Development of flexible-printable device processing technology

— For achievement of prosumer electronics —

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We have worked on the development of the flexible-printable device processing technology as a processing technology of information terminal device that can make the best use of user's individuality. We have succeeded in the development of several low-temperature printing technologies for flexible active devices such as flexible displays and circuits. In this research, we have paid attention especially to the social requirements for the technology, and positions of respective technologies in the total set-up concept. We believe that it would contribute to the expansion of information technology in the world.

Keywords **:** Display, information terminal device, flexible device, process innovation, organic semiconductor, printing

1 Background: flexible information terminal device in demand

As IT technology has deeply penetrated the society today, development of technology that improves usability will diffuse IT technology further and is expected bring forth economic impact. The new technology may also contribute to sustainable society by conserving resource and energy for transportation and communication. The development of technologies for software and hardware for sustainable society is being conducted actively, and the international competition in this field is becoming fierce.

The hardware for IT technology can be roughly divided into “central-mainline technology” where information are collected and processed and “terminal-access technology” where information are received and distributed (Figure 1). The former, as exemplified by computer, emphasizes “high speed,” “high capacity,” and “standardization,” and various R&D efforts are conducted mainly in silicon technology. On the other hand, the latter, as exemplified by display, emphasizes “diversification,” “mass diffusion,” and “usability,” and there are demands to accommodate various uses and places where the technology is used. For further diffusion and expansion of IT technology, diffusion of information terminal is essential, and creation of more convenient terminal is awaited. To create new information device, it is important to understand the market demand. Particularly, as the general public is becoming accustomed in using the network, demands for usability are increasing. For example, we well as demands for hardware such as being light, thin, or doesn’t break when dropped, there are demands for usability such as not being affected by place or environment in which the device is used (everywhere device), or user can customize the device to

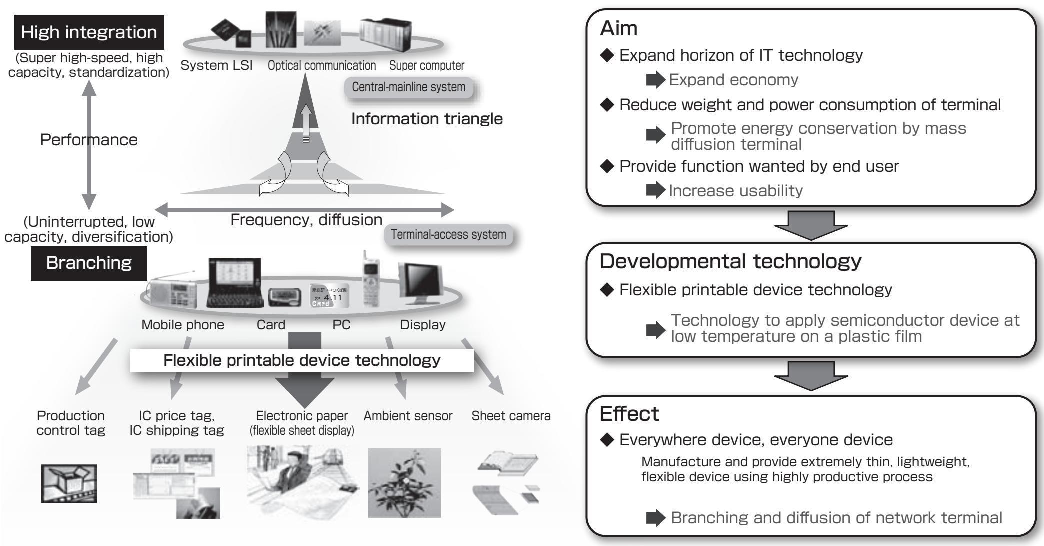

Fig. 1 Development of flexible printable electronics technology.

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their wish (everyone device). To respond to diverse individual demands, conventional technology that only fulfills uniform specification cannot accommodate individual demands, and is not economically feasible as industry. Therefore, it is necessary to develop technology that provides degree of freedom and can accommodate as much diverse specifications as possible.

On the other hand, with the recent rise in consciousness for energy conservation, there are demands for large-scale energy conservation in the semiconductor process (process innovation in semiconductor technology). Particular emphasis is break away from vacuum, high temperature, and photolithography processes. These are major social demands that cannot be ignored regardless of the target.

2 Objective of R&D

2.1 Toward prosumer electronics

To realize technology that may fulfill diverse demands of information terminal device such as "light and flexible," "high productivity manufacturing," and "wanted by consumer," one of the major goals is to develop technology with high degree of freedom for accommodating diverse specifications, such as "flexible printable device processing technology" where the device can be fabricated on flexible substrate such as plastic and paper using solution process. At the same time, this technology enables low environmental impact process, and break away from vacuum and high-temperature processes. Therefore, this is an important technological goal that must be realized.

The ultimate goal of technology is to allow people to create what they want, that is, production of terminals by consumers themselves or prosumer electronics (prosumer = producer + consumer). If the ultimate goal is to have the information terminal device to reflect the user's personality, then the technological goal will be to make the tools available at personal level.

To realize this goal, it is not sufficient to simply fabricate the device on flexible substrate with solution process, but the device must be fabricated with simple material and simple process (low-temperature application at 150 °C or lower) using simple machine. The Authors set these as technological goals and worked to meet this goal.

2.2 Match between needed function, device performance, and process condition

The information terminal device fabricated using these technologies must at least have performance required for intended use. Even if a technology has outstanding performance, it will not generate technological value if it is difficult to fit into the total system. On the other hand, even if a technology has inferior performance, it will be effective if it fits well in the system. The importance is the value created when the technologies are fitted together in total. This is the concept of optimally consistent device. Therefore, in this R&D, the goals were to design device while clearly imaging the final product, to extract basic specification, and to develop technology that matches the process condition.

3 Development of key technology

3.1 Extraction of developmental technology

There are many elemental technologies that must be developed to achieve the above goal. We drew the scenario by extracting major technological issues and by presenting solutions, to show whether "flexible printable device processing technology," which we used as symbolic concept, is realizable at all. For example, flexible device means fabrication of device using flexible material. The most suitable material to the flexible device is organic material, but when organic materials are used, there is always temperature limitation in processing. It is necessary to demonstrate that the device with required device performance can be manufactured at processing temperature 200 °C or less where the material will not disintegrate. Also, it is also necessary to show that using printing as processing method would secure processing accuracy to improve the device performance.

Therefore, we worked on technological developments to demonstrate that solutions were available for main issues, and obtained the following results.

3.2 Low-temperature application process

For lower temperature of manufacturing process, it should be a good idea to use alternative energy to heat energy for manufacturing. Since heat energy is transferred evenly and gradually over the reaction field, evenness is a major characteristic of film that is the other area where energy transfer is not required, as energy spreads gradually and evenly to all parts, and various sub-reactions take place. To avoid this, we developed a new technology to use alternative energy such as light and mechanical energies.

(1) Multiple-source photooxidation method

One of the important factors that may be the key to stable operation and high performance of device is SiO_2 insulating film. To form enough high-quality of a SiO_2 insulating film on the device, processing temperature of at least several hundred degrees is normally necessary. We developed low-temperature fabrication process, in hopes that the technological concept would be accepted if this important constituent of the device could be processed within the limit indicated in the specification (processing temperature 200 °C or less).

When a silicon compound reacts with oxygen at several hundred degrees, silicon dioxide (SiO_2) is formed. If this reaction can be occurred to form a high-density thin film by using soluble material, insulating layer of electronic device can be obtained by liquid phase process. However, this is an oxidation reaction that normally requires high-temperature treatment at 500 °C or above after film preparation. It is known that catalysts is useful to reduce process temperature. However, this is not adequate for electronic device use because it often acts as impurities in the device. Therefore, we considered providing required energy locally using light energy, and tried to develop technology that would promote this reaction. As result, we succeeded in developing a new technique by introducing multiple-source photooxidation method (Figure 2)[1]. Points for this new technological development were: selection of material with combined species that were less likely to be subject to stress failure on reaction precursor in forming SiO_2 film; selection of light source with sufficient energy to excite this combined species; and selection of separate light source sufficient to excite the active species to react with this precursor. Particularly, major point in appealing the significance of newly developed process is that the reaction can be promoted using a conventional light source such as lamp, rather than locally high-density energy source such as a laser. By keeping the maximum reaction temperature of the entire process to 200 °C or less, occurrence of defect due to contraction and expansion of film could be controlled, and as result, highly dense SiO_2 film was obtained. The formed SiO_2 film showed high resistivity over 10^{15} Ωcm and high dielectric strength over 7 MV/cm. This technology is currently considered for preparation of a dielectric layer of TFT for display use, especially for displays with flexibility and large size.

(2) Triaxial distributed pressure annealing method

Even for "flexible printable device processing technology," there are major limitations in the specification depending on the technology used. For example, for electronic display of memo level information, the limitation of production cost is extremely severe. In this case, expensive material cannot be used. Low-temperature processing must be used and there is limit on usable materials, but it is necessary to show that technological application is possible under this condition.

Therefore, we developed technology to print wiring and electrode with low-resistivity on a conventional plastic film such as PET using conventional conductive inks. Conductive ink is normally thermally annealed at 400 °C or higher to reduce resistivity after forming the printed pattern. Recently, using nanoparticles of metals has been suggested to lower the annealing temperature. However if the material cost increases by using nanoparticles, the aforementioned objective is defeated. Therefore, we worked on low-temperature annealing technology to obtain low resistivity with conventional ink, and succeeded a new technique to reduce process temperature by using pressure as alternative energy to heat (Figure 3). Here, the point was also how to lower the temperature required for reaction. In this technology, low temperature was achieved by using pressure energy. Pressure energy was locally applied as anisotropic energy instead of applying energy homogeneously. That is, energy was concentrated onto necessary area and was not dispersed to surrounding area that did not require it. As result, in printing pattern using conventional silver conductive paste, we obtained resistivity 6×10^{-6} Ωcm at reaction temperature 120 °C or less (for comparison, resistivity of bulk silver $=1.6\times10^{-6}$ Ωcm). Considering that heating to 200 °C or more was needed to obtain similar resistivity even when silver nanoparticle paste was used, it can be seen that pressure energy is extremely effective in lower temperature in annealing.

3.3 Printable device manufacture process

The greatest hurdle in developing printable device processing technology is whether the process specification requirement of being "printable" and the device specification requirement of being high performance can be both realized. For device performance, whether processing accuracy can be

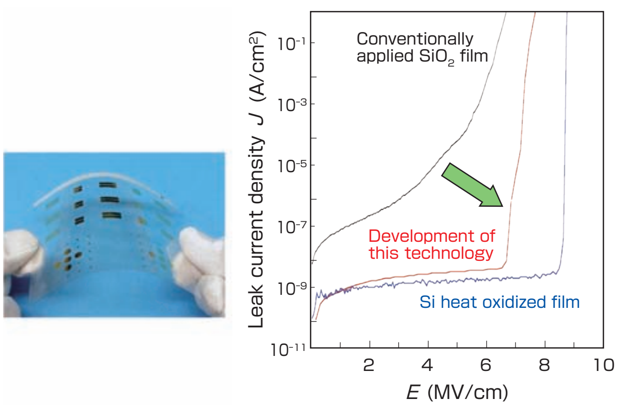

Fig. 2 Development of multi-source photooxidation method for forming dielectric layer by low-temperature printing.

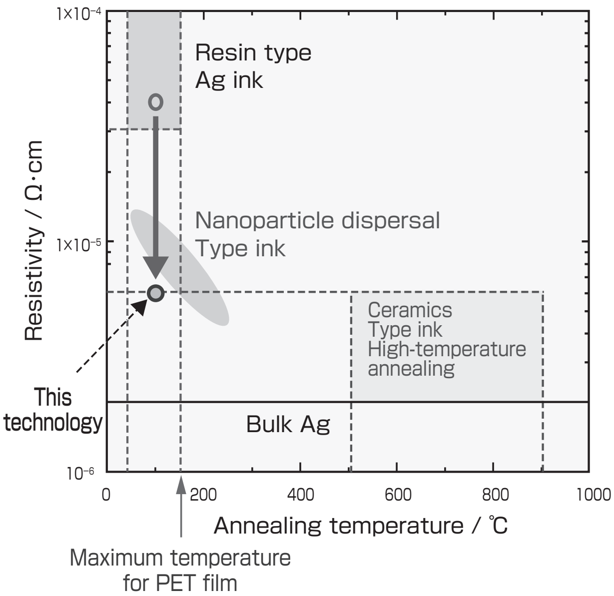

Fig. 3 Development of triaxial distributed pressure annealing method for forming low-temperature printed conductive pattern.

maintained is always questioned, since microfabrication control is required to some extent. Normally in liquid phase process, the microfabrication accuracy in in-plane direction is not high (up to several tens μm) when fabricating the device. Therefore, it was thought that transistor element that required high in-plane fabrication accuracy would not be able to perform sufficiently. Therefore, we decided solving this technical issue would be a breakthrough in establishing printable device manufacture technology, and started seeking solution.

Top & bottom contact transistor

As point of technological development, the fact that in-plane fabrication accuracy was only several tens of μm, must be accepted, and then we decided to employ elemental device structure design for constructing the moving part (channel) of several μm or less, which determined the device performance. Hence, we developed a new device structure named "top & bottom contact transistor" (Figure 4)[2]. The channel size that determined the device performance required control of μm or less and was designed to be aligned in film thickness direction, so control could be provided by film thickness. By doing so, high fabrication precision in plane direction would become unnecessary. As result, it basically became possible to fabricate transistor with short channel by layers of printed lines, and we succeeded in forming channel length at sub-μm level. Using this element device structure, we demonstrated performance of 0.2V/dec or less for SS value, which is field-effect modulation factor of output current, for transistor formed entirely by printing using polymetric semiconductor with relatively high mobility ($\mu = 10^{-2}$ cm/Vs level). It was shown that both manufacture process of being printable and high performance of device could be met simultaneously.

4 Scenario for industrial application

Explained above are the main elemental technologies that we developed. Looking at them individually, perhaps one can see technological value is very specific, singular technology. However, different world will emerge if one understands the scenario for development and positioning of the technology.

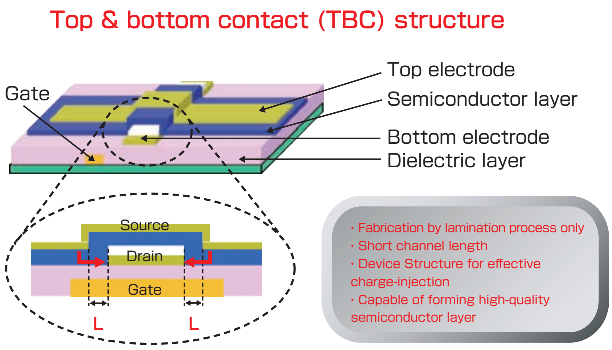

Fig. 4 Top & bottom contact (TBC) structure for forming all-printed element.

Next, the Authors will describe the scenario for technological development that was conducted toward industrial application.

4.1 Different demands from end users and technical users

Even if innovative technology is developed, unless we understand who wants such innovation, others may fail to see the appeal point of technology, and then it does not get introduced to the world. Therefore, we placed importance on analysis and understanding who wanted what. The demand of people who use it (end user) is the most important for information terminal device. Then, can technological demand be met by providing things that end users want? It is not that easy. Technological demand will not be valid unless it matches the demands of device producers or manufacturing companies. For example, say we can provide technology that enables production of highly usable terminal that end users will love at 10 yen apiece. However, even if one hundred million terminals are sold, sales is only one billion yen. Large corporations cannot do business, so they do not want this technology. However, it will be feasible for a small company. This is why we must ask, "Who will want this technology?"

4.2 Creating a player map

It is useful to create a player map to address the above question "Who will want this technology?" Since demands vary according to technological level even for similar technology, this map can be used to clarify the values of developed technology. Table 1 shows the technological phase, target product, and main target companies, and Table 2 is a player map that shows the technical issues in each technological phases and how they can be solved.

For example, there are many kinds of displays. It is necessary to combine several complex technologies for complex display such as for television (Phase I), and this is conducted by large display manufacturers. In this case, scenario of business development is determined by market demand, and the issue of pioneering technology development is whether to develop innovative technology that realizes the scenario or to provide technology that can respond to social needs.

Table 1. Development scenario.

Technological phase	Market example	Technological level	Technology user
Phase I	Television Mobile phone	Vacuum batch process	Major specialty company
Phase II	Electronic paper RF-ID tag	Roll to roll	Major emerging company
Phase III	Sensor Smart object	Conventional printing	Small & middle company
Phase IV	Label ID label	Private manufacturing	Venture, individual

Next, new displays such as electronic paper (Phase II) do not require major technology as in television. Therefore, it is technology wanted by companies that wish to create new industry. In this case, new market must be pioneered, so discovery of function unseen in conventional technology will be the priority of development. However, there is limitation that the technology must be capable of fabricating relatively simple things. Although technology for simple display such as indicators and tags (Phases III, IV) may be simple, it can be technology from which totally new industrial product can be created, and it will be wanted by small & middle companies and ventures. Here, there may be more technological limitations such as unable to use expensive, special material or high cost manufacture technology, and therefore requires technological development dedicated for the purpose.

Some examples of what can be read from the player map are shown.

①Is the individual elemental technology to be developed in match with overall set-up concept? Are there any gaps in technology or player?
②Does the technology to be developed have chance of becoming leading technology?
③Is the technology to be developed something that can be developed in multiple directions?
④Can the technology to be developed gain competitive position?

The technological position can be seen clearly on the player map, and it is extremely useful in judging whether a technology will become winning technology. "Winning technology" is determined based on whether it can lead new industry (leading technology), can respond to social demands such as energy conservation (social technology), or whether it can support industries with weakness in technological development (small-middle company supporting technology).

4.3 Linear and non-linear models of technological development

Table 2. Player map of technological development.

	Material				Process	Device	Prototype
	Conductor	Semicon-ductor	Dielectric material	Peripheral material			
Phase I For major specialty company	Company	Company	Company	Company	Company	Company	Company
Phase II For emerging company	Company	Company	Company developed technology	Company		Company	Company
Phase III For small & middle company	Company developed technology		Company developed technology	Company developed technology			
Phase IV For venture and individuals	Company (developed technology)		Company (developed technology)	Company (developed technology)	University		
Basic		University	University		University	University	

There are two styles of technological development: linear model where clear, integrated goal is set and development is planned toward achieving that goal; and non-linear model where clear, integrated goal is difficult to set although target image is sort of there, and scenario to get to the goal is unclear, and appearance of jump-up technology is awaited (Figure 5). The latter non-linear model of technological development is often employed when specifications are diverse as in information terminal device technology.

In the non-linear model of technological development, there is expectation for jump-up technology, and it is difficult to conduct development in an orderly manner. However, analyzing the technological fields that employ this model, there are many exceptions. The "information terminal device technology," the topic of discussion in this paper, is one example. There is gap in technology because there is no technological player, and it looks as though people are waiting for jump-up technology to fill in the gap. In this case, clear planning can be done by organizing the existing technologies.

4.4 Presenting effectiveness and innovativeness of technology as product

It is effective to present the developed technology, even if it is single technology, as prototype by combining it with related technologies. The point is to show that technological development can be done by using set of technologies, and to take lead in the technological concept. However, important point is to deliver clear message as well as fabricating a prototype and showing its function. For example, in the above development by the Authors, we added unique message. For "multiple-source photooxidation method," our goal was to use it in printed TFT for display. In the initial stage of prototype fabrication, we were first in the world to succeed in showing moving image in color on organic TFT driven LC display (Figure 6)[3]-[5]. As this was time when many have high expectation for printed TFT technology, our demonstration

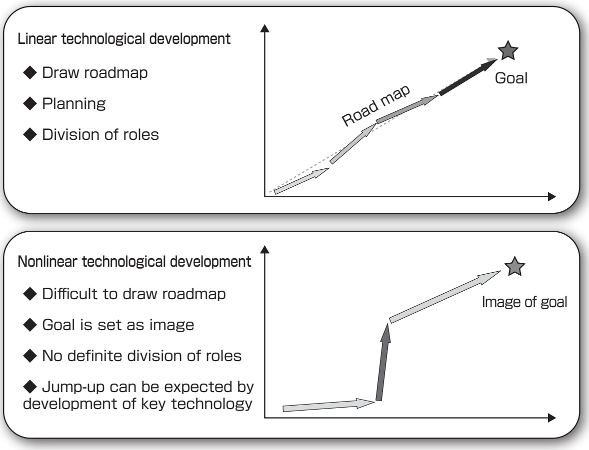

Fig. 5 Linear model and nonlinear model of technological development.

became news throughout the world. In this technology, we communicated the message that in the future this technology will enable large-surface, ultra-thin, wall-type screen television, and appealed high reliability and ability to fabricate large surface area in addition to high performance.

“Triaxial distributed pressure annealing method” was demonstrated by creating prototype all-printed RF-ID tag (Figure 7)[6]. It was shown that RF-ID tag could be formed on a film by printing only for the first time in the world. It contained message that in near future, flexible information terminal would become available, and we were able to appeal our goal of technological development.

The above examples of technological developments are not fabrication methods of active layer (semiconductor layer) that generally draws more attention, but are formation technology of electrodes, wiring, and dielectric layer that are often left behind. There is another reason for presenting our development effort in these left-behind technologies, and that is to fill in the player gap. In certain technological concept, attractive elemental technology attracts many players of technological development, and certain degree of technological advance can be expected. However, in aforementioned elemental technologies, development does not take place, not due to technological hurdle, but due to other factors such as business. In this case, it is difficult to find set of technologies even if one wanted to. In some cases, technological concept cannot be “totally consistent.” Therefore, to appeal that the technological concept can be totally consistent, it is necessary to attempt filling the gap in

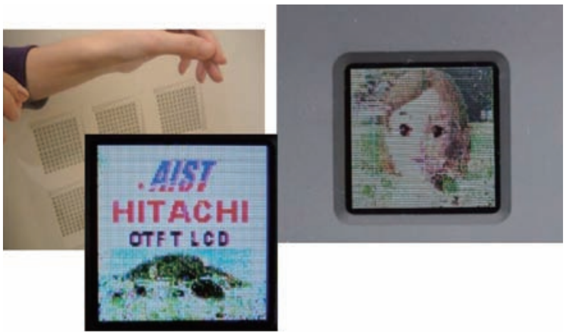

Fig. 6 Development of organic TFT driven color LC display.

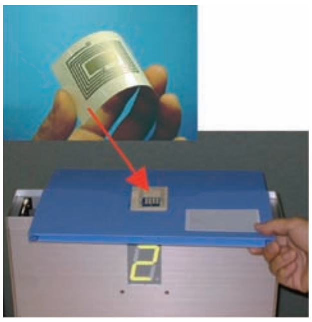

Fig. 7 Development of all-printed flexible RF-ID tag.

technology. It is concept of technology for that “last piece” to completion. As researchers at national institution, we decided to play the role of showing that development concept can be provided in total set, to show leadership for the direction of technological development, and to reduce risk of development efforts by the industry.

We shall give specific example of practical application of this effort. As side-development of printable device technology (top & bottom contact transistor technology), we developed 3-dimensional nanoporous device (Figure 8)[7]. This is device technology designed to effectively utilize wall fabrication that is one of the characteristics of liquid phase process, and we created a device (agricultural sensor) that enables highly sensitive measurement of substance that passes through or are incorporated into the pore of the porous material. This was technology developed as result of request from end users (farmers). The request was to develop highly sensitive agricultural sensor that can be used easily by farmers, for product control of produce. Considering the set of technologies, materials were available, fabrication process could be done readily with current technology, system developers existed, and of course, there were users. Only factor nonexistent was device developer. Here, there was “gap in technological.” In this case, there were no technicians who would work on this technology since it was not profitable. Therefore, as researchers of public institution, we decided to engage in “division of role for risk sharing” where we would actively take up elemental technology with high risk of development. As result, we created terminal device that was provided through set of technologies (Figure 9)[6]. This was effective in delivering strong message for prosumer electronics. Forms and specifications of the attached sensor had to be changed according to the type of produce. Also, places where sensors could be attached were different. Moreover, the sensor must not interfere with the produce. We launched this product with message that the information terminal device that can meet various and specific needs can be developed jointly with actual user (agricultural experiment station).

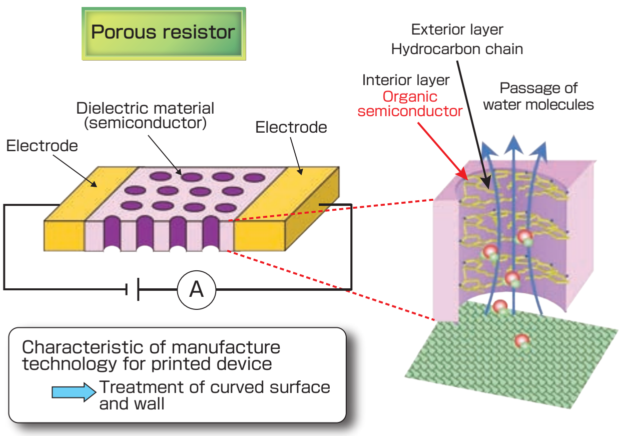

Fig. 8 Development of 3-dimensional nanoporous device for flexible sensor.

We believe that the greatest significance of our prototype was to show the validity of technology, that sufficient performance could be obtained when technologies are used in set. We were able to appeal the attractive point of technology that we could create things that we never saw before (Figure 10).

It is uncertain whether the prototype itself will be taken up by companies for final product realization. However, we think delivering messages will contribute greatly to corporate decisions of whether to employ these technologies as targets of realization.

5 Future issues and developments

As described above, the field of information terminal technology to which printable device processing technology is being applied has characteristic of becoming more branched as it diffuses further into the society and the required technological specification becomes diverse. If one jumps into development to meet each and every demand, there will be as many technologies as demands, and strategic, planned technological development becomes impossible. As effort to be strategic, we placed particular emphasis on planar and continuous aspects of future technological development.

5.1 Set of technologies and timing

For industrial technology today, it is extremely difficult to achieve technological concept with single technology. In many cases, technologies from different fields are required to supplement development. In case the target is current and the developed technology is intended to replace current technology, it is probably not necessary to pay attention to related technologies. However, in case the goal is new technology that may lead to creation of new market, that is, if it is pioneering technology, it is mandatory to pay attention to combination with other technologies, and build a technological system. Therefore, planar development or development of set of technologies is important.

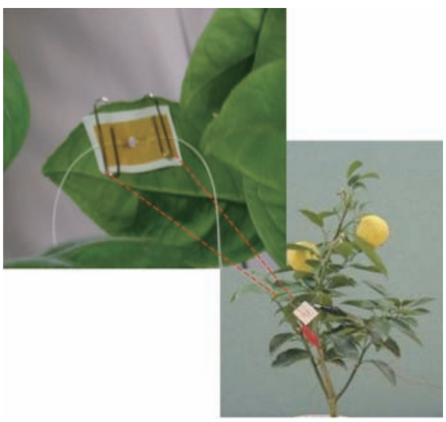

Fig. 9 Development of flexible transpiration sensor for agricultural use.

There is one important point that must not be forgotten. That is the concept of development phase or knowing where the currently developed technology is positioned. Grouping technologies into set is routine, and companies that engage in development as business do so regularly. However, when time concept of development phase is considered, one realizes that it is not a singular concept. The company starts grouping technologies into set only when the technology is near completion and enters the phase when the overall scenario becomes visible. Even a company must struggle with a single technology for which the scenario is unclear, and must wait a while before the scenario can be written.

Another point is that to aim at target that couldn’t group technologies into set because there was “gap in technology.” This means that the technologies could be bundled together only after development of new technology. Since this often leads to new products and new industry, it is worth working hard. In corporate activity, when gap occurs in area outside the company’s technological domain, nothing can be done and the development may have to be given up.

Therefore, the issue is who will be the first to present the scenario for industrial development. For industrial technology, the key point is to discern which is technology that is likely to win, and that is what we pursued.

5.2 Continuous development leads to early diffusion

Moreover, continuous development of technology, or pioneering of next technology, is very important. How technology is developed as industrial technology under which scenario is extremely important for realization. It is particularly important in our field where technological development tends to be single shot. Single-shot technology may be useful to meet special demand but its wide diffusion may be difficult. On the other hand, showing the second and third hands for technology that others find interesting presents the depths of the technology and is useful in drawing more attention. As result, speed of diffusion into the industry will increase for related technologies. That is why it is important to continue pioneering technology and to present scenario of how the technology will grow.

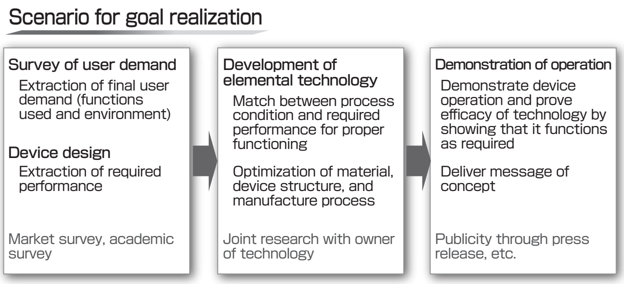

Fig. 10 Scenario for realization of flexible printable electronics.

6 Conclusion

We were able to engage in research and produce results acceptable to the society, because we formed research teams where the members worked closely and each R&D could mutually supplement each other. In this point, there is definite advantage of organized research. On the other hand, steady academic activities are at the basis of multi-faceted technological development. Without work in *Type 1 Basic Research* and academic societies, there might have been less interest in our technology.

In the future, we plan to work as team on the technological development to create new industry, while balancing *Type 1* and *Type 2 Basic Researches* and by presenting scenario for development of industrial science.

Note

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Engineering Sciences, Kyushu University in March 1995. Joined the National Institute of Materials and Chemical Research, Agency of Industrial Science and Technology (current AIST) in April 1995. Has worked on research for light-emitting devices such as organic EL and mechanoluminescence. Worked mainly on *Type 1 Basic Research*, and in this paper, worked on basic scientific analysis of development technology.

Discussion with Reviewers

1 Positioning of flexible-printable device processing technology

Comment (Hiroshi Tateishi)

If my understanding that the research objective of this paper is expressed by its title "development of flexible-printable device processing technology" is correct, I think the description of social value of this research objective is insufficient. Specifically, there is a gap between specification required for information terminal device - various uses, everywhere device, everyone device - and the concept of flexible-printable device. Flexible-printable device is one of the options that fulfill the above specification, and I don't think it is everything. Unless you provide details (or specifications) about the condition in which flexible-printable device becomes best choice among several candidates, the argument will be flexible-printable device first. Demand for energy conservation during manufacture process is not sufficient as explanation. I think the explanation on why this device is necessary or effective for certain demand is lacking. This problem is apparent in Figure 1. There is a clear gap between the layer surrounded by "branching" and flexible-printable device. According to this figure, it seems that the flexible-printable device will solve all problems, but I don't think things are so simple.

Answer (Toshihide Kamata)

Information terminal device technology has been called as 'low-end target', and many people hold impression that it is accessory technology that can be accomplished when high technologies are employed. Contrary to such perception, this technological field is not really pioneered, and placed in situation where there is almost no technology applicable to industry use. This is because there is no matchmaking between technological demand and market demand, and it shows that industrial technology cannot be developed from technological indicator alone. If I accept your point, I think we will fall back into this vicious cycle where things are built up from technological indicator. To break this cycle and to pioneer technological field, one good method is to present an example of symbolic technology that may solve this issue and pull the technology under its flag. In this paper, the concept "development of flexible-printable device processing technology," which we perceive as the best technological indicator right now, is used symbolically to explain the technological strategy for pioneering this technological field. The social value of this strategy is to lead the expansion of information terminal device technology, which is stalled at this moment. Therefore, to discuss the details of other supplementary technologiesy will divert the main point under discussion, and I think describing them in this paper will bring about an adverse effect.

Comment (Naoto Kobayashi)

What are the main competing technologies in the R&D for "flexible-printable device processing technology"? For example, I think there are cases in which one uses not only organic devices but also heterogeneous materials and devices such as inorganic semiconductor and glass materials and other cases in which one uses different synthetic method and process with the same organic devices. I think it will be easier to understand if you show comparison of performances (benchmark) targeting for a certain purpose. You wouldn't have to show all examples, but I think you should show some characteristic examples.

Answer (Toshihide Kamata)

I've added some remarks in the text. In technological development there is linear model where goal is set and research progresses according to plan, and nonlinear model where goal setting and planning are difficult although there is a final image, and here, I am engaging in discussion on how to conduct technological development by nonlinear model.

Although people often think that the nonlinear model advances by flash insight, I am trying to show that it is possible to conduct logical and planned technological development by employing method where overall map is drawn (overall systematization) and some important points are extracted. Therefore, I believe the nonlinear method for creating research plan is, rather than starting from material science such as organic or inorganic materials, to consider materials systematically from physical property axis of flexibility, chemical property axis of solubility and so on. The optimal materials are then selected according to situation one after another.

The important point is not to create a monoaxial technological development plan by setting benchmark for one technological indicator, but to plan by creating a map and discerning technological matches (several may be present), and to sharpen those areas. I want to express that this method is appropriate in this technological field. For this reason, I think the range of technological development will be narrowed if thing starts from technological seeds.

Comment (Hiroshi Tateishi)

I looked at Figure 1 again after reading your response, and perhaps this figure is the starting point of why I was mislead. Since there is picture of flexible-printable device technology beneath 'the central-mainline system → terminal-access system', I perceived unconsciously that "flexible-printable device technology will replace current terminal device technology." Perhaps although they exist at the same level in that they are "terminal devices," we should understand rather "flexible-printable device technology is a development in different direction." While current technology is, in general, characterized by the fact that they are "general-purpose technology that can do anything," flexible-printable device technology should be understood as "technology of simplified function that specializes in particular demand of end user." However, if necessary technology is different for each device, it will not be economically feasible, the manufacturing technology for flexible-printable device must be "general and has degree of freedom that allows accommodation of various demands" or else it will not help expansion of this technology. I think this will be the main point of the paper. If my understandings are correct, can you please add this point in the paper?

Answer (Toshihide Kamata)

Thank you very much for spelling out the main point of the paper. The above comment is indeed what I wish to emphasize. I made some additions to the introduction.

2 Direction of technological development

Comment (Hiroshi Tateishi)

I feel that the expression "phase" used in Tables 1 and 2 is strange. Normally, phase implies that it is developed one after another, but the phases here do not seem to evolve in order IV → III → II → I. Isn't it closer to "level"?

Answer (Toshihide Kamata)

The "technological phase" described here develops in order I → II → III → IV, and I feel the word 'phase' is appropriate. Your indication "evolve in order IV → III → II → I" is incorrect understanding, and it is extremely important to understand to read this paper. It is not necessarily true that more complex technology will be developed as technology approaches the end user, such as information terminal device. That is because there will be no development as industrial technology unless there is match between the demands of user and manufacturer. For example, Phase I is technology where the intent of the manufacturer is easily reflected since it is strongly characterized as mass production of uniform standard. Because technology provider and producer both exist, marketing as industrial technology is done relatively quickly. However, Phase IV is technology for users. Since manufacturer may not see business opportunities, it is less likely to be taken up by producer and technology provider, and therefore it is not likely to be pursued as industrial technology. Therefore, the technology corresponding to Phase IV lags behind compared to Phase I in terms of indicator of degree of success in industry, rather than indicator of technical ease/difficulty. It can be said that technology develops in branches in order of Phases I → II → III → IV.

In this paper, one of the main arguments is to raise issue on how to develop technology that is difficult to market from the technology oriented strategy, yet in demand by many people (users).

3 Role of AIST

Comment (Naoto Kobayashi)

The development scenario of Table 1 and player map of technological development of Table 2 are extremely useful and unique attempt to describe this field. If the technology aims to become "prosumer technology" in the future, a place (time and space) for the developer, the technological user, and the end user to closely exchange opinions will be important. Do you have any good ideas for such exchanges?

Answer (Toshihide Kamata)

Prosumer technology, in other words, is a concept of "self sufficiency," and ultimate venture when seen from another angle. Therefore, I think we must do away with the concept of role sharing, because I feel that if people are asked to exchange opinion based on their assigned role, things are less likely to be realized. For actual realization, I think it is important to raise consciousness: "I will be the implementer of prosumer technology." To accomplish this, it is necessary (1) to set up place for providing technological information, (2) to present model for taking leadership in methodology, and (3) to provide tool for actual implementation. Among these, I think, (1) and (3) should be positioned as public service from perspective of risk sharing. For (2), it is like showing a new technological lifestyle such as a second job. Public institution like AIST should suggest and show example of style of industrial technological society for both cases.

Question (Hiroshi Tateishi)

Looking at Tables 1 and 2 from the viewpoint of Discussion 1, I understand that the concepts are organized well, but there is no description of the positioning of AIST (Kamata Group). Is it possible to specifically describe the AIST strategy in these tables?

Answer (Toshihide Kamata)

Since this is a published paper, I avoided being too self-assertive, and I consciously refrained from the "we are" tone. Yet in fact, the analytical statement of this paper strongly states the position of AIST and our aim (leadership in technological concept, risk sharing, etc.). As you indicate, I consciously added the subject "we" in the revision.

4 Basic concept about technological development

Question (Naoto Kobayashi)

To consider material, process, and element as a set of technologies is extremely important. I also think the concepts of continuous development and planar development, where the integration with heterogeneous technologies that must be used for supplementation, are also important. I think these are common to the development of industrial technology in general. Are there any other characteristic issues unique to R&D for "flexible-printable device manufacture technology"?

Answer (Toshihide Kamata)

In technology in which many of the specs are determined by the end user, such as in information terminal device technology that "flexible-printable device manufacture technology" is involved, technology tends to be used for small-volume multiple-products, and the technological development takes nonlinear model without uniform indicator. In this case, if just one of the technological concepts does not fit with manufacturer's business concept,it does happen that consistency in material, element, and module cannot be maintained. As a result, in many cases, the technological concept fails to bloom as industry. There appears "a gap of technology" in a series of elemental technologies, and technological blossoming fails due to this limitation. Moreover, this "gap of technology" occurs not because of technological difficulty but due to business concerns, and no player is likely to show up no matter how long one waits.

The concept of "planar development" described in the paper does not express the necessity for gasping the overall picture to check our position, rather it tries to express the necessity for grasping the overall picture to prevent "gap of technology" as well as the fact that there are issues that must be tackled by players who share the risk in areas of "gap of technology." Also, I emphasized "continuous development" because I wanted to solve the problem that "technological development seem to be for single target application and one cannot see the depth of technology," which is common issue for technology for small-volume multiple-product application. By providing specific case where technology that may seem like single technology application can be developed sideways, we wanted to show the depth of technology, and that it is necessary to lower the entry barrier as player of technological development.

Question (Naoto Kobayashi)

I understood that the synthetic method as *Type 2 Basic Research* for this work is described in details in 4.4 "Presenting effectiveness and innovativeness of technology as product." Particularly, you explain that "multiple-source oxidation method" and "triaxial distributed pressure annealing method" are "supporting role technologies" that fill the "gap of technology," but the whole technology will not be complete without them, so I think they are extremely essential. As a synthetic method, it is understood as 'built-in type', *i.e.*, putting in the last piece to complete the whole puzzle. If this is the case, you may need an expression that emphasizes such role (rather than supporting role). What do you think about this, including my interpretation?

Answer (Toshihide Kamata)

I realize that "supporting role technology" is somewhat negative expression and not appropriate. As you indicated, it is technology absolutely necessary for total design. I changed the expression to "gap-supplementing technology" → "gap-filling technology" and "supporting role technology" → "last piece technology".

5 Strategy to assess individual elemental technology

Question (Naoto Kobayashi)

You have indicated that, "a device may not be created even with extremely superior technology, but even if some parts are inferior in performance, it may become effective technology if there is a good total performance." This seems very important. If this is called an '*optimally consistent device*', it depends on technological development strategy that how many individual elemental technologies composing the device are allowed, and that how much higher performance is sought in some of the composing technologies. Do you have any idea on how to assess them (or to determine what the optimum is)?

Answer (Toshihide Kamata)

Considering the fact that technology is accepted as it has advances against the existing ones , I think "optimall consistency" must be understood as function of time. Technology will be accepted if people can see clear differentiation against current status. However, it will not be accepted if the step of advancement is too big. Therefore, I think the first point in assessing technology is to recognize that "optimal consistency" must always walk in time, and to make sure that the differentiation can be clearly discernable in the footstep. How assessing is done means being able to recognize the differentiating point. I think it is important for the developers to go out in the society and brush up the feeling when they become a regular member of the society. I want to repeat the point again that in our technological field, technological specification is determined overwhelmingly by end user rather than manufacturer, and the important point is how to be socially oriented rather than technologically oriented.