raw materials. Typical curves are shown in figure 2.

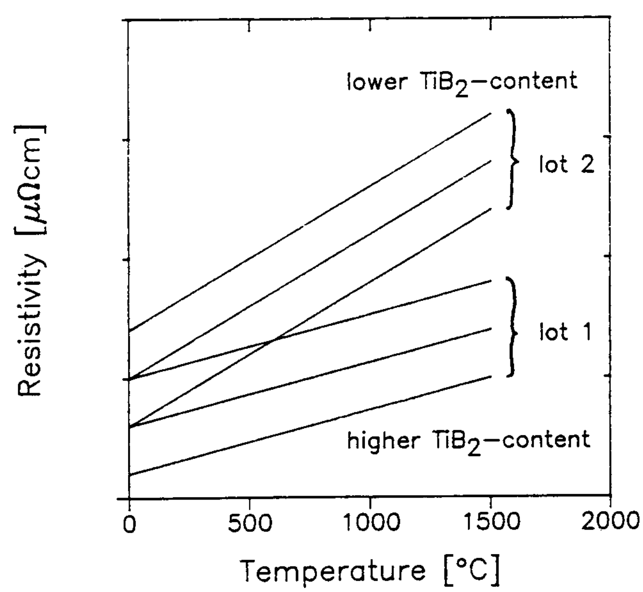


Fig. 2: Resistivity of various boat compositions with identical raw materials vs temperature

Boats with identical chemical composition show parallel curves of the temperature dependence of resistivity.

The slopes of the curves for boats with different TiB_2-contents are in accordance with the definition of the temperature coefficient of resistivity (see section 1).

However, due to the presence of the temperature independent resistivity, R_x, one can achieve significantly different resistivities at operating temperature even for similiar room temperature resistivities. In other words, a controlled influence on R_x will allow a controlled determination of hot resistivities even for different cold resistivities or different chemical compositions.

As already mentioned, the complex nature of R_x is not fully understood and therefore a complete control of R_x has not yet been achieved.

The present knowledge allows a wide range of possibilities to optimize the properties of ceramic evaporation boats according to the requirements of the process or different fields of application.

Some possible aspects are discussed in the following section.

CONSIDERATIONS FOR THE OPTIMIZATION OF BOAT PERFORMANCE

An important characteristic of a ceramic evaporation boat is its resistivity which is essentially determined by the ratio of TiB_2 and BN. The cold resistivity ranges are usually fixed by the manufacturer of the metallizer. The basic guidelines are power supply of the metallizer, boat's geometry and rate of aluminum to be evaporated. In addition to electrical properties, other characteristics like wettability, break-in behavior and stable evaporation behavior are important for the process, which is also true for the lifetime of the boat. These factors are also affected by the ratio of TiB_2 and BN. Our experience shows that the above mentioned requirements cannot be met completely in every area.

Typical restrictions for a longer lifetime at a certain evaporation rate are, for example, limitations in the power supply of the metallizer (voltage and/or current) or the wettability which is deteriorated by lowering the TiB_2-content.

Keeping this in mind, it is obvious that compromises must be found between the boat properties and the customer requirements. From the point of view of a boat manufacturer the control of the temperature independent resistivity, R_x, is a valuable tool as shown in the following two examples.

Example 1:

Problem: Reduced lifetime due to current limitation, present hot resistivity does not reach upper limit of available voltage; wettability must not being deteriorated.

Solution: Keep TiB_2-content constant. Increase R_x

Example 2:

Problem: Customer wants to increase boat width (→ larger cavity area) to increase evaporation rate; no reduction in lifetime due to current limitations requested; wettability must not being deteriorated.

Solution: Keep TiB_2-content constant. To keep the boat's resistance constant at operating temperature, R_x must be increased to compensate for the increase of the conductive cross section.

Similar considerations can be made for other problems.

CRITERIA FOR OPTIMUM BOAT PERFORMANCE

Currently, the typical specification criteria for ceramic evaporation boats are the boat's dimension and resistivity at room temperature. Other relevant properties like wettability or resistance against corrosive attack of aluminum are not specified. As already mentioned all the described properties depend essentially on the ratio of TiB_2 and BN.

Our investigations show that the resistivity at room temperature is not sufficient to describe the electrical properties of evaporation boats. The ratio between the hot and cold resistivity and temperature dependence also have to be taken into account.

The important practical aspects of our work are as follows:

a) Within one set of boats to be used in the same metallizing cycle, similar hot resistivities can be achieved by putting together only boats with identical chemical composition.

b) In a set of boats with identical chemical composition a small range of cold resistivities lead to a small range of hot resistivities.

c) For a given set of boats with identical chemical composition, the relative variation of the hot resistivities is smaller than that of the cold resistivities.

As a result of our recent studies, we think, that particularly for the latest generations of metallizing machines, the range of resistivities that can be used is significantly wider than it is reflected in present specification criteria of ± 50 or ± 100 μΩcm respectively.

A crucial point for a good performance is to have very similiar hot resistivities within one set of boats.

CONCLUSION

Ceramic evaporation boats are used in many fields of application, e.g. producing condensor foil, packaging materials, barrier films and protective coatings. Due to different requirements of the Al-coated product, the operating conditions during metallization can vary. As a result, the evaporation boat must also satisfy different requirements for different applications. From the point of view of a boat manufacturer, this means different types of boats for different applications. Our studies of the electrical properties of evaporation boats have revealed that the control of the temperature independent resistivity, R_x, which is inherent in the boats, offers the ability to adjust certain boat properties according to the requirements of the process.

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