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ABSTRACT

Wire bonding has become one of the primary methods of interconnection for automotive-electronic units. This includes : ignition modules, pressure sensors, voltage regulators, anti-lock braking modules, air-bag systems, distributorless ignition modules, etc. As the technologies in the automotive field increases, both the wire bonders and the wire have to keep pace. One of the improvements over the past few years was the development of corrosion resistant wire used for automotive-electronic applications. Corrosion resistant wire is unique in that there are some essential dopants in the wire that prevent the wire from physical damage.

INTRODUCTION

"The American automotive industry today is attempting to achieve world class distinction. While this phrase means different things to different people, the definition in the automotive electronic module industry seems to be 10 years or 100,000 miles without failure." [1] One method that automotive-electronic designers and manufactures are striving to achieve this goal is by utilizing wire bonding as the main interconnection method within the modules used in under-the-hood applications. This paper will focus on the use of aluminum-based wires used by the high-speed wire bonders in the manufacturing of automotive modules.

RESULTS & DISCUSSION

Since the 1970's, the use of electronic modules to replace mechanical systems has been on the rise. However, the transition from mechanical to electrical also introduced new design issues that the engineers had to consider. With the newer developed wire bonders, this method of interconnection has made major strides in replacing other interconnection methods such as welding or soldering. Not only has wire bonding with aluminum based wires improved the quality of the interconnects, but it has also been more efficient in cost reduction programs than the other two methods. [2]

In some instances, electronic modules that were placed in certain areas beneath the hood of the automobile were exposed to salt spray, water, various automotive fluids, etc.. If any of these items were able to penetrate the internal sections of the electronic modules, then the aluminum wire may be negatively affected. In addition, some of the plastic housings that these electronic modules are incorporated into are susceptible to out-gassing of corrosive vapors which could deteriorate aluminum wire. If any of these items were able to penetrate the internal components of the electronic module, serious damage could result to the entire package.

Aluminum wire is the medium that is used to connect the module's lead frame to the electronic circuit board. If this connection is physically damaged, then the module fails or behaves differently from what it was designed to do. To assist in alleviating this failure mode, wire manufacturers developed an aluminum based corrosion resistant wire.

The first type of electronic modules in the 1970's used printed circuit boards. As the conversion of mechanical to electrical systems increased significantly into and throughout the 1980's, the module sizes became smaller to conserve space. This resulted in hybrid circuits using ceramic substrates, eventually replacing the printed circuit boards. As mentioned earlier, these hybrid modules have plastic housings which may introduce a variable that is potentially troublesome for normal 99.99% aluminum wire.

MOLD COMPOUNDS

In 1985, Onuki, Suwa, Koubuchi, and Asai of Hitachi needed to develop a corrosion resistant aluminum alloy wire used in a resin molded device. They found that "in resin molded devices, corrosion of bonding wire is accelerated by impurities from resin". [3] In addition, Adams, Knoell, and Larner state that, "when plastic packages absorb moisture from the environment, high temperatures, ..., can cause the moisture inside the package to rapidly expand and crack the plastic". [4] These two references cite that the plastic housings are capable of out-gassing. These vapors may carry with them detrimental items that could attack the wire and cause it to corrode.

OTHER SOURCES OF CORROSION IN ELECTRONIC PACKAGES

In addition to external items already mentioned previously (e.g. automotive fluids, plastic molding compounds), there are other sources that could affect the corroding effect of aluminum wires. These other sources are within the electronic package. One major culprit are halogens. "Halogens are pervasive and are well known to corrode aluminum metallization in integrated circuits." [5] Chlorine, a halogen, could be present from epoxy die attach materials.

Various intermetallic formations between different metal systems also may contribute to form corrosive properties. One such intermetallic is Copper-Aluminum and this issue gets worse with the presence of moisture and halogens. [6] Proper cleaning of the hybrid substrate, before wire bonding, could help eliminate any corrosion-inducing variables originating from the components on that hybrid device.

DOPANTS USED FOR ANTI-CORROSION WIRE

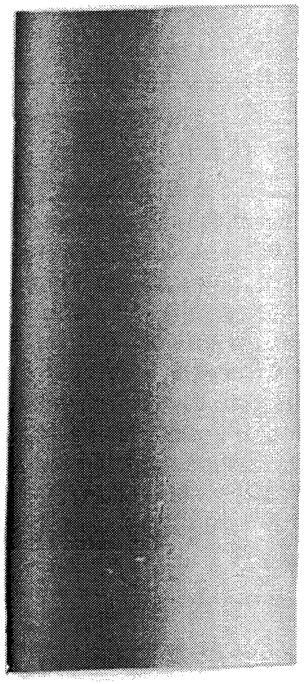
A typical aluminum wire used for wire bonding applications is of the 99.99% purity level. There are many other dopants (in parts per million) present in this 99.99% aluminum. To make aluminum wire anti-corrosion, a key dopant is nickel. Table 1 shows an elemental breakdown of what is present in corrosion resistant aluminum wire.

Table 1 Typical Elemental Breakdown of Corrosion Resistant Wire (numbers are in parts per million)

Si 2.6	Ag < 10	In < 2
Fe < 20	B < .5	Li < .1
Cu < 20	Ba < .1	Na < .2
Mn < 20	Be < .1	Pb < 1
Mg < 20	Bi < 10	Sb < 5
Cr < .5	Ca < 1	Sn < 2
Ni 50	Cd < 2	Sr < .2
Zn < 1	Co < 3	V < 1
Ti < .5	Ga < .5	Zr < .3

Nickel and aluminum form a strongly cathodic constituent ($NiAl_3$) that usually has an adverse effect on the corrosion resistance of aluminum alloys. Nickel is used mainly in alloys that require high strength and hardness at elevated temperatures; ...". [7] This nickel additive helps protect the grain boundaries in the aluminum wire from corrosive attack. Figure 1 shows a scanning electron microscope photograph of the surface finish of aluminum wire that has a nickel dopant present. The photograph was taken at 100 times magnification and it shows a 254 micron size wire (10 mils).

Figure 1 SEM Photo of Anti-Corrosion Al Wire



TESTING WIRES FOR ANTI-CORROSION PROPERTIES

There are two applicable specifications presently available for testing wires for their anti-corrosion properties. The JEDEC Standard JESD22-A102-B "Accelerated Moisture Resistance - Unbiased Autoclave" was released by the EIA (Electronics Industries Association) in March, 1991. Its purpose is that "it employs severe conditions of pressure, humidity and temperature that accelerate the penetration of moisture through the external protective material (encapsulant or seal) or along the interface between the external protective material and the metallic conductors that pass through it".

The test conditions stated in JESD22-A102-B are as follows :

* Temperature 121 +/- 1 °C

* Relative Humidity 100%

* Vapor Pressure 15 +/- 1 psig

* Duration of test 24 to 336 hours

The procedure of the test is to place the devices into a chamber for the specified period of time. Many companies differ on how often they monitor the samples throughout the duration and also on the failure criteria.

Another related specification is available from NACE (National Association of Corrosion Engineers) and it is Standard TM0171-95 Item No. 21203 "Standard Test Method Autoclave Corrosion Testing of Metals in High-Temperature Water". This standard establishes the laboratory test setup and apparatus of the autoclave test system. Another term given to the autoclave test is the "pressure cooker" test.

TEST DONE ON SPM WIRES

In the fall of 1996, Semiconductor Packaging Materials (SPM), a manufacturer of aluminum-based wires subjected many different alloys of aluminum to the autoclave test at Northrup Grumman in Rolling Meadows, Illinois. The wires that were tested included :

* 99.99% Aluminum
* 99.999% Aluminum
* 1% Silicon Aluminum
* Aluminum Nickel (AlNi)
* 0.5% Magnesium Aluminum
* 99.99% Aluminum Anti-Corrosive (AlCr)

Below is a chart that shows a matrix of which wires were tested.

Table 2 Matrix of Wires Subjected to Autoclave Test

wire size in microns (mils)

---------	25.4 (1 mil)	50.8 (2 mils)	127 (5 mils)	307.7 (12 mils)	384.6 (15 mils)
1%SiAl	X				
AlNi		X			
99.99% Al			X	X	X
99.999 % Al					X
.5%Mg Al			X		
99.99% AlCr			X	X	X

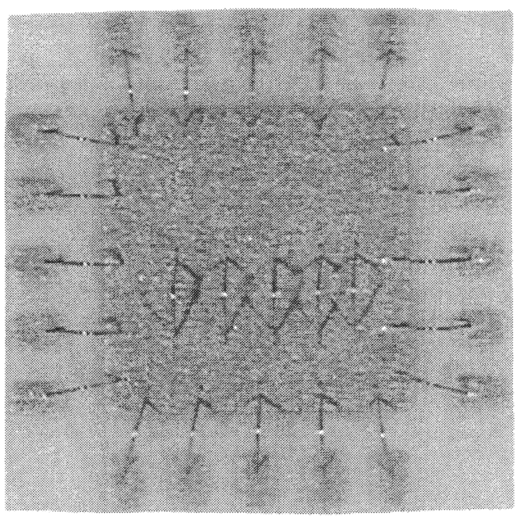
The 1% Silicon Aluminum wire was wire bonded to gold thick film coupons using a West Bond Model 4500B Wire Bonder. The Al-Ni wire (50.8 microns diameter) was wire bonded to aluminum coupons using an Orthodyne Electronics Model 360C Wire Bonder. The large diameter aluminum wires were wire bonded to aluminum coupons using an Orthodyne Model 20 Wire Bonder. Default settings for power, force, and time were used on all wire bonders. A Dage BT-22 Microtester was used to do all destructive pull testing on the wire bonds.

Wire bonds were made on the coupons and to ensure correct settings were used on the wire bonders, destructive pull testing was done. All wire bonds were done in the same plane to avoid any height discrepancy in hook placement during destructive pull testing and any wire sway during submersion in the test chamber. The minimum breaking load requirement was half the tensile strength of the wire. In addition, a maximum coefficient of variation of 20% was used to verify that the relationship between the average and the standard deviation of the breaking load was in a state of process control.

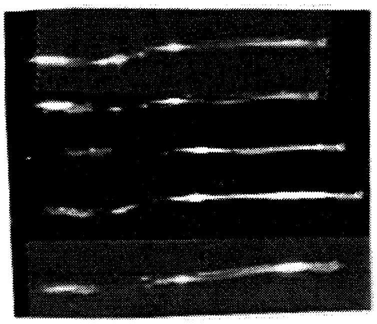
Below are two photographs that show a typical layout of the wire bonds on the coupons.

Figure 2 Photographs of Wire Bonds on Coupons

1% Si-Al Wire (25.4 microns) on Gold Thick Film



99.99% Al (307.7 microns) on Aluminum Coupon



TEST SETUP & PROCEDURE

Northrup Grumman did the Autoclave Test in accordance with the EIA Specification JESD22-A102-B and the NACE Standard TM0171-95. The samples were taken from the test chamber at the end of every 24 hours and destructive pull testing was done on a sample of 10 wires. The same criteria for destructive pull test and coefficient of variation was used throughout the 96 hour test (minimum breaking load of wire bond is half the tensile strength of the wire and the coefficient of variation could not exceed 20%).

AUTOCLAVE TEST RESULTS

All wires subjected to the Autoclave Test successfully passed 96 hours. One of the reasons why the wires that did not have the nickel dopant present passed, was that these test coupons were not incorporated into a plastic package nor was any encapsulant used to cover the wire bonds.

CORROSION RESISTANT WIRES AVAILABLE

As the packaging density of electronic packages continues to increase, more wire sizes are readily available in the corrosion resistant type that accommodate the end user's applications. A growing trend now occurring in the microelectronics industry is using 50.8 micron wire (2 mils) that is corrosion resistant. Below is a table that shows typical elongation and tensile values for the most common aluminum wires that are anti-corrosion for wire sizes from 50.8 microns (2 mils) to 508 microns (20 mils).

Table 3 Elongation & Tensile Values for Aluminum Wires that are Corrosion Resistant

Wire Size in microns (mils)	99.99% Al CR
50.8 (2 mils)	1-5% 50 gr. min. tensile
127 (5 mils)	5-12% 100 gr. min. tensile
254 (10 mils)	10-18% 350 gr. min. tensile
307.7 (12 mils)	12-20% 625 gr. min. tensile

CONCLUSION

Autoclave testing is important for end users in automotive applications. It helps in determining just how well the electronic module will sustain itself in a corrosive atmosphere. However, it is recommended that the end user determine whether the Autoclave Test is actually required. Depending on where the module is physically located within the automobile and what type of environment it will be exposed to will assist in determining if the Autoclave Test is applicable. Not all electronic modules used in automotive applications need to be subjected to the Autoclave Test.

Testing units to the Autoclave by the end-user is recommended for a few reasons. Only the end user can actually determine how long the duration of the Autoclave Test should be and what the failure criteria is. The end user should have the complete package (wires already bonded within the plastic housing) undergo the Autoclave Test. It appears that the molding compound is a strong factor in determining just how much corrosion activity is present during the Autoclave Test. What makes it difficult for the end user is that molding compounds vary between suppliers.

Overall, the Autoclave is an important test to use for automotive electronic modules when applied properly.

ACKNOWLEDGMENTS

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BIOGRAPHY

Mike McKeown has been employed at Semiconductor Packaging Materials (SPM) as an Applications Engineer since December, 1995. Previous to that was a Process Engineer at Standard Motor Products specializing in wire bonding applications.

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