Precision Molding of Polymeric Multi-Channel Optical Interconnection Devices Considering the Coefficient of Thermal Expansion of the Materials

Seung-Ho Ahn, Sang-Pil Han, Choon-Gi Choi, and Myung-Yung Jeong

ABSTRACT—*Polymeric multi-channel optical interconnection devices that are usually fabricated by transfer molding are indispensable for parallel interconnection in high speed, high capacity optical communication systems. This paper proposes a design technique considering the thermal behavior of materials, such as shrinkage and expansion during the molding process, to satisfy geometrical requirements that have less than 1 μm tolerance. We also designed molds considering the thermal effects of the materials and fabricated multi-channel optical fiber connectors that have less than 1 μm tolerance.*

I. Introduction

Polymeric optical multi-fiber connectors are typical components for parallel optical interconnection in high speed, high capacity optical communication systems [1]. Generally, these connectors are fabricated by a transfer molding technique, such as that used for semiconductor IC packaging, using an epoxy molding compound (EMC) [3]-[5]. EMC transfer molding processes that are used in fabrication of optical interconnecting devices have several merits, such as precision molding, mass production, and low cost. However, there are some problems to be considered in mold design: shrinkage of the EMC and expansion of the mold materials. Typically, molded products are ejected from the mold at 175 °C and cooled down at room temperature, where the molded parts shrink to a degree determined by the coefficient of thermal expansion (CTE). Therefore, the CTEs of the materials have had to be considered and the molds designed slightly larger than the required dimensions of the fabricated products. Multi-fiber connectors require fabrication tolerances of less than 1 μm to satisfy an optical loss requirement of about 0.3 dB in a single mode application. However, there are several difficulties in making the required shape because of thermal behavior, like shrinkage and the expansion of materials.

Our study investigated the effects of the thermal properties of both the mold materials and the EMC by thermomechanical analysis (TMA). In addition, we propose a design method for molds considering the characteristics of the materials and present the results of our fabricated multi-fiber connectors.

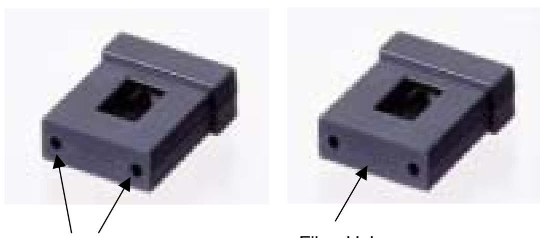

Fig. 1. The shapes of multi-fiber connectors (8-channel on the left, 12-channel on the right).

II. CTE Analysis and Mold Design

For precision polymeric molding, the CTEs of the EMC and mold materials are required in order to calculate the extent of shrinkage or expansion during the process. From the

Manuscript received Dec. 16, 2002; revised May 20, 2003.

Seung-Ho Ahn (phone: +82 42 860 4840, email: shahn@etri.re.kr), Sang-Pil Han (email: sphan@etri.re.kr), Choon-Gi Choi (email: cgchoi@etri.re.kr), and Myung-Yung Jeong (email: myjeong@etri.re.kr) are with Basic Research Laboratory, ETRI, Daejeon, Korea.

calculation, the final dimensions of the fabricated products can be anticipated. In this study, we designed molds to make precision products based on these calculations.

The deformation equation for calculating dimension changes (ε) as a function of temperature is as follows.

$$\varepsilon = \alpha \cdot \Delta T = \frac{\Delta L}{L}, \quad (1)$$

$$\alpha = \begin{cases} \alpha = \alpha_1, & \text{if } T \le T_g \quad (2) \\ \alpha = \dfrac{\alpha_1 (T_g - T_0) + \alpha_2 (T - T_g)}{(T - T_0)}, & \text{if } T \le T_g, \quad (3) \end{cases}$$

where α_1 and α_2 are the CTEs below T_g and over T_g; and T_g, T_0, ΔT, L, ΔL are the glass transition temperature, applied temperature, difference of temperature, length of the specimen, and dimension change of L, respectively.

As a polymeric material for molding, we used an epoxy-molding compound with good dimensional stability, moldability, elasticity, and strength. Generally, as the silica content of the EMC increases, the CTE, thermal shrinkage, and moisture absorption decrease while the elastic modulus, thermal conductivity, and viscosity increase. The CTE of the EMC also abruptly increases when the temperature exceeds the T_g, which is contrary to the typical T_g [2]-[5].

For the analysis, an EMC with a silica content of 89 wt% was used. This EMC had a CTE of 9 ppm/°C and an elastic modulus of 2500 GPa (KCC, 5950GX[TM]). Table 1 shows the changes in the CTE as the EMC is heated over T_g as determined by TMA. Over T_g, the CTE of the EMC drastically increased to 35 ppm/°C.

Table 1. CTE characteristics of the EMC (5950GX™).

	Below T_g (α_1)	T_g	Over T_g (α_2)
Silica 89%	9 ±3 ppm/℃	115 ±10℃	35 ±10 ppm/℃

We made these CTE measurements in order to understand the extent of shrinkage during the molding process. Temperature ranges for the measurement were from room temperature (25 °C) to the molding temperature (175 °C). Figure 2 gives the normalized results of the dimension changes of the EMC specimen as a function of temperature. Also illustrated in Fig. 2 is the abrupt change in elongation at T_g (115 °C).

The dimensions of molds will also increase because of the thermal expansion of materials at the molding temperature. We used a carbide alloy with a CTE of 5 ppm/°C as a mold material. Figure 3 shows the two normalized elongations of the carbide

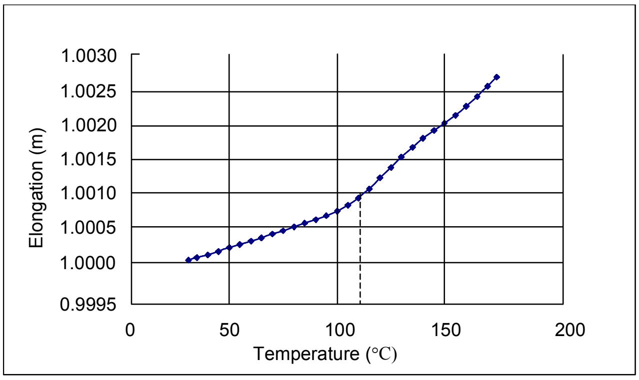

Fig. 2. Elongation of the EMC as a function of temperature.

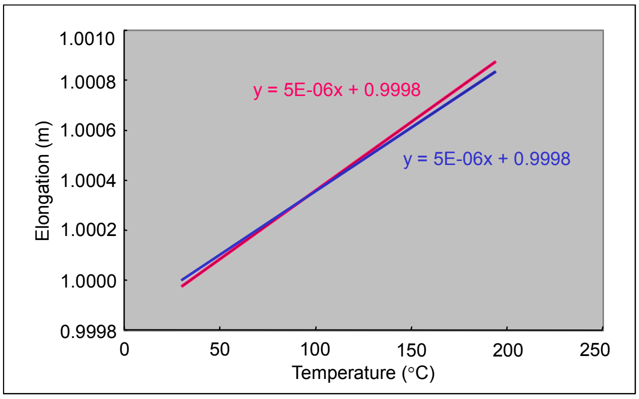

Fig. 3. Elongation of the carbide alloy as a function of temperature.

alloy as a function of temperature measured by TMA. The elongation is almost linear and different from the EMC.

The discrepancy in the CTEs between the EMC and carbide alloy need to be considered for the mold design. To apply the measured CTEs of the materials for the mold design, the non-linear changes and differences in the CTEs between the two materials need to be considered. Because the EMC had a non-linear CTE and greater thermal shrinkage than the carbide alloy, the CTE of the EMC was recalculated by linearly connecting the value from room temperature to the molding temperature. From the recalculated CTE of the EMC, we calculated the extent of shrinkage of the EMC after the molding process. The extent of expansion of the carbide alloy could also be calculated from the measured CTE. We then applied the shrinkage and expansion of the materials to the mold design. Consequently, the molds were made slightly larger than the required dimensions of the multi-fiber connector in consideration of the thermal influences. The design procedures for the pitch of the guide holes are as follows.

(i) Modified CTE of the EMC from (3):
(9 ppm/°C×90 °C+35 ppm/°C×60 °C)/150 °C =19.4 ppm/°C

(ii) Expansion of the carbide alloy:
5 ppm/°C×150 °C×4.6 mm=0.00345 mm
(iii) Shrinkage of the EMC:
19.4 ppm/°C×150 °C×4.6 mm=0.013386 mm
(iv) Calculated pitch of guide holes (4.6 mm–(i)+(ii)):
4.6 mm–0.00345 mm+0.013386 mm≒4.610 mm.

From the above procedures, the pitches of the fiber hole and guide holes of the molds were designed to be 250.56 μm and 4.610 mm, respectively, while the required pitches of the fiber holes and guide holes of the fabricated multi-fiber connector were 250 μm and 4.6 mm, respectively.

III. Fabrication Results

For the fabrication of multi-fiber connectors, hole-type molds were designed for maintaining the precise pitches of the fiber holes. During the molding process, micro pins were inserted into the micro holes of the mold and the pitches of the pins were maintained by these holes. For precision molding, micro hole-type molds with a pitch tolerance of 0.5 μm were machined. Hole-type molds have several merits, such as uniform pitches and small Y-displacements, compared with V-groove type molds.

Generally, transfer-molding processes consist of preheating, insertion, pressure loading, curing, and demolding (part ejection). Molding conditions were a curing temperature of 175 °C, curing time of 2 minutes, and transfer pressure of 250 psi.

After the fabrication, we measured the geometrical dimensions of the multi-fiber connectors with a non-contact 3D measurement system and compared the results to the design value. The average pitch of the fiber holes of the 8-fiber connectors was 249.78 μm. For the 12-fiber connectors, the average pitch and average Y-axis displacement of the fiber holes were 249.84 μm (Fig. 4) and 0.46 μm (Fig. 5), respectively, and the average pitch of the guide holes was 4.59969 mm. From these results, we obtained good fabrication dimensions with a tolerance of less than 1 μm.

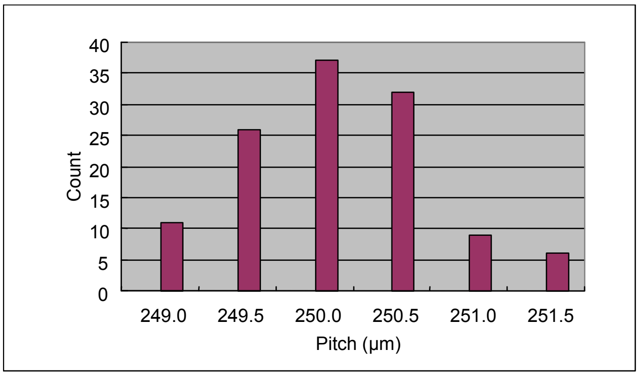

Fig. 4. The Pitch of fiber holes (12 channels).

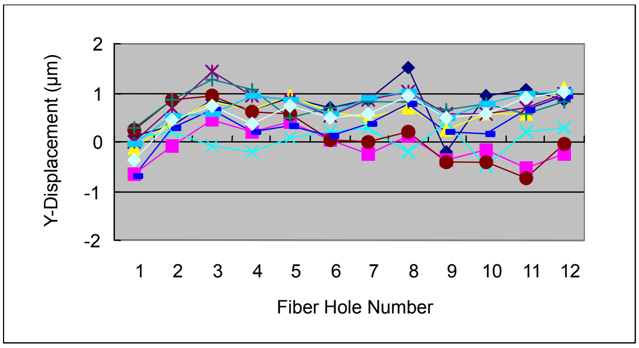

Fig. 5. Y-Displacements of fiber holes (12 channels).

IV. Conclusions

Polymeric multi-fiber connectors are typical components for parallel optical interconnection in high speed, high capacity optical communication systems. For the precision fabrication of multi-fiber connectors, the correct mold design is indispensable. Mold dimensions need to be changed according to the materials because of the different thermal behavior of materials. If the physical properties of the materials are known, parts can be fabricated to the required shapes precisely by applying the characteristics of the material to the mold design.

For a precision mold design, we measured as a function of temperature the CTEs of a carbide alloy and an EMC. The CTE of the carbide alloy was 5 ppm/°C. With the EMC, the measured CTE abruptly changed from 9 ppm/°C to 35 ppm/°C at T> T_g. Typically, the cited CTE of an epoxy molding compound is below T_g. The CTE was recalculated by linearly connecting the room temperature value to the value at the curing temperature and applying it to the mold design directly. Multi-fiber connectors were fabricated and measured. We obtained excellent dimensions with a tolerance of less than 1 μm. These results are applicable to the fabrication of multi-fiber optical interconnecting devices, various optical waveguide components, and packaging that requires sub-micron accuracy.

References

[1] S.H. Ahn, S.P. Han, C.K. Choi, M.Y. Jeong, and T.G. Choy, "8-channel Polymeric Optical Fiber Arrays for PLC Devices Packaging," *Proc. of OECC*, 2001, pp. 451-452.

[2] D.K. Shin and J.J. Lee, "Effective Material Properties and Thermal Stress Analysis of Epoxy Molding Compound in Electronic Packaging," *IEEE Trans. on CPMT*, vol. 21. no. 4, Nov. 1998, pp. 413-421.

[3] L.P. Rector, S. Gong, and K. Gaffney, "On the Performance of

Epoxy Molding Compounds for Flip Chip Transfer Molding Encapsulation," *Proc. of the 51st IEEE Electronic Components & Technology Conf.* 2001.
[4] M.M. Konarski, "Effects of Tg and CTE on Semiconductor Encapsulants," *Loctite Technical Paper*, 2000.
[5] S. Chew, "Thermal and Viscoelastic Characterization of Transfer-Molded Epoxy Encapsulant During Simulated Post-Mold Cure," *Proc. of ECTC*, 1996, pp. 1032-1038.