IMPROVEMENT OF MATERIAL PROPERTIES OF PRINTABLE ADHESIVE

Jae-Hoon Kim*, Joon-mo Seo*, Young-Ju Kang and Byoung-Un Kang***

*Electronic component R&D center, LS cable Ltd.
** Triz engineer, LS cable Ltd.

Abstract

In order to print uniform pastes on PCB without clogging, bubble and bleeding-out problems, TRIZ and other field of related studies were applied to simulate the issue and suggest solutions. That is, the defects were analyzed by tools like Root & Cause, Structural Analysis, Knowledge Search, Inventive Principle, Patent Search and Technical & Scientific Effect. Thereby, effective solutions were derived for the defects, which were verified through the practical data from several experiments. Finally we could get enhanced ways to reduce the defects (approximately 0%), followed by high yield % in mass productions.

Keywords: Paste, Screen printing, MRT, A/B/C-stage, TRIZ, Root & Cause, Structural Analysis, Knowledge Search, Inventive Principle, Patent Search and Technical & Scientific Effect, Chip-attach, Substrate, Semi-conductor, clogging, bleeding-out.

1. Introduction

Film type or paste type adhesives can be used to attach a chip onto PCB in semiconductor packaging processes. And, paste type adhesives have been replacing film type adhesives because they cost less. There are two types of the paste according to curing steps: One is the dispensing type paste that is converted from A-stage to C-stage. The other is the screen-printing type paste, which LSC has been researched and developed, is converted from A-stage to B-stage, and then to C-stage, consequently. A-stage is a liquid phase and B-stage is partially-cured phase. C-stage is completely cured phase.
The adhesive should have an appropriate shape in order to have a good semiconductor packages because the inappropriate shapes can result in the defects during chip-attaching or wire-bonding, followed by reliability failures.
Therefore, in this paper, it is focused to have the printed shape of screen-printing type paste properly by improving the defects, such as clogging, bleed-out and bubble.

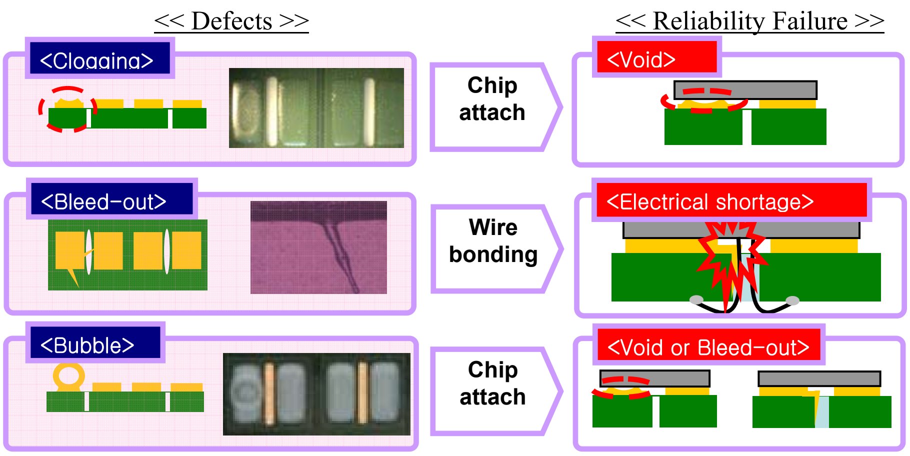
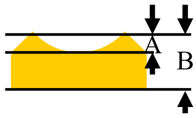


Figure 1. shows defects during printing processes which results in reliability failures

Figure 1 shows the kinds of defect after printing processes, which cause and various problems in the chip attachment or wire-bonding, followed by reliability failures. In other words, the defects are to be improved so that the reliability failure cannot be induced. The following shows the customers' specifications for the defects:

	Processibiliy			**Reliability**
	Clogging	Bleed-out	Bubble	MRT/ Elect. Shortage
Customer Spec.	 (A / B) x 100 ≤ **20%**	None	None	Lv 2a*/ No shortage
LSC's current status	**Over ~25%**	**o**	**o**	**Not Stable**

*The lower the value, the higher the reliability level pastes have (refer to JEDEC standard).

Table 1. Required customers' quality spec. vs. LSC's current status

In order to improve the current status satisfying the customer specs., LS Cable organized TRIZ team to analyze the causes and suggest solutions.

2. *Problem Solving Scheme*

As shown in Figure 2, some causes or factors for the defects are revealed through Analysis and Technical tools. Then, appropriate solutions are suggested, which will be verified by experiments. If the experimental results are good, the solutions will be applied to actual mass production lines. Otherwise, overall analysis process should be repeated from the beginning.

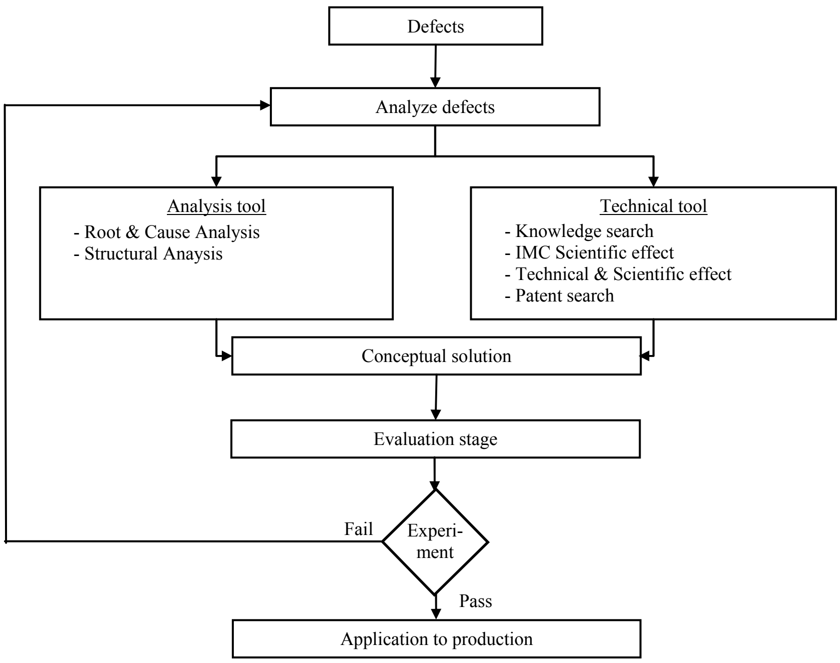


Figure 2. Problem Solving Scheme

3. Problem analysis
3.1 RCA (Root & Cause Analysis)

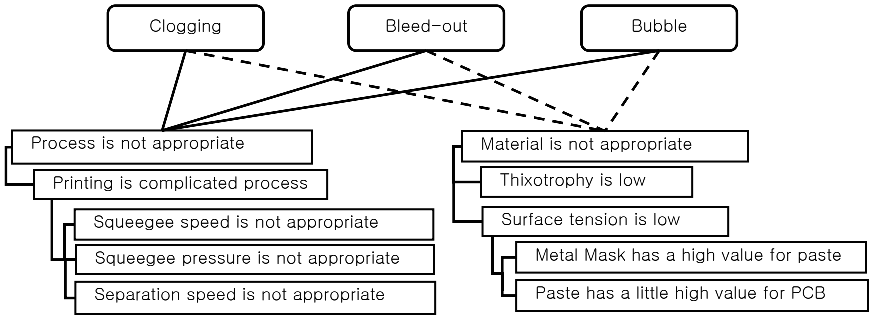


Figure 3. Root & Cause Analysis

It is found that there are several factors for the defects, as shown in Figure 3. Mainly, they are considered in aspect of process and material itself: process factors, such as screen-printing parameters (squeegee speed, squeegee pressure and separation speed) or material factors, such as thixotrophy or surface tension.

3.2 Process view
3.2.1 Structural analysis

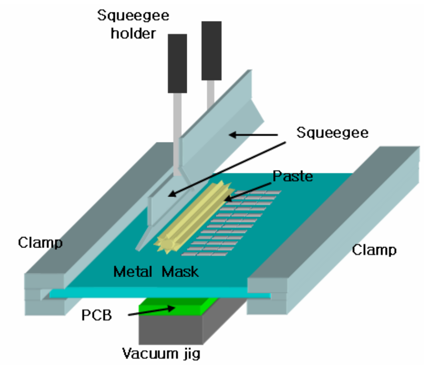


Figure 4. Schematic diagram of printer structure

Figure 4 explains the structure of printer with paste and PCB. Basically, a screen-printing process is composed of 5 main steps. In order to find the key process causing defects, structural analysis for the process was used.

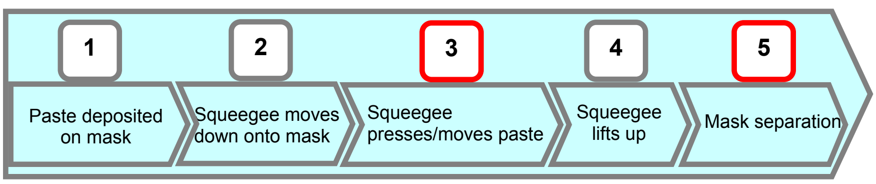


Figure 5. Screen-printing process

The figure 5 shows the main steps of screen-printing process, where the steps 3 & 5 are assumed to generate the defects. Table 2 shows the useful functions and undesirable effects of the processes depending on different operation parameters.

Process step	Function	Undesirable effect
1. Paste deposited on mask	Paste is placed on mask to be printed	None
2. Squeegee moves down onto mask	Squeegee is located onto mask to print paste	None
3. Squeegee presses / moves paste	-Press with appropriate pressure / move at appropriate speed -Deposit paste onto desired area of PCB	- Mask warped if the pressure is too high - Clogging & Bubble generated if the pressure is too low - Paste deposited insufficiently if the speed is too high - Low processibility if the speed is too low - Clogging, bleed-out and bubble generated reciprocally depending on the pressure and speed occasionally.
4. Squeegee lifts up	Give the space where mask can be separated up from paste and PCB	None
5. Mask separation	Separate mask from paste deposited on PCB	- Clogging, bleed-out and bubble generated reciprocally depending on separation speed very often.

Table 2. Useful Function and Undesirable Effect of Process

It is revealed that the process steps 3&5 generate undesirable effects, the defect. In addition, the steps include the following factors that are adjustable printing parameters: Squeegee pressure, squeegee speed and separation speed. And, according to the undesirable effects, there are technical contradictions for the pressure and the speed, respectively. However, squeegee pressure and squeegee speed must have fixed parameters constrained by customers. Therefore, only the separation speed is the adjustable factor in order to improve the defects.

3.3 Material view

3.3.1 Surface tension

It is also necessary to find the cause from a material itself, that its surface tension and thixotrophy may be main factors for the defects.
The surface tension difference between mask and paste affects a wetting behaviour of paste implying that surface tension of A paste is lower than that of B paste (surface tensions of masks are the same) as shown below:

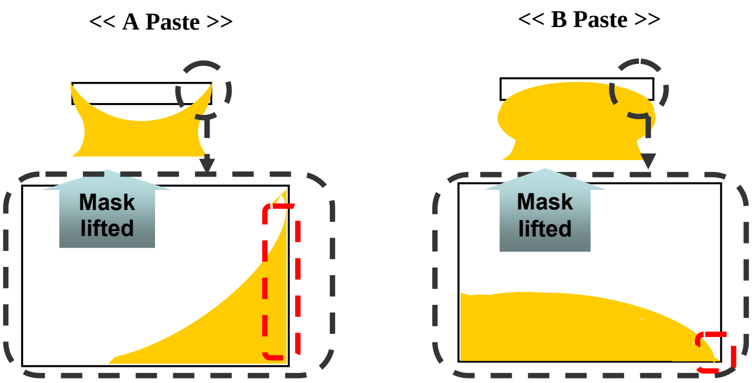


Figure 6. Surface tension of paste affects wetting behaviour

The relationship of surface tension among mask, A paste and B paste is :

$$|\text{Mask} - \text{A paste}| > |\text{Mask} - \text{B paste}| \approx \text{A paste} < \text{B paste}$$

"A paste" relatively tends to be dragged up when the mask lifts causing the defects implying that it is desirable to have less wettability of paste on mask but better wettability on PCB. In other words, in order to minimize the defects, the ideal relationship of surface tension should be Mask < Paste < PCB. However, the relationship in real is

Paste < PCB < Mask. Therefore, the surface tension of paste should be high enough not to be dragged up by mask when lifted, or that of mask should be low enough not to drag it up. However, the modification of the mask, "Separation by Space", plating it with Teflon or Ni (electroless), etc., is limited by customers because it costs them extra money. In addition, paste materials should be changed in order to have its surface tension get increased, which is not recommended, either since it may change its overall properties inducing unexpected results. That is, improving the surface tension is not the way to improve the defects.

3.3.2 Thixotrophy

It is the reversible reduction in viscosity of some media under the influence of a shear stress. A shear stress arises between the layers of a moving medium due to a mechanical load. The motion can be flowing, mixing or vibration. Therefore, as mask lifts up, the viscosity of paste near the mask wall, η', gets decreased so that paste can be dragged little minimizing the defects, as shown in Figure 7.

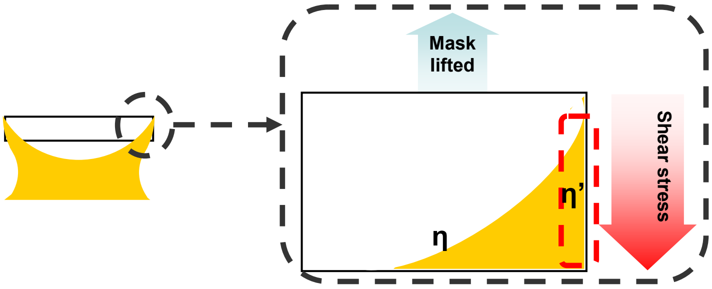


Figure 7. Thixotrophy can be the important factor for the defects

In general, the measure of thixotrophy of fluid is the viscosity ratio of fluid at different rpm:

$$\frac{\eta \ @ \ X \ (\text{rpm})}{\eta \ @ \ 10\ X \ (\text{rpm})}$$

In order to minimize the defects, reduce the amount of paste dragged by mask, the thixotrophy of paste should be high enough that η' should get decreased abruptly when the mask lifts up. Therefore, the thixotrophy of paste needs to be increased to the certain level that minimizes the defects.

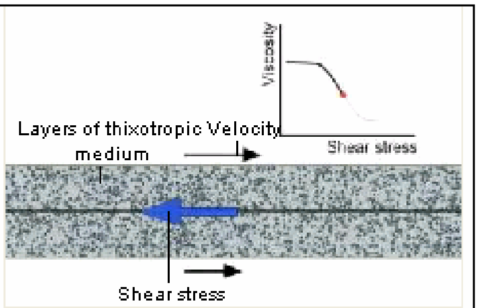
4. Solution of problem

Some concepts from other technical fields, patents, etc., were derived. By using Goldfire ver. 3.5, the related knowledge was searched with "How to increase thixotrophy?" as query, and approximately 293 related patents were searched. Basically, the most of them recommend to add fine particles and dispersant agents into a system. The following Table 3 shows the summarized key data.
According to Table 3, addition of fine silica seems to be one of most appropriate solutions because LSC paste already has one as a component in the system - the existing resource. Therefore, at least, it may not degrade material properties by adding one with different sizes. In addition, it is often required to add dispersant agent for surface treatments of such fine silica because it tends to be agglomerated very easily. The smaller the particle size, the more agglomerations it has. Thus, the fine silica should have its surface treated with appropriate dispersant agent before it is applied to pastes.

Moreover, Goldfire ver. 3.5 was used to find the related solutions - applying IMC Scientific Effect, the ways to increase thixotrophy were analyzed as shown in Figure 8 & 9.

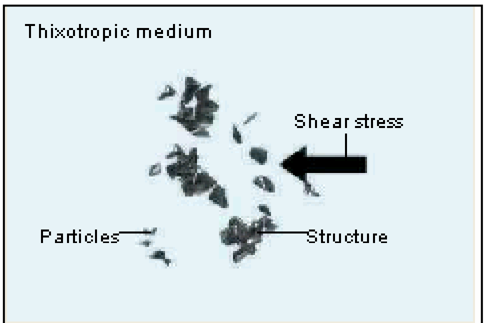
Patent No.	Key words
US3982334	Cab-O-Sil, ethylene glycol
US20070072981	thixotropic agent
US20070074900	filler
US20030089251	Beads
US4895598	polymer particle
EP0878839	large quantity of filler
US7154657	fumed silika
US6414077	fumed silika, propylene glycol
US20060262374	filler
wo2006070674	microfine inorganic powder with hudroxyl group
us20050154110	surface area, small particle
us20050131131	thixotropic agent
ep1526144	thickening agent
us20040131688	fumed silika, ultra disperse agent, surface area
us20020046851	inorganic particle
us5510436	clay particle
us5013383	Cabot Corporation (Tuscola, Ill.) as CAB-O-SIL
ep1760123	thixotropic agent
ep1571684	silica, fused silica or core shell rubber in the form of fine particles of particle size no more than 1 μm
us20040071925	SiO2 fine particles

Table 3. Summarized patents related to increase thixotrophy of a system



The shear stress affects the viscosity of a thixotropic medium

Figure 8. Relationship between viscosity and shear stress



The shear stress destroys the structure of the thixotropic medium

Figure 9. Relationship between particle size and shear stress

In Figure 8, a viscosity decreases as shear stress increases, where the viscosity is the function of thixotrophy. In Figure 9, a thixotropic medium requires high shear stresses to destroy its particles. In other words, the same amount of shear stress is applied to mediums with different particle sizes, the medium with smaller particles tends to get higher effects of the shear stress on its viscosity or thixotrophy. Therefore, the medium with smaller particles is likely to have better thixotrophy than that with larger ones.

Throughout the above studies, it is concluded that “Separation Speed”, “Add filler” and “Surface treatment of filler” are the main factors critical to improve the defects as shown below in Table 4, which will be focused on in this project

			Remark
Process	Squeegee pressure	Optimize parameters	Must be an equal or faster than customer spec. due to processibility : Modification is constrained by customers
	Squeegee speed	Optimize parameters	Must be an equal or lower than customer spec. due to mask abrasion : Modification is constrained by customers
	Separation speed	Optimize parameters	**Must be an equal or lower than customer spec. due to processibility : Modification is not limited by customers**
Material	Thixotrophy	**Add filler**	**Very resonable to apply to increase thixotrophy**
		Surface treatment of filler	**Very Reasonable to apply to prevent the filler from being agglomerated**
	Surface tension	Coat mask surface	Not reasonable to apply - Costs a customer extra money
		Change material	Not reasonable to apply - May change paste properties
		Change PCB	Not reasonable to apply - Fixed by customer

Table 4. Evaluation stage of effective factors for the defects

5. Experiment I & Result I

	Spec.	Defect			Remark
		Clogging	Bleed-out	Bubble	
Separation Speed (mm/sec)	0.1~1.0	△	x	o	Reciprocal action to one another
	1.1~10.0	o	x	x	
	10.1~20	x	o	x	

(X : Not cccuring, O : Occurring, △ : Occurring occasionally)

Table 5. Contradictions of printing parameters to one another

Through the previous study in this paper, the separation speed was selected to improve the defects. The speed was adjusted 0.1 to 20mm/sec, which induced physical contradictions to one anther among the defects as shown in Table 5. But, there is no way to solve the contradictions by changing the speed. Therefore, it was found that the separation speed, process optimizations, cannot be the solution for the defects.

5. 1 Experiment II

Four different experimental conditions were applied in this experiment, where different sizes of nano-fillers were added into paste resins. Then, they were printed, b-staged, chip-attached, wire-bonded and reflowed.

		Experiment 1	Experiment 2	Experiment 3	Experiment 4*
Material Property	Primary Particle size (nm)	**7**	**12**	**17**	**22**
	Thixotropic index	**5.9**	**5**	**3.5**	**2.5**
	Viscosity (cP, @ 0.1rpm)	39,000 ± 10	45,000 ± 10	47,000 ± 10	50,000 ± 10
	BET surface area m2/g	150	100	80	50

* Previous status of LSC paste

Table 6. Experiment conditions

It is observed that thixotrophy increased as the particle size decreased, as shown in Table 6.

6. Result II

In correspondence with different conditions, the defects and reliability results were analyzed as shown in Table 7. As thixotrophy increased, processibility and reliability improve as shown in Table 7. However, the reliability for experiment 1, 2 and 3 is not perfect, that the void is found occasionally (~15%), which is assumed to be resulted from agglomerations of filler. Thus, the reliability should be improved by minimizing the defects and the agglomeration at the same time.

<table>
<tr><td colspan="2"></td><td>Experiment 1</td><td>Experiment 2</td><td>Experiment 3</td><td>Experiment 4</td></tr>
<tr><td rowspan="3">Defect</td><td>Clogging*</td><td>x (12.0%)</td><td>x (13.1%)</td><td>x (11.7%)</td><td>o (26.8%)</td></tr>
<tr><td>Bleed-out</td><td>x</td><td>x</td><td>x</td><td>o</td></tr>
<tr><td>Bubble</td><td>x</td><td>x</td><td>x</td><td>o</td></tr>
<tr><td colspan="2">Reliability</td><td>Void between chip/paste (Acceptable)</td><td>Void between chip/paste (Acceptable)</td><td>Void between chip/paste (Acceptable)</td><td>-Void between chip/paste and paste/PCB
-Electrical shortage (Fail)</td></tr>
</table>

*Clogging can be measured by Alpha Step surface profiler and expressed as % for total paste thickness
(X : Not cccuring, O : Occurring, △ : Occurring occasionally)

Table 7. Processibility and reliability for increased thixotrophy of paste

7. Experiment III & Result III

Only three experiments, 1, 2 and 3 were carried out with surface treatments by three new different agents A, B and C as shown in Table 8:

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Reliability</td></tr>
<tr><td>Experiment 1</td><td>Experiment 2</td><td>Experiment 3</td></tr>
<tr><td rowspan="3">Surface treatment</td><td>A</td><td>△</td><td>o</td><td>o</td></tr>
<tr><td>B</td><td>x</td><td>o</td><td>△</td></tr>
<tr><td>C</td><td>x</td><td>△</td><td>△</td></tr>
</table>

(□ : Acceptable but not perfect, O : Pass, X : Fail)

Table 8. Reliability results after surface treatment of filler with different agents

Paste resins with different surface treatment agents were printed, b-staged, chip-attached and reflowed. It is observed that the agent A is appropriate for the resins of Experiment 2 and 3. And the agent B is appropriate for the resin of Experiment 2. It can be said that it is not always recommended to have small particles since there is the agglomeration issue. That is, the smaller the particles, the more the agglomerations systems may have. The particle size of Experiment 2 seems to be appropriate, such that it provides no defects but good reliability being de-agglomerated efficiently by common commercial surface treatment agents.

8. Conclusion

8.1 There are several factors that may cause the defects that could be revealed and analyzed, and some solutions are suggested by tools like Root & Cause, Structural Analysis, Knowledge Search, IMC Scientific Effect, Patent Search and Technical & Scientific Effect.

8.2 It was found that it is most reasonable and efficient way to improve the problems by increasing thixotrophy of adhesive adding nano-sized filler:

<table>
<tr><td>Experiment</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td colspan="2">Remark</td></tr>
<tr><td rowspan="3">Processibility (Defects)</td><td>Clogging (%)</td><td>12.0</td><td>13.1</td><td>11.7</td><td>26.8</td><td rowspan="4">Effected by Filler</td><td rowspan="5">Effected by Filler & Surface treatment</td></tr>
<tr><td>Bleed-out</td><td>None</td><td>None</td><td>None</td><td>Yes</td></tr>
<tr><td>Bubble</td><td>None</td><td>None</td><td>None</td><td>Yes</td></tr>
<tr><td rowspan="2">Reliability</td><td>Without modification of surface treatment</td><td>Acceptable but not perfect</td><td>Acceptable but not perfect</td><td>Acceptable but not perfect</td><td>Fail</td></tr>
<tr><td>With modification of surface treatment</td><td>Acceptable but not perfect</td><td>Pass</td><td>Pass</td><td>-</td><td></td></tr>
</table>

8.3 Modification of thixotrophy improved the processibility and reliability. However, in order to have a better reliability, filler agglomerations should be reduced by applying an appropriate surface treatment agent.

It was possible to have a good quality of adhesive through TRIZ, resulting in passing the qualifications by “ H” company in Korea and “ F” company in Taiwan.

9. References

1) Genrich Altshuller, 1997, 40 Principles, Technical Innovation Center.
2) Young-Ju Kang, Alexander Skuratovich, Pyeong-Kwan Chung, 2004, "TRIZ applied to Axiomatic Design, and case study; improving tensile strength of polymer insulator", ETRIA 2004 Conference Proceedings, Nov 3-5.
3) Genrich Altshuller, 1996, And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving, Technical Innovation Center.
4) VE+TRIZ Method for technical system improvement, LS-Cable, 2005.
5) Goldfire 3.0 workbook, TRIZ Korea, 2006.