Encapsulation Process for Electronic Devices Using Injection Molding Method

TADAMOTO SAKAI

The Japan Steel Works, 1-6 Funakoshi-minami Aki-Ku, Hiroshima, 736 Japan

ABSTRACT

In this article, a new encapsulation injection molding method for electronic devices such as integrated circuits (ICs) is described as a superior technology to the conventional transfer molding process widely used in the electronics industries. The quantitative analysis has been carried out utilizing a computer simulation program covering cavity-filling behavior to analyze the relationship between the deformation of gold wires that are bonded with mounted IC chips and mold geometries, operational conditions, and physical properties of a thermoplastic encapsulant, i.e., polyphenylene sulfide. As a result, a new technology to encapsulate ICs has been established, preventing no practical gold wire deformation or break-up damage. © 1993 John Wiley & Sons, Inc.

Introduction

Plastic packaging for semiconductor products such as integrated circuits (ICs) has been commercially made by means of a transfer molding method using epoxy resin. The epoxy resin is one of the thermoset plastics unable to be reused after being molded. Therefore, it is said that a material utilization ratio is usually 30–50 wt% due to a large amount of unrecyclable runner and sprue parts when the transfer molding process is used. One of the weak points is that this molding process has basic difficulties for the automation and consecutiveness of a manufacturing line.

To solve these issues, the development of a thermoplastic encapsulation process of injection molding has long been required.[1] Melt viscosities of thermoplastic materials, however, are usually much higher than those of thermoset polymers. The high melt viscosity may cause damage or deformation of gold wires that are bonded between an IC tip and a lead frame. Figure 1 shows the characteristics of bonded gold wire break strength for various types in general used for IC tips.[2] These bonded wires are so fine that only a small amount of force may be needed to damage them. Therefore, it has been said that the application of an injection molding process for semiconductor encapsulation would be difficult if not impossible in practice. Recently, some thermoplastic materials able to be used for the encapsulation molding,

Advances in Polymer Technology, Vol. 12, No. 1, 61–71 (1993)

CCC 0730-6679/93/010061-11

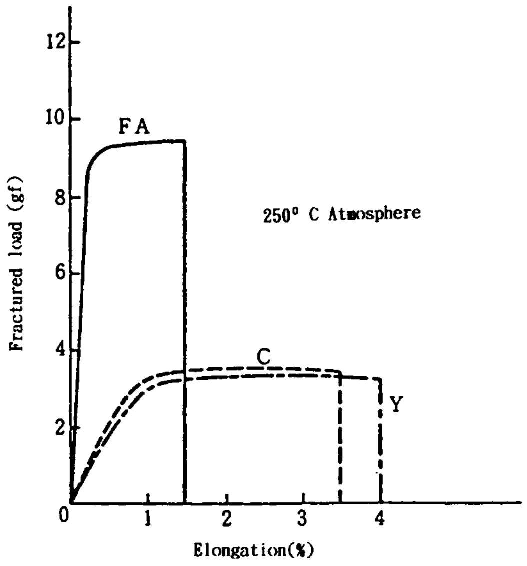

FIGURE 1. The strength of bonded gold wires.

such as polyphenylene sulfide (PPS) and liquid crystalline polymers, have been developed.[3,4]

In this article, the development of a plastics encapsulation process for ICs using PPS as a typical thermoplastic encapsulant with excellent electric properties and high temperature resistance is introduced.

Testing Equipment

A testing injection molding machine used for the encapsulation experiments with the thermoplastic polymer is shown in Figure 2. This experimental apparatus is a vertical-type injection molding machine specially designed for the purpose of encapsulation molding. The machine has a rotary base to change each mold in turn so as to easily insert lead frames and take out molded products.

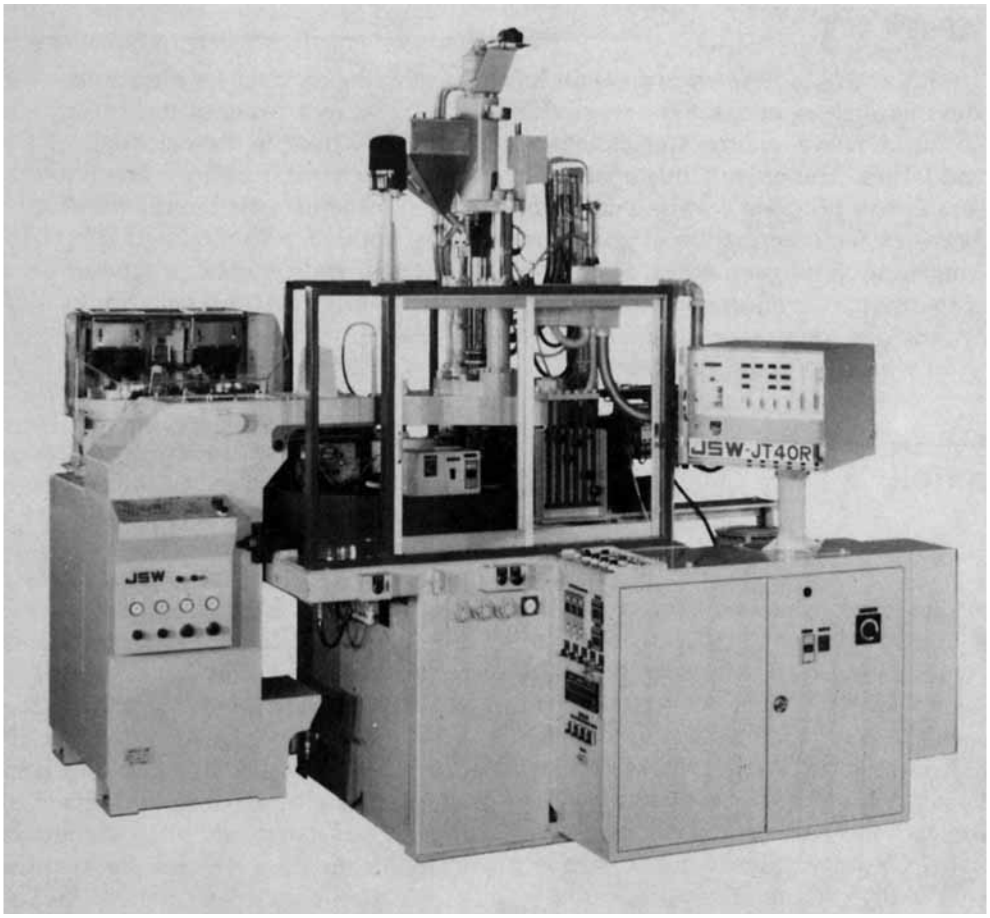

FIGURE 2. JSW encapsulation injection molding machine.

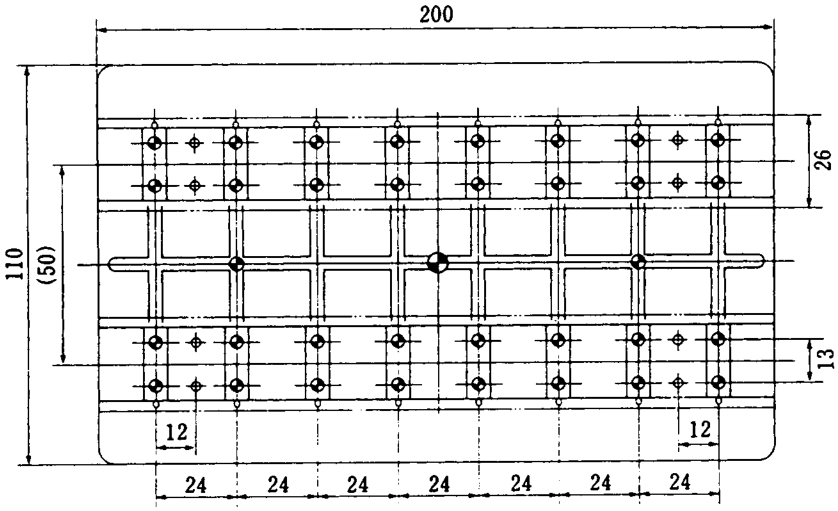

FIGURE 3. Geometry of cold-runner mold with side gates.

To prevent the drooling of molten material with a low melt viscosity at the nozzle, a "shut-off" valve is furnished at the exit of the reservoir of the injection molding unit.

The temperature of the plasticating cylinder can be raised to as high as about 400°C so that injection molding experiments for an encapsulant with a high melting temperature can be carried out. With regard to injection molding pressure, a hydraulic pressure control system with both closed- and open-loop controls has been designed so as to carry out encapsulation experiments under a pressure of less than 10 MPa.

The structure of a cold runner-type mold to be furnished with two lead frames is shown in Figure 3. This shows a side gate-type mold. The total number of cavities is 16 and each cavity pitch is 24 mm.

Testing Material Used in This Study

In addition to the necessity for providing good adhesive properties with lead frames, a plastic encapsulant used for molding has to satisfy physical properties such as thermal expansion coefficient, thermal conductivity, moisture resistance, and electrical characteristics. Further, it is important that the materials have good processability for injection molding.

In this study, we tentatively used PPS with a low melt viscosity (LP-1) developed at Toyo Soda Co. as an encapsulant. The relationship between melt viscosity and polymer temperature of the encapsulant is shown in Figure 4. This material contains inorganic filler such as silica and glass fibers at 60–70 wt%. To avoid the abrasion of molding machine parts, we used a special steel alloy screw and bimetallic cylinder reinforced with iron boride, so-called "N-alloy 80C," with excellent abrasion and corrosion resistances. These have been developed at The Japan Steel Works (JSW) for use in injection molding machines for molding high-performance ceramics powder.[5]

Each lead frame having eight IC chips was used for this study, and each IC chip is bonded with 16 gold wires of about 20 μm diameter.

Experimental Results

PRELIMINARY EXPERIMENTS

Preliminary experiments were carried out using a commercial JSW injection molding machine with a closed-loop controlling system to examine the influence of molding conditions on wire damage and deformation. An example of the gold wire deformation observed by soft X-ray radiography is shown in Figure 5. Through these preliminary tests, all trials ended in failure in obtaining products encapsulated within a commercially allowable

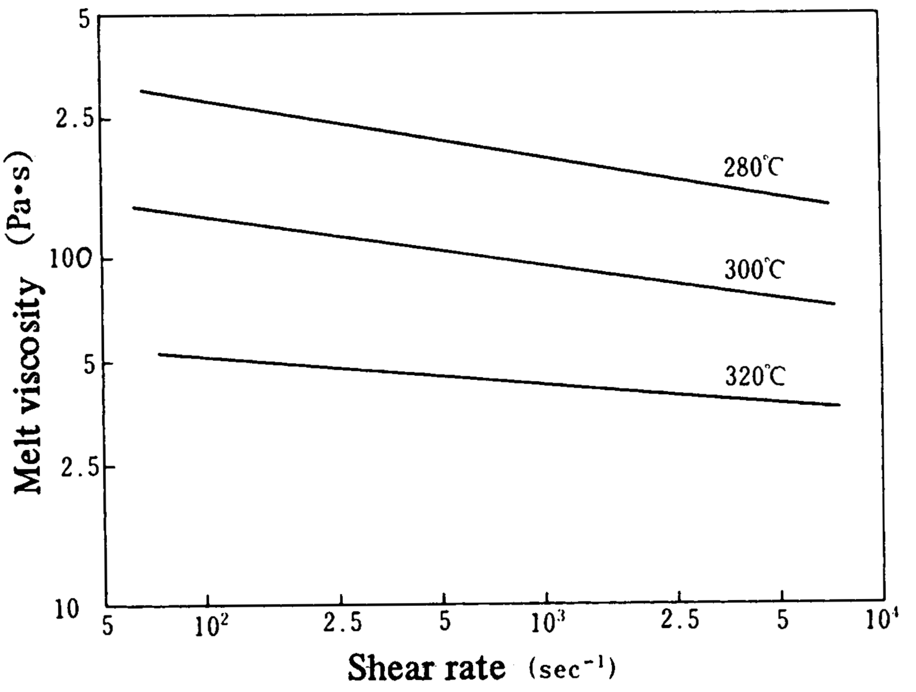

FIGURE 4. Flow characteristics of PPS compound.

deformation because of the occurrence of excessive deformation or break of bonding gold wires.

When mold temperature is raised over the freezing point of PPS, molten PPS can flow into the cavities without solidification. In the first step of this study, we consider that the influence of molten polymer flow on the bonded gold wires can be clearly analyzed under such molding conditions. Figure 6 shows the results of the relationship between the deformation level of the gold wires and the filling pressure when the mold temperature is raised over the freezing point of PPS. This suggests that we may expect to obtain good products, preventing the deformation of bonded gold wires

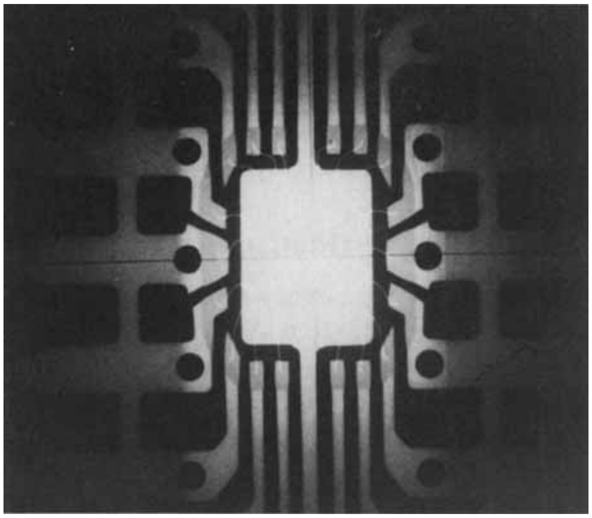

FIGURE 5. Preliminary test for encapsulating.

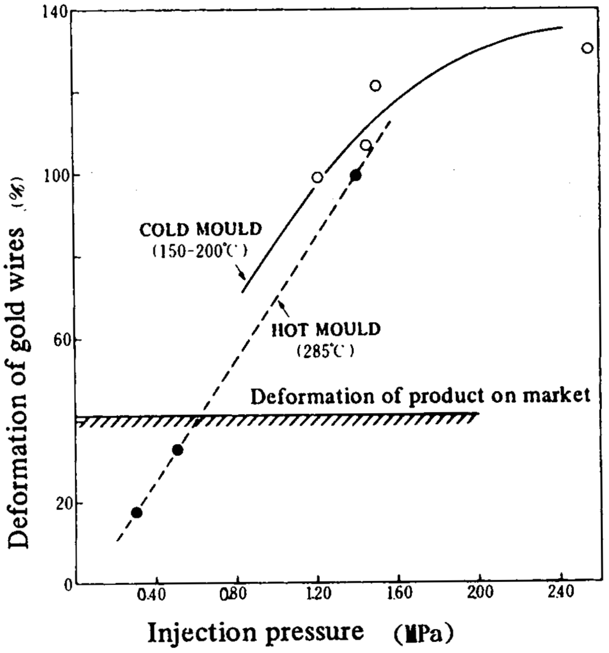

FIGURE 6. Deformation of gold wires and filling pressure (preliminary experiment).

within the same practical level as commercial ICs on the market encapsulated with epoxy resin, if filling conditions can be successfully controlled within a certain range.

ANALYSIS OF MOLTEN POLYMER FLOW

To analyze the relationship between the degree of gold wire deformation/damage and the optimum encapsulation conditions including physical properties of the encapsulant, mold geometries, and operational parameters, we tried to apply a quantitative analysis for molten polymer filling behavior in the cavities using a mold-filling simulation program commercially available such as Mold Flow™.[6]

First, in carrying out the encapsulation molding under the side gate system the flow behavior in the cavity was observed using the so-called "short shot" method. The result is shown in Figure 7. From this observation, it was found that molten polymer flows in the cavity just the same as an ordinary well-known fountain flows along both sides of the lead frame. Second, we carried out verification tests to compare the experimental and theoretical calculation using Mold Flow™. The results are shown in Figure 8, where dotted lines represent theoretically calculated values, while solid lines represent actually measured ones and hatching marks show the solidification time, the so-called "gate sealing." It can be seen that the theoretically calculated values show considerably good agreement with the experiments concerning both the filling pressure and solidification time.

Figures 7 and 8 suggest that the filling behavior in the encapsulation cavities can be satisfactorily analyzed by using a commercial computer simulation method, i.e., Mold Flow™.

ENCAPSULATION MOLDING USING A COLD-RUNNER SYSTEM WITH SIDE GATES

Because there were some difficulties in obtaining a large number of lead frames already bonded from IC manufacturers, the quantitative evaluation was carried out under injection molding conditions using Mold Flow™. The experimental results were analyzed for experimental deformation of bonded wires and compared with the theoretical cavity-filling behavior.

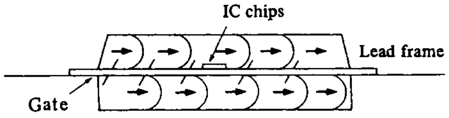

FIGURE 7. Flow of molten polymer in the cavity.

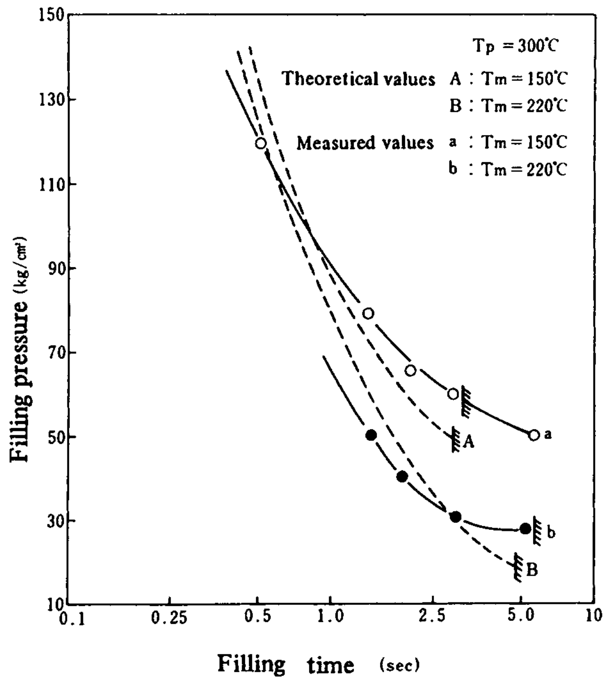

FIGURE 8. Comparison between theoretically calculated values and measured values.

Figure 9 shows the relationship between the de-

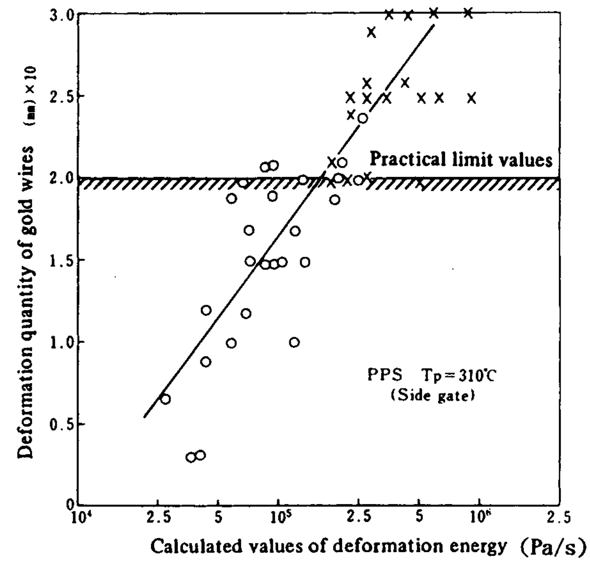

FIGURE 9. Relationship between deformation of gold wires and deformation energy.

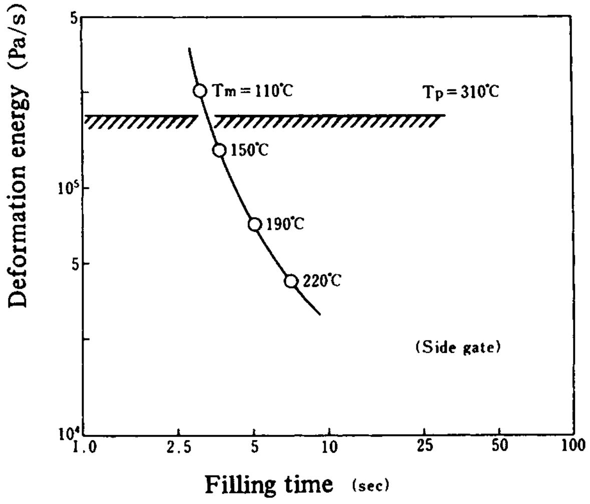

FIGURE 10. Theoretical estimation of injection molding condition.

gree of wire deformation experimentally measured and the filling parameter, which is calculated as the product of the shear stress and shear rate in the cavity using the Mold Flow™ simulation method. The degree of wire deformation and break-down was observed using soft X-ray radiography. The hatched line in Figure 9 represents the deformation limit of gold wires allowable in practical use. If the deformation exceeds the level of this line, an IC product encapsulated should be rejected. As a result, it was found that the filling parameter (defined as deformation energy herein) is closely related to the measured deformation of the gold wires. The deformation energy of molten polymer in the cavity is the function of polymer temperature, mold temperature, mold geometries, and various encapsulant material properties such as melt viscosity and thermal conductivity.

Figure 10 shows an example of theoretically estimated conditions for obtaining practically encapsulated products with the deformation of gold wires below the allowable level. It can be readily seen from Figure 10 that a mold temperature must be set in the range of 150–220°C to cause wire deformation within the tolerable limits, when a molten polymer temperature is selected at 310°C.

We carried out the injection molding experiments for IC encapsulation molding. In accordance with this calculation, Figure 11 shows the experimental results using the 16-cavity side gate cold-runner system. Consequently, it was confirmed that the products obtained from the experiments had no excessive deformation on bonded wires even if the injection molding method is applied.

On the other hand, the relationship between

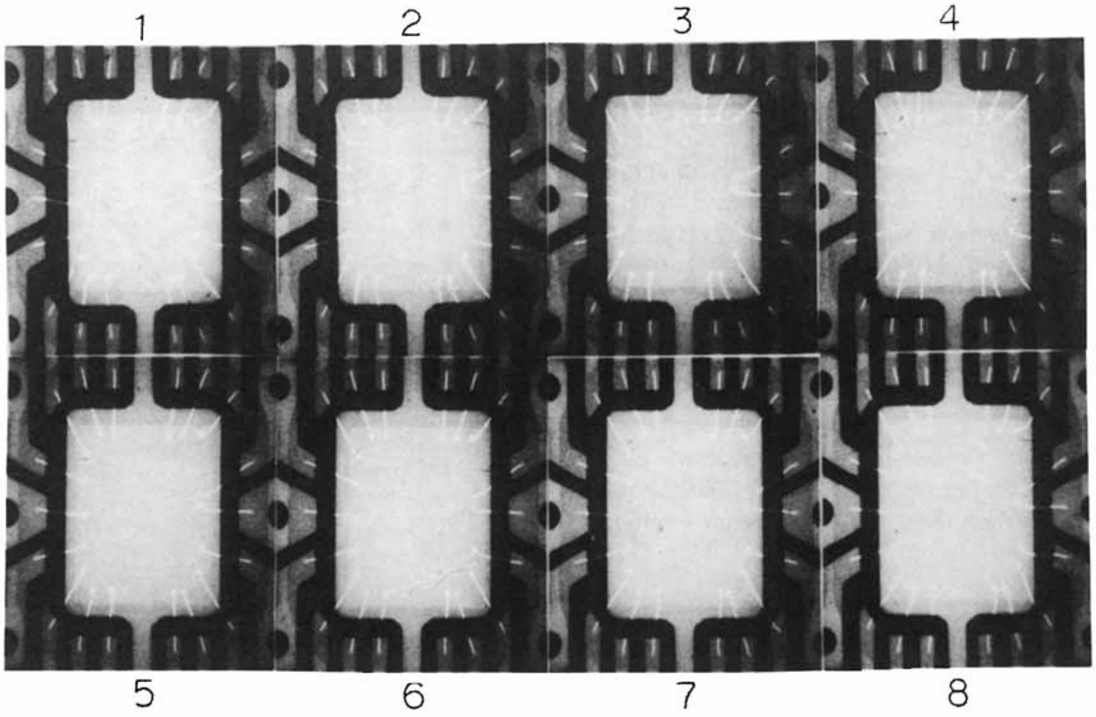

FIGURE 11. Encapsulated ICs by injection molding of cold runner side-gate system.

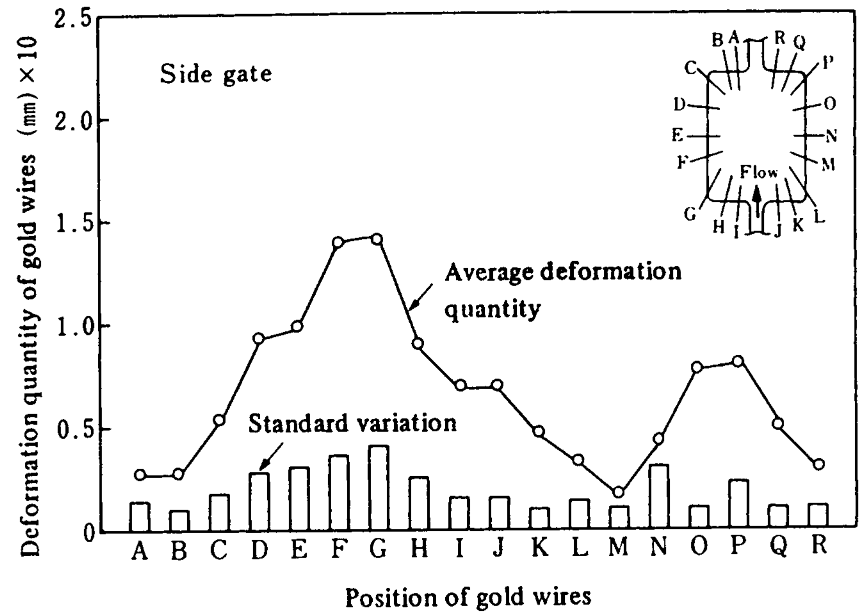

FIGURE 12. Relationship between bonding position of gold wires and deformation quantity.

the position of bonded wires and the deformation degree was also examined. The results are shown in Figure 12. The bonded wires with large deformation values are the wires of F, G and O, P in Figure 12. These are positioned to be slightly deviated from E and N rectangular to the molten polymer flow. This stems from the influence of fountain flows from the other side of the lead frame. However, our attention had to be paid only to the bonding wire positions of F and G, where the greatest deformation amount is obtained.

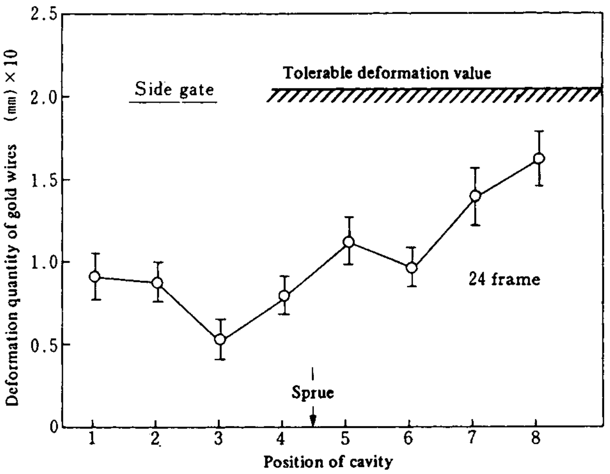

FIGURE 13. Control of gold wires deformation percentage among cavities.

Figure 13 shows the results of the evaluation made on the deformation of gold wires under the same injection molding conditions for a certain running period. Twenty-four lead frames were used in the experiments. The comparison was illustrated with the variance of the maximum deformation values at each cavity. From the result, which can be seen in Figure 13, it was confirmed that the deformation of each wire could be controlled within the tolerable range among each cavity as long as the molding conditions and mold geometries are optimum for the encapsulation. Figure 14 shows an example of the optimum gate balance for the encapsulation injection molding observed using the short shot method. There exist some differences from the gate balance state of a general injection molding process for common products such as a cassette case.

ENCAPSULATION MOLDING OF ICs USING A COLD RUNNER SYSTEM WITH A CENTER GATE

When a side gate system is used, bonded wires are deformed by the molten flow to the bending direction. Molten polymer can be injected into a vertical direction by arranging the gate on the back of the IC chip. This means that with the center gate the wire deformation to the bending (flowing) direction can be prevented.

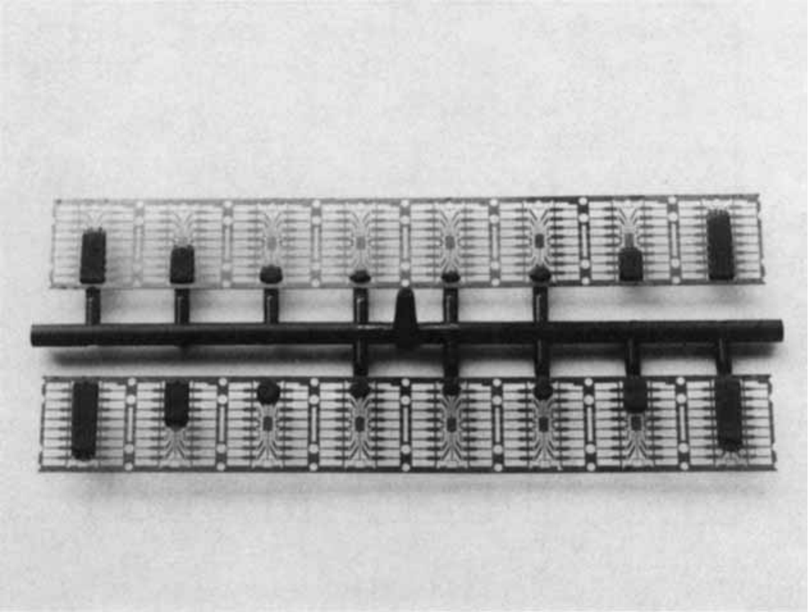

FIGURE 14. Optimum gate balance for encapsulation molding.

Using a pigmented tracer into the transparent polymer, polymethyl pentene-1, we visualized and observed the filling flow behavior of the center gate mold. The results are shown in Figures 15 and 16. It can be clearly seen that the cavity is filled with radial expansional flow from the center gate and bonded gold wires are pulled into a vertical direction by the molten polymer flow gushing from the opposite side of the lead frame. For this reason, if the pulling force in the tensile direction generated by the molten polymer flow becomes excessively large it will cause a break of 20-μm gold wires bonded between the lead frame and IC chip. Figure 17 shows the experimental result of an excessive injection molding force. Some bonded wires have been broken down at the bonding posi-

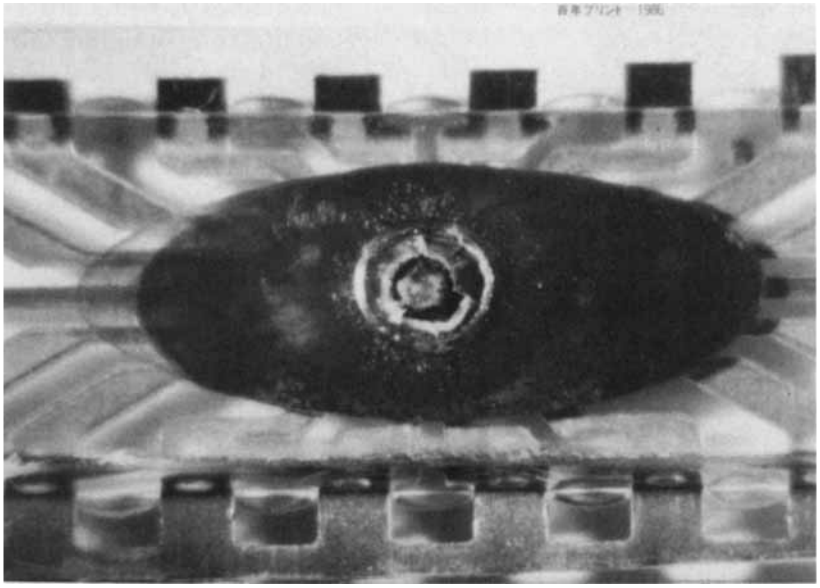

FIGURE 15. Molten polymer flow in the center gate cavity.

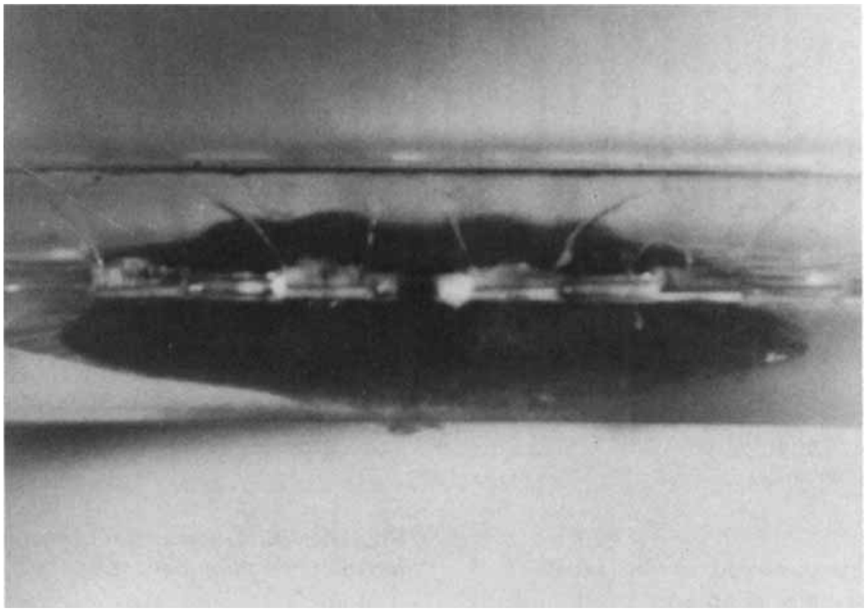

FIGURE 16. Molten polymer flow in the center gate cavity.

tion as can be observed using soft X-ray radiography.

As described in the previous section, theoretical calculation was carried out to quantitatively predict the filling behavior of the center gate mold system. Figure 18 shows the relationship between shear stresses in the cavity and the subsequent wire breaking. In Figure 18, x represents the breaking of bonded wires. As a result, it was found that there exists a close relationship between the shear stress in the cavity and the breaking problem. From these experiments, we can conclude that good encapsulation will be carried out if the shear stress is designed below the level of the hatched line by optimizing the mold geometries, injection molding conditions, and material properties, etc.

Thus, using the center gate system optimized as described encapsulation molding experiments on ICs were carried out within the range of the theoretically estimated injection molding condition.

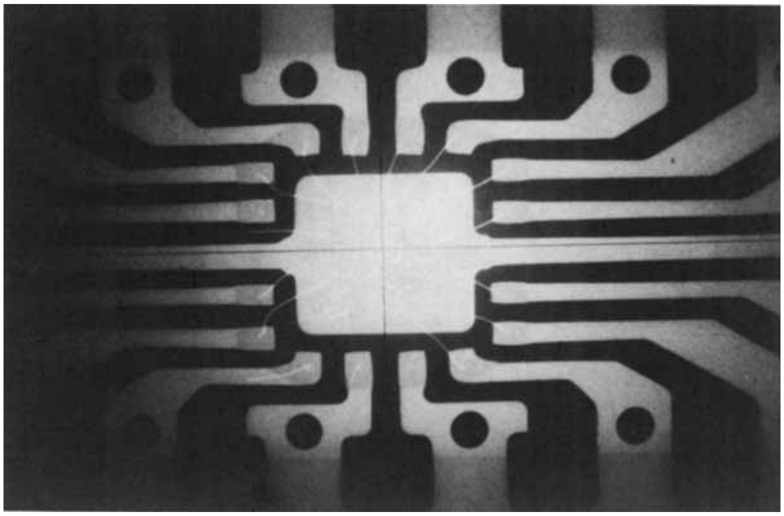

FIGURE 17. Injection molding with center gate mold.

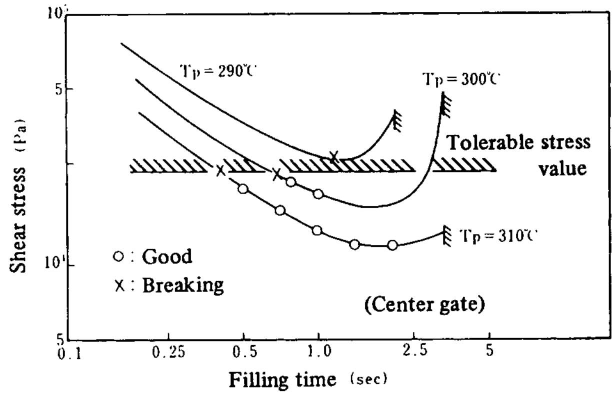

FIGURE 18. Relationship between breaking of gold wires and shear stresses.

The results can be observed in Figure 19. It is clearly shown that there is no wire break and the deformation of gold wires is acceptable.

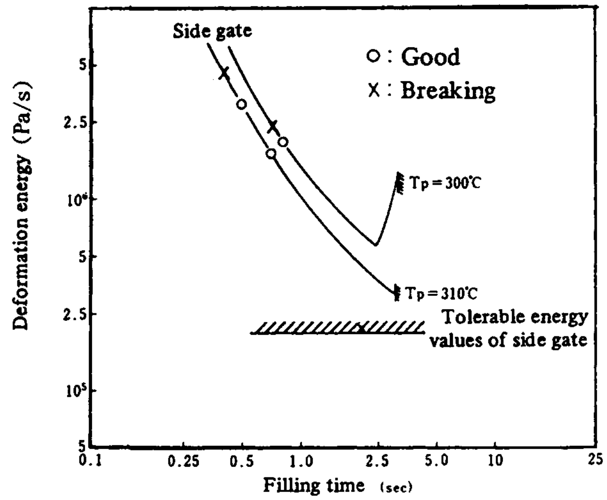

FIGURE 20. Comparison of range in injection molding condition between center gate and side gate mold.

When the side gate system is compared with the center gate one, it was expected that the deformation resulting from bending of gold wires at the side gate would occur easier than the breaking from the tensile direction at the center gate. Figure 20 shows the theoretical calculation of the filling flow energy in the case of the center gate system. If the side gate system is used for the encapsulation, the tests should be carried out within the deformation energy shown by the hatched line in Figure 20. However, in the case of the center gate mold the wire deformation to the bending direction is not great even if the encapsulation is carried out under as high as 10 times the deformation flow energy as that of the side gate system. Therefore, as far as the deformation flow to the bending direction is concerned the center gate system can provide wider controlling range in injection molding conditions. This means that the center gate system

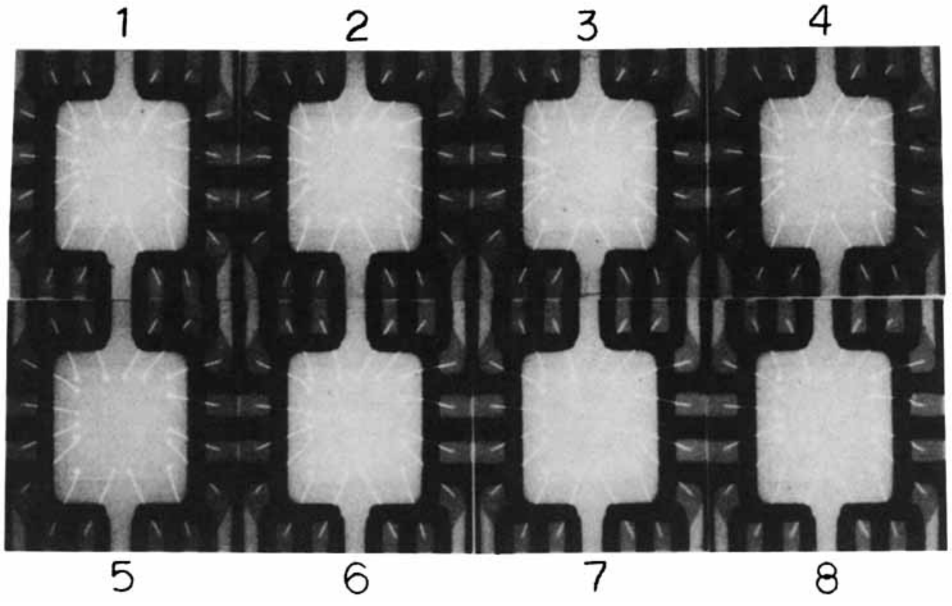

FIGURE 19. Encapsulated products obtained by the center-gate mold (long gold wire).

is advantageous over the side gate except for the remaining gate mark on the opposite surface of IC products.

Conclusions

As a method to replace transfer molding, a new resin encapsulation technology with the injection molding method has been established. The results covering the successful development of an injection molding machine for encapsulating electronic parts such as ICs has been described in this article.

The development on a new encapsulant suitable for the injection molding method has been gradually advancing and certain materials have been put on the market as of an encapsulation molding grade.

The automation and continuity of an encapsulation process by using the injection molding method can be easily realized, and therefore cost savings in encapsulation is expected. For this reason, the practical application of this method has just begun to penetrate into the relatively simple electronic parts manufacturing industry. It is anticipated that this injection molding will find its growth in the field of encapsulation for electronic parts, including ICs, in the not too distant future.

References

1. T. Sakai, *Gohsei Jushi*, **31**(8), 7 (1985).
2. M. Hayakawa (Ed.), *Handbook of Semi-Conductor*, Science Forum, 1986, p. 199.
3. T. Sakai, S. Yamamoto, T. Shiroganeya, and A. Kosaki, *Seimitsukogakkai*, **54**(12), 2277 (1988).
4. H. Sakai, M. Adachi, and K. Suzuki, *Seikeikakou*, **2**(3), 220 (1990).
5. T. Sakai, *Adv. Polym. Tech.*, **11**, 53 (1992).
6. Mold Flow™ Simulation Program, Mold Flow Company, Australia.