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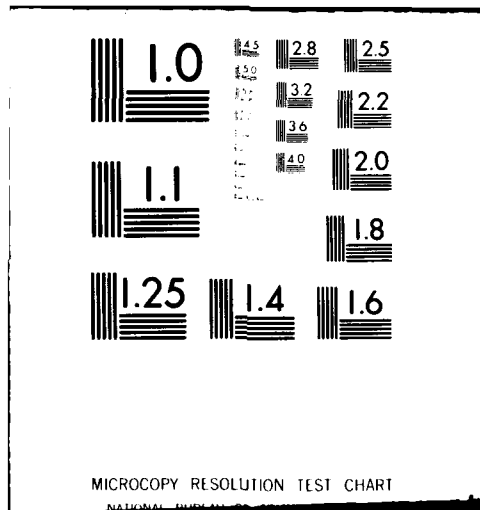
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THE CAUSES OF DEFECTS IN SEMICONDUCTOR DEVICES SEALED IN PLASTI--ETC(U)
NOV 80 J NOWACKI, K SZYSZEJ
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SEALED IN PLASTIC

by

Janusz Nowacki, Katarzyna Szyszej

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THE CAUSES OF DEFECTS IN SEMICONDUCTOR DEVICES SEALED
IN PLASTIC

Janusz Nowacki, Katarzyna Szyszej

Semiconductor devices should operate without failures and in any environment. It is known from practice, however, that a considerable percentage of products have defects or fail within a short period of time. The defects in devices such as diodes, transistors or integrated circuits may be caused by a number of factors. Among the types of damage seen in devices which are encapsulated in plastic materials one can differentiate damages common to devices encased by various materials, independent of the type of housing and damages characteristic solely of devices encapsulated in plastics. Semiconductor devices are very sensitive to many effects, and a defect in a device results from a change in any electrical characteristic going beyond the norm of its initially design.

Basic defects occur most often under the influence of such factors as impurities, various mechanical effects, or humidity, and are generated primarily in the course of production. The effect of impurities in reducing the reliability of integrated circuits has been studied in detail by D. Graft [1]. The impurities may be introduced at any stage of production: with air, water, chemicals etc. These impurities may be particulate (hair, fibers, metal filings, dust, etc), organic (oils and other organic matter), and ionic impurities. They always lower the efficiency of production.

The possibility of mechanical damage is also rather high, particularly because of the fragility of silicon and germanium plates which are used most often to produce semiconductor elements. They are very sensitive to shock of any kind, to pressure or contact, especially with rough and hard objects.

Excessive humidity is harmful not only when acting on the unshielded element (direct action during production) but

it may also damage devices encased in certain types of plastic, and may also cause corrosion of metal substrate.

A plastic housing that is improperly produced may cause various defects which will affect profoundly the operation of the device. This problem is very important because a well-functioning semiconductor device will cease to operate or will be damaged by an improper housing. Studies of this kind were done by J. Brauer, V. Kapfer and A. Tamburrino [2].

Electronic devices encapsulated in plastic may undergo damage consisting of:

1. external leakage currents,
2. external and internal corrosion of metal substrate,
3. internal electromechanical effects,
4. thermomechanical effects,
5. mechanical defects.

We will discuss more extensively these defects in order to illustrate their causes.

External leakage currents.

In the case of plastic housings a considerable percentage of the defects is generated because of humidity penetrating the layer of material sealing the device airtight [3], and because of the effects of various expansion coefficients of the materials next to each other [4].

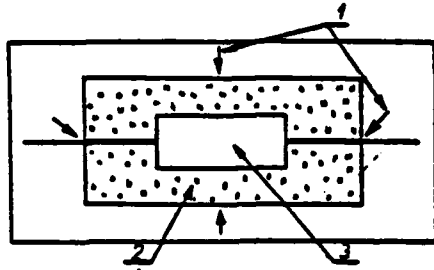


Fig. 1. Penetration of humidity through the housing and along the outgoing leads: 1-humidity, 2-plastic, 3-semiconductor element.

The penetration of humidity may be approximately defined by the equation:

$$P = (D \cdot C) / L$$

where:

- D - diffusion coefficient at given temperature,
- C - absorption of water under the conditions in question,
- L - thickness of sample.

Humidity may penetrate along the connections which protrude from or go directly through the material. This is illustrated schematically in Fig. 1.

The external leakage currents are generated as a result of corrosion of the metal substrate and humidification of the housing. The mechanism of these effects is probably related to the fact that the material of which the housing is made becomes more hydrophilic and its conductivity increases, which causes the appearance of large leakage currents.

If the material of the housing is connected too rigidly with the leads, then microscopic cracks may appear on the housing surface which allow the penetration of humidity and help to generate leakage currents [5]. Cracks on the sur-

face of the housing may also appear when the leads are bent.

Water may also be adsorbed or condensed in hydrophilic surfaces between metallization. In this case there may also appear leakage currents, and at the same time foci of corrosion may be started.

Corrosion of the metal substrate

Corrosion of the metal substrate occurs most often when ionic impurities are present, which are carried by various substances, e.g. water [6]. Ionic impurities (ions of sodium, chlorine, copper, magnesium, ferric, manganese, lead, silicon, gallium, etc) which may originate from a sealing material such as resin, filler and other additives, cause reactions at the metal surface and at the same time change the electrical parameters of the device dramatically - depending on the relative content and the type of impurities. These reactions may be of the following types:

$Me = Me^{n+} + ne$ - dissolving and precipitation of metal, or

$Me + nOH^- \rightarrow Me(OH)_n + ne$

$mMe(OH)_n \rightarrow Me_m O_n + mn/2 H_2O -$

- generation of insoluble precipitates of hydroxide or oxide of the metal.

Frequently a "porous" type of corrosion is observed, which is characterized by corroding and even breaking of the connections of the package.

When the metal substrate is covered with gold, porous corrosion may also appear. During cyclic studies of resis-

tance to humidity at elevated temperature it is very important to have an appropriate quality of the gold surface because too thin a gold layer is not the main factor in corrosion. In the case of leads out of the device, sometimes even gold does not prevent corrosion [7].

At the points of contact between the housing and metal substrate (the lead), the small cracks present sometimes in the housing can cause bridge defects. However, this is more important in the case of ceramic housings rather than for plastic housings since the metal substrate is often not covered by a layer of gold up to the point of the "real" connection, which causes corrosion at the connection of metal substrate tracery with the ceramic.

Internal electrochemical effects.

A very frequent cause of internal electrochemical effects at the surface is the corrosion of the internal metallization, which may appear.

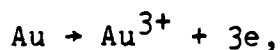
1. in the metal plating applied onto the semiconductor element itself,
2. on internal wires, beam leads, or metal substrate.

It is known that penetration of humidity favors electrochemical corrosion. One of the more important internal defects is corrosion of aluminum which causes electrochemical degradation of the device. The humidity penetrating into sealed devices contains and transports ions. Thus ionic impurities may originate outside and, as has been mentioned, may also originate from the material used for airtight sealing. Therefore, this weak electrolyte solution may carry

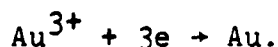
ionic current sufficient for the generation of electromechanical effects. These effects may occur with and without a current load. The most typical defects related to this are the opening and closing of the circuit.

The defect of open circuit appears in the case of aluminum (always in the area of anode) and other metals which give an isolating product in their reaction with water. A thin layer (20 to 100 Å) of aluminum oxide Al_2O_3 , which is generated at the metal surface, should protect it against the action of water. However, the presence in water of small amounts of chlorine, ammonium, copper, iron, etc. ions increases the rate of activation of the oxide layer and accelerates the reaction of aluminum with water. This reaction occurs, at a correspondingly lower rate, even in the absence of external voltage. Initially, it occurs at isolated points, but it may lead to corrosion of the entire metal. At first the product of the reaction is a non-conducting gel of the aluminum hydroxide precipitate $Al(OH)_3$, followed by aluminum oxide Al_2O_3 which leads to the opening of the circuit (Fig. 2).

In the case of gold plating there may occur a defect of circuit closing. This is the result of electrolytic precipitation on the anode of the ion from cathode. Dissolving of the cathode takes place according to the reaction:



and the deposition of gold on the anode is the opposite reaction:



The chlorine ion present in solution is especially harmful to gold plating because a water-soluble chloride $AuCl_3$ is pro-

duced (Fig. 3).

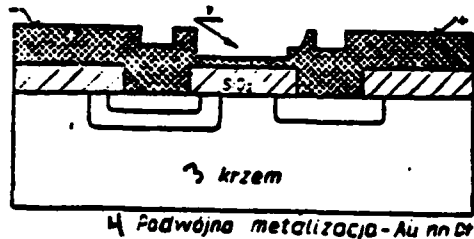


Fig. 2. Defect of opening of circuit: 1-circuit opening, 2-isolation resulting from the generation of isolating products. 3-silicon, 4-double metal plating - Au on Pt.

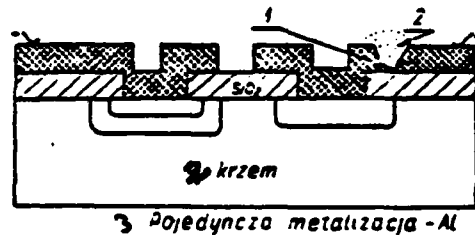


Fig. 3. Defect of closing of circuit: 1-displacement of the current path on the surface of oxide, 2-silicon, 3-single metal plating - Al.

The defects caused by electrocorrosion mentioned above are related to a similar defect which consists in the appearance of displaced path of breakdown. This is caused by the presence of high-resistance bridges at a point where the circuit can be shorted and (gold) ions may be deposited, leading to displacement of the breakdown path.

We should also note the possibility of the appearance of one of many intermetallic Au-Al compounds, [Au-Al] namely $AuAl_2$, which is characterized by considerable fragility. In electronic devices this compound is generated under the influence of the catalytic action of silicon at elevated temperature at points of contact between aluminum and gold. A defect of this type is very troublesome - it causes breaks and disappearance of connections. It is known among electronic engineers under the name of "purple plague".

R. Olberg [8] has studied the behavior of hermetically sealed electronic devices under current load in various conditions. He found that at high-temperature current load there may be losses which are probably caused by migration of polar groups, present in some plastics, to the surface of

the device and the orientation of polarizable groups in the electrical field. After the electrical field is removed, a partial thermal dispersion of polar groups takes place. In the case of ionic impurities, especially ions of alkaloid metals, these losses are irreversible. This causes a dramatic degradation of electrical parameters of the semiconductor device and is related directly to the internal surface effects.

Thermomechanical effects.

Thermomechanical effects in devices with plastic housings may occur in an environment free of humidity, or the so-called mild environment. Namely, there may be breaking of connections and connecting wires, cutting of connections etc. because of the differences in expansion coefficients of the sealing material and the metal elements of the device (die and connecting wires). These defects occur most often at the connections at the base of metal substrate.

Certain materials may have temperature limitations, since at high temperatures there are irreversible changes, e.g. in silicon systems with gold plating at the temperature of about 375°C there may be diffusion, or eutectic gold-silicon may be formed.

In the course of temperature cycle and thermal shocks thick platings of masking resins may also break, which in turn may cause more intense leakage currents.

According to some authors [2], after tens or hundreds of temperature cycles there may be defects of fatigue type.

The effect of low temperatures on sealing materials, which under these conditions become harder and contract, may also cause breaking of the wire and damage to internal connections. The micro-disruptions generated, depending on the

temperature, sometimes give a break, and at another temperature operate normally.

Mechanical defects.

Mechanical damage is related to the effects partially discussed above. In addition, there may be defects generated as a result of pressure, e.g. during assembly of elements [1], transmission of stresses to the circuit by a coating which generates piezoelectric effects or breaking and cutting of the connections [4].

Very serious damages may be generated when electronic elements are sealed by the method of transfer molding. If molding is improperly conducted, the molding compound may cause immediate defects such as breaking or shorting delicate wire leads.

Some defects are generated with time. Studies of this aspect of electronic devices have been described by C. Lascaro [9]. He has found that, as a result of the action of humidity, the defects may appear after the time shown in the table had elapsed:

Time (days)	Effects
1	surface humidification, vapor condensation
10	absorption of humidity, first effects of corrosion
30	migration, shorts, cracks
60-120	mechanical defects resulting from corrosion

Effect of the sealing material.

A separate problem is the effect of airtight sealing

material on the semiconductor element. Many defects related to plastic housings have been discussed previously (e. g. the effect of the penetration of humidity or ionic impurities). It seems, however, that a more detailed description is indicated.

Most ionic impurities come from contamination of fillers and from degraded materials. Acidic and basic hardeners for resins which can be hardened by heat may cause corrosion of metal parts. The acid anhydrides in use harden epoxy resins after a prolonged period of time, and the remaining acidic groups, which are never completely reacted, create the danger of ionic impurities.

Some materials deteriorate more abruptly as the result of e.g., prolonged action of humidity, and therefore housing made of these materials ensure the reliability of operation of the device for a shorter period of time. Certain molding compounds, after hardening, may transmit their own stresses to the semiconductor element.

Licari and Browning [10] have established the effect of stoichiometry and purity of the components (fillers, accelerators, hardeners), as well as the epoxy resin itself, on the reverse leakage current of microdiodes at elevated temperatures.

As mentioned above, all polar groups present in the material cause a degradation of the electrical parameters of the semiconductor device. In this case, as time goes on, as temperature is raised or under current load, the changes in electrical characteristics are ever greater.

The conditions of the environment in the area of p-n junction are very important. When the surface of the semiconductor crystal becomes contaminated, a reversal of semi-

conductor effects may take place and immediately cause alterations in electrical characteristics.

A reversal of the effects may also occur as a result of ionic impurities of the resin itself. The character of a silicon resin (appropriate ratio of aromatic and aliphatic groups) may also influence the character of those areas of the semiconductor which are surrounded by this resin [11]. A resin which contains more aromatic groups attracts electrons, and thus a surface more resembling the p-type is formed, rather than n - type. A reverse situation is present when the resin contains more aliphatic groups.

The defects discussed in this article, which may occur in semiconductor devices sealed in plastic, do not encompass all possible defects. We should remember, however, that many factors influence the quality and time of correct operation of semiconductor devices, and therefore one should consider all of these factors in the production of housings (especially plastic housings), in order not to eliminate or shorten the time of correct operation of a semiconductor device as a result of improper or defective sealing.

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