THE ELECTRICAL PROPERTIES OF ZOT AFTER A LONG TERM EXPOSURE TO THERMAL VACUUM ENVIRONMENT

by

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ABSTRACT

Experimental results show that the moisture content of ZOT paint provides a medium for ionic conductivity to occur, increasing its observed conductivity significantly. By extrapolating the test data the resistivity of ZOT, in the absence of moisture, is determined to be 10^{14} ohm-cm. Therefore, ZOT cannot be regarded as a conductive paint.

INTRODUCTION

The Galileo (GLL) spacecraft (Leung, 1985), which was launched from Shuttle in October, 1989, will orbit Jupiter in 1995. One of the scientific objectives of Galileo is to perform detailed measurements of the charged particle distributions at Jupiter; in particular, the charged particles that carry the current in the Io flux tube. The Plasma Instrument (PLS) on board Galileo was designed to accomplish this goal. It has the capability of measuring charged particles in the energy range of 0.1 eV to 5 eV.

In order for PLS to achieve its measurement objectives, the electric field gradient in the vicinity must be minimized. For this reason, a rigid equipotential requirement was imposed on Galileo. Specifically, the potential difference between any two surfaces had be less than 10 volts, making Galileo an almost equipotential spacecraft. In order to qualify as such most of the Galileo surfaces were made from conductive materials. However, in some cases, conflicts with other engineering constraints required the use of new materials with marginal or unknown properties. The acceptability of these materials was usually evaluated by tests which included:

1. measurement of conductivities;
2. measurement of the surface potential in the simulated charging environments.

Usually at least one of the above tests was performed. A typical example is the evaluation of thermal control white paint. Unlike the black paints, which can easily be made conductive with the addition of the appropriate amount of carbon, white paints are usually nonconductive. For Galileo, an effort was made to identify/formulate paints which would satisfy the Galileo equipotential requirements. Zinc orthotitanate (ZOT) was identified as a possible candidate conductive white paint. During the development of the Galileo spacecraft, several sets of tests were performed to determine the acceptance of ZOT paint. This paper summarizes the results obtained in the latest round of tests.

TEST SETUP AND ENVIRONMENTAL CONSIDERATIONS

Since the space environment plays a very important role in determining the electrical properties of a material, the parameters which can affect the electrical properties of ZOT must be carefully considered in this test. For paints, the important parameters are:

1. space plasma environment,
2. surface temperature,
3. moisture content.

Extensive literature is available on the simulation of the charging environment in space (Adamo, 1985). For this program, the energetic electron environment of Jupiter is simulated by the use of a mono-energetic electron beam. Although this technique may over estimate the levels of differential charging, it does provide an upper bound to the predicted charging levels.

In a typical test, a test sample is irradiated by an electron beam (Fig. 1) and the resulting surface potential is measured by a non-contacting electrostatic probe. The parameters of the electron beam are selected so that the charging environments to be encountered can be adequately simulated. For the Galileo project, these environments are Jupiter's Plasma Sheet and Earth's Geosynchronous environment. Table 1 shows the test parameters corresponding to these two environments.

Table I. Simulation of Galileo Charging Environment

Regions	Electron Beam Parameters
Jupiter's Plasma sheet	10 KeV at 0.05 nA/cm^2
Earth's Geosynchronous	10 KeV at 0.5 nA/cm^2

Temperature is a very important factor in determining the conductivity of a non-conductive material. For a good dielectric material, the conduction of charge/current is a direct result of electron motion through the material (Sessler, 1980) and hence its conductivity is directly proportional to the mobility of elec- trons within the material. Depending on the particular material, the electron mobility can be very sensitive to temperature. Therefore, the charging of ZOT should be performed at its predicted temperatures. In the test setup, a baffle which allows the passage of liquid nitrogen (LN_2) or hot gaseous nitrogen is used to control the temperature of the test sample (Fig. 1).

When paints are first mixed and applied to a surface, their moisture content is usually very high. Even after curing, water molecules are still chemically bonded to the paint constituents, and these molecules are often difficult to remove. In addition, ZOT absorbs moisture from the ambient environment rapidly. In an environment of 50% relative humidity, the moisture content of ZOT could amount to as high as 0.1% of its mass.

The presence of moisture can modify the observed conductivity significantly through the process of ionic conductivity. In the presence of water content, the chemicals in the paint can be dissociated into ions. For example, in ZOT the following dissociation process may take place:

$$Zn(TiO_2) \; \text{-->} \; Zn^{++} + TiO_2^{--}$$

In the presence of an external electric field due to charging or from an external bias, these ions can move along the field lines and contribute to the measured current. Consequently, the observed conductivity of ZOT is usually higher in the presence of moisture. For an aqueous solution, the ionic conductivity increases with the number of ions present (Crow, 1974). For this reason, the apparent conductivity of ZOT would increase with the amount of water in the paint.

The Galileo spacecraft will transverse within 0.5 AU of the sun, and six years will elapse before its first encounter with Jupiter. It is expected that the moisture content of ZOT will be almost zero by the time of the Jupiter encounter.

Originally, it was believed that if a material evaluation test was performed under vacuum conditions, the moisture content of the sample would not be significant, and the ionic conductivity would not play a role. However, preliminary results of conductivity measurements (Robinson, 1981) obtained under vacuum conditions seemed to indicate that the conductivity of paint does tend to decrease as a function of time. A possible explanation for this phenomenon is that the water content of the paint sample has not been completely eliminated. Consequently, a method must be devised to perform the charging/ conductivity tests with the water content of the paint sample resembling what it would be after prolonged exposure to the space environment. For this recent test program, the ZOT paint sample was exposed to a sequence of thermal/vacuum conditions aimed at driving the water out of the test sample in the shortest time possible.

DESCRIPTION OF TEST TIMELINE

The timeline of this test sequence is shown in Figure 2. In designing this timeline, the cost of using the vacuum chamber (which is the main cost driver) was taken into account. Therefore, only five days of test time was allotted. The sample was placed in an oven and after being prepared, underwent a preliminary bakeout process at 140°C under atmospheric pressure. The sample was then transferred to a vacuum chamber and underwent further bakeout at a temperature of 120°C. This bakeout process occurred with the ambient pressure maintained at 10^{-5} torr or below. During this time, the sample was irradiated by an electron beam and the resulting surface potential was measured (Fig. 2). At the end of the fourth day, the bakeout process was terminated. The surface potential of the ZOT paint sample, when irradiated by an electron beam at various temperatures, was taken and measurements were performed over a two day period. Once the ZOT sample was placed in the vacuum chamber, it was continually exposed to vacuum conditions during the five days of test. This was to prevent the absorption of moisture content from the atmosphere.

RESULTS OF THE ELECTRON BEAM IRRADIATION EXPERIMENT

Figure 3 shows the surface potential of ZOT when it was irradiated by a 10 KeV electron beam at different current densities. For each beam current density, the ZOT surface was irradiated for a period of 10 minutes. At low current densities, <0.1 nA/cm^2, the 10 minute interval was probably not sufficient for the paint surface to come into equilibrium. At Jupiter, the environment is very dynamic; Galileo is not expected to stay in the same type of environment for more than 10 minutes. Therefore, these test results provide reasonably good predictions of the charging conditions that Galileo may have at Jupiter. One of the most distinct features of Figure 3 is that the surface potential increases with the duration of the bakeout period. That is, the effective conductivity of ZOT decreases as a function of the time exposure in vacuum. The potential of the paint surface after 66 hours of bakeout is several times the charging level before the bakeout process (all measurements were taken at 25°C). This indicates that moisture content plays a very important role in determining the charging level. The test results also imply that exposing ZOT to four days of vacuum bakeout does not completely deplete the test sample of water content. An increase in the charging level between day 4 and day 5 indicates that an equilibrium moisture content level was never achieved.

As expected, the charging level and hence the conductivity of ZOT decreases with its temperature (Fig. 4). For this study, the paint sample was allowed to come into equilibrium with the hot/cold plate for an hour before the initiation of electron beam irradiation. The test results show that the conductivity changes by more than two orders of magnitude, from 400K to 240K (127°C to -33°C). Between 240K to 94K (-33C° and -179°C), the change in charging potential is extremely small. In Figure 5, the resistivity of ZOT as a function of temperature is plotted. This resistivity is derived from Ohm's law and assumes uniform irradiation of the ZOT surface. The data indicates that the resistivity of ZOT can be as high as $3x10^{15}$ Ohm-cm, therefore, it should not be considered as a conductive paint.

DISCUSSION

The test results clearly demonstrate the dependence of ZOT's charging level/conductivity on its moisture content. It should be noted that the time allotted for vacuum bakeout is not sufficient to completely eliminate the water content of ZOT. However, an upper bound in the surface potential can be developed from the surface potential data at temperatures below the freezing temperature of water. As the temperature of the test sample is lowered to below 273K (0°C), the water inside the sample should be frozen and the degree of ionic conductivity should be completely curtailed. Consequently, the surface potential measured at temperatures below 273K could be free of the effects of ionic conductivity. The data displayed in Figure 3 indicate that the water content of the sample was completely frozen at 240K (-33°C). The variation in the surface potential between 240K to 94K could be due to variation in the mobility of ZOT at different temperatures. Since the surface potential varies slowly at this temperature, the resistivity of ZOT is a weak function of temperature between 240K and 94K.

Using the data at 240K, an upper bound on the surface potential of the ZOT sample can be obtained. If this approach is taken, the worst case potential of ZOT in the Jovian Plasma Sheet environment would be 150 volts, and its surface potential in the vicinity of Earth's geosynchronous environment would be 1500 volts.

Charging only occurs on shadowed surfaces. Since the photo-current dominates the electron current of the expected environment (Table 1), no charging should occur at sunlit surfaces.

CONCLUSIONS

The presence of moisture provides a medium for ionic conductivity to occur in ZOT paint, increasing its observed conductivity. When most of the moisture is eliminated the conductivity decreases by more than two orders of magnitude. Therefore, care must be taken when using ZOT (or other 'conductive paints') in space systems.

As for the ZOT surfaces of Galileo, they violate the equipotential requirement and work is being performed to evaluate the impact of this on the plasma instrument.

ACKNOWLEDGEMENT

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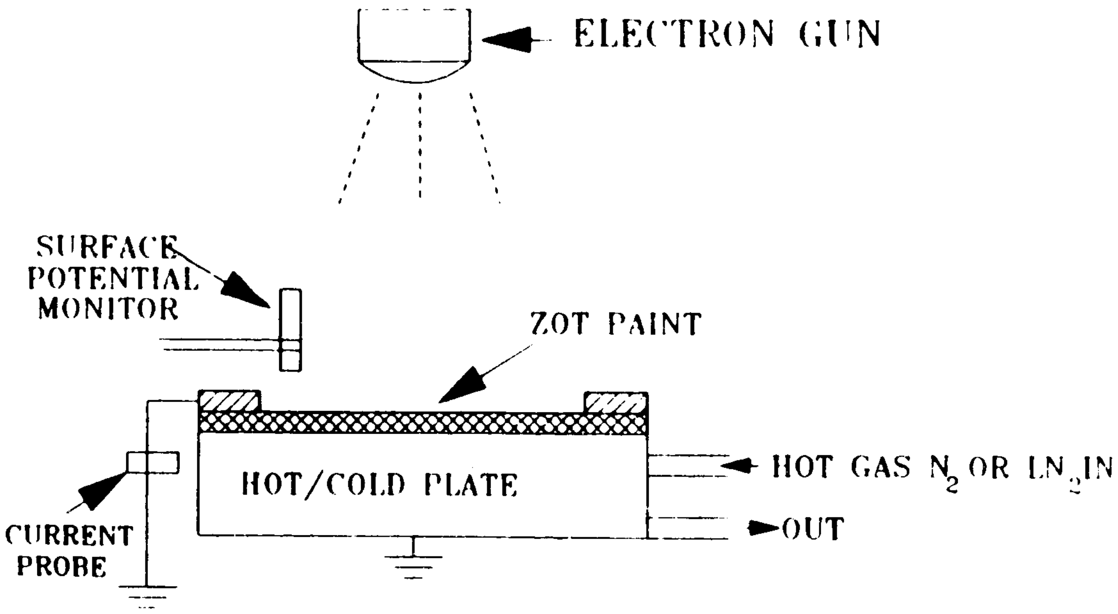

Figure 1. Schematics of the experimental setup.

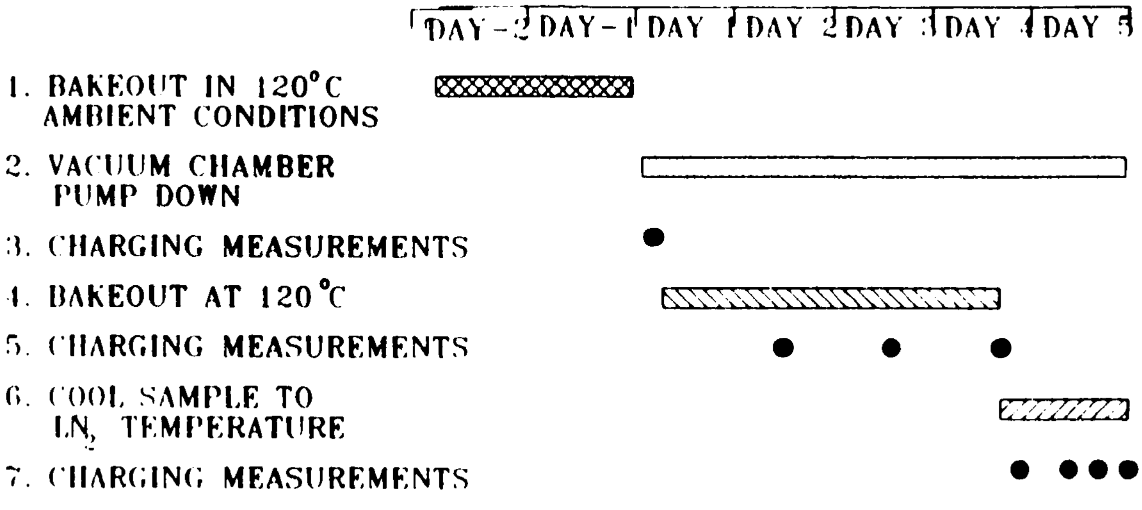

Figure 2. Timeline of test sequence.

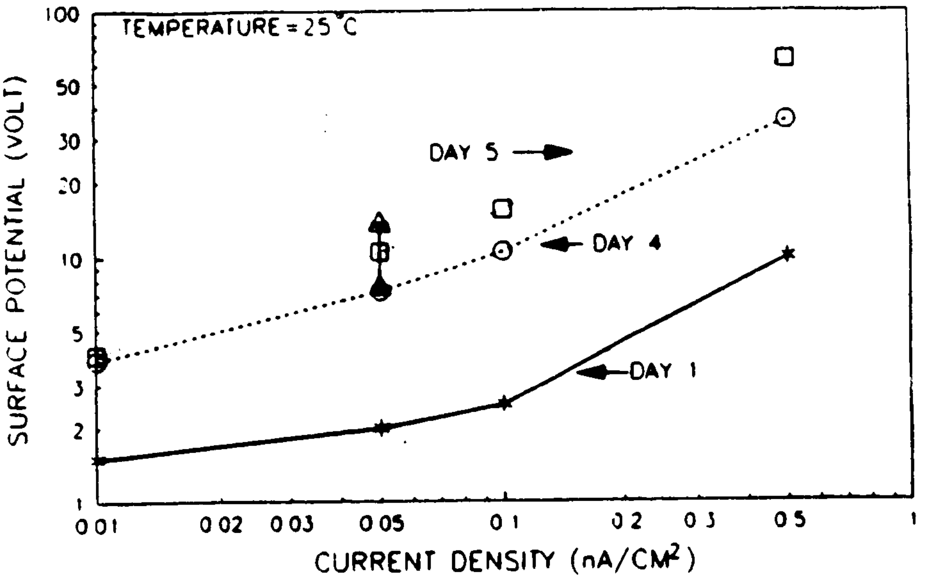

Figure 3. The surface potential of ZOT when it is irradiated by a 10 KeV electron beam at different current densities.

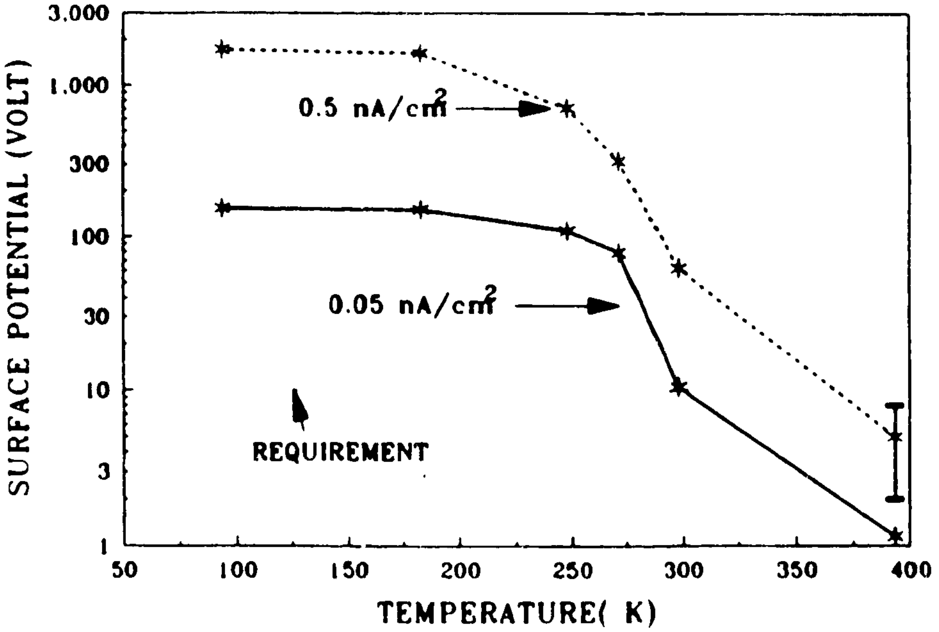

Figure 4. Surface potential of ZOT as a function of temperature at two different current densities. The dotted line indicates the Galileo surface potential requirement.

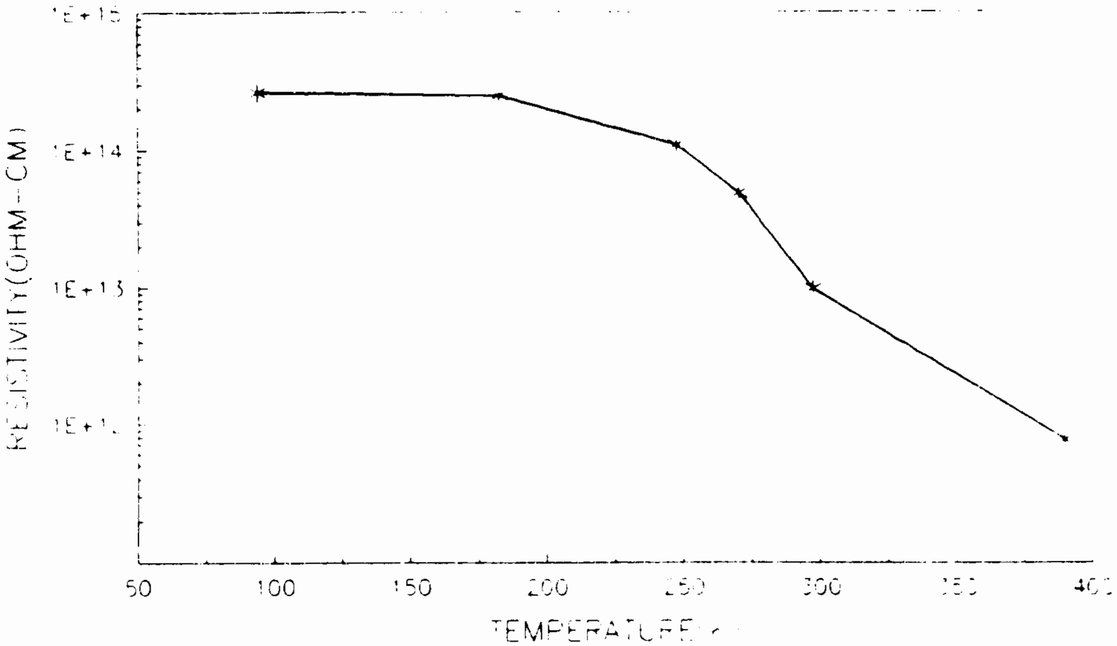

Figure 5. Resistivity of ZOT as a function of temperature.