

Disruptive Technologies: Opportunities for Organic Chemicals in Information Technology

OBI Naoki

Current information technology is based on a technology using silicon and related materials. This paper will look at the possibilities for new technologies that use organic materials and new manufacturing methods. Examples of innovations are light-emitting materials and electric circuits. This paper examines technologies and companies from the perspective of disruptive technology and business model. The results suggest that there are many opportunities for chemistry and chemicals to be used in new technologies for the development of displays, light-emitting materials and electric circuits. While the disruption of technologies is not easy to predict, however, it may occur if successful innovations emerge.

1 Models of Innovation and Disruptive Technology

Innovation, which is important for a company to grow, has been studied by a number of scholars over many years. Moreover, many models, such as the Schumpeter I and II models, the Incremental-Radical dichotomy model, the Abernathy-Clark model, the Henderson-Clark model, the Utterback-Abernathy model, the Tushman-Rosenkopf model, and Foster's S curve models, have been developed.¹⁾

Recently Christensen proposed a new framework for the impact of sustaining and disruptive technological changes. Christensen studied the history of hard disk drive industry from the viewpoint of innovation, disruption of technologies and companies in the industry. He proposed a framework based on the following findings.²⁾ The first finding is the distinction between sustaining technologies and disruptive technologies. Sustaining technologies are technologies that improve the performance of established products in the mainstream market. Disruptive technologies are new technologies that help develop new products, whose performance may not be as good as the established product but which bring new features and new customer value. Products made by disruptive technologies are generally cheaper, simpler, smaller, and frequently, more convenient to use. This ancillary performance from the viewpoint of the main market is an important element for disruptive technologies. The second finding is that sustaining technologies often overshoot market requirements. When performance of products based on sustaining technologies overshoot

the requirements of low-end users, they allow products based on disruptive technologies to enter the low-end market initially and the main market later on. The disruptive technology may improve its performance and compete with sustaining technology in the future. The third finding is that established companies cannot financially rationalize investment for disruptive technologies. This is because profit of new business is smaller than that of old business.

Established firms often fail when they are not able to manage disruptive technologies and try to fight against them with their existing technologies. One of the key findings is that the companies that entered emerging market has much higher success rate and higher sales.³⁾

Another important suggestion of disruptive technology is that there may be no market for disruptive technology in the beginning or prior to the commercialization. Learning and discovery are very important to manage disruptive technology.⁴⁾ Examples of those disruptive technologies are Honda motorcycles in North American market and Intel microprocessors according to Christensen.⁵⁾ Honda's little 50 cc Supercub was much smaller than other bikes and had no market when it was first introduced. It created a new market and then became an established motorbike years later. Intel's original microprocessor was used for a Japanese calculator. This microprocessor was small and simple but had limited capability compared with the circuit used in the large computers. However, the Intel's microprocessors became the company's robust business years later.

2 Selected New Technologies

This section will focus on new technologies such as organic light-emitting diodes (OLED), solar cells and electric circuits (conducting polymer). These technologies are chosen not only because chemicals play an important role but also because the products and technologies are closely interrelated. Conducting polymers for conventional use such as anti-static applications are excluded from the discussion.

2.1 Organic Light Emitting Diodes (OLEDs)

There are two types of OLED: one is a low-molecular type and the other is a polymer type. The technologies for both are closely related to the technologies previously developed for other applications such as organic photoconductors (OPC) for copy machines and p-n junction of organic compounds for solar cells. The first organic light-emitting diode was developed in the 1960s and used anthroquinone. The breakthrough was made by Kodak (published in 1987) using new light emissive materials (tris-[8-hydroxyquinolynite] aluminum). Organic light-emitting diode and conducting polymer have received great attention, particularly so since Prof. Hideki Shirakawa, Prof. Alan J. Heeger and Prof. Alan G. MacDiarmid received the Nobel Prize in 2000. The first OLED display was commercialized by the Japanese electronics company, Pioneer Corporation, in 1997, and was used for electronics equipment for automobiles.

OLED technology has advanced significantly in recent years. The advantages of organic light-emitting diode compared with liquid crystal display include response time and viewing angle. Large-size, full-color displays have not yet been developed. However, Sony has announced in February 2001 its intention to complete the building of the production technology for a 13-inch full-color display with Universal Display Corporation (UDC) by 2003⁶⁾ Samsung announced the success of a prototype of 15.1-inch full-color display in November 2001^{7,8)} In March 2003 Chi Mei Optoelectronics (CMO) announced a prototype of a 20-inch full-color display based on OLEDs by International Display Technology (IDTech).⁹⁾ Among the companies and universities doing leading research in organic light-emitting diode are Cambridge Display Technology (CDT)^{10,11)}, Uniax Corporation^{12,13)}, Universal Display Corporation

(UDC)^{14,15)}, and Eastman Kodak Company.¹⁶⁻²⁰⁾

2.2 Conducting Polymer and Electric Circuits

Current inorganic microelectronic devices are generally fabricated with techniques such as diffusion, thermal oxidation, ion implantation, photolithography, etching, evaporation, sputtering, chemical vapor deposition (CVD) and high-temperature (>1000 °C) film growth. New technologies using organic compounds as functional materials or a dispersion of inorganic nanocrystals are emerging to make electric circuit, transistor, memory, and related materials such as transparent plastic electrode. Unlike the current silicon-based technology, the new technology offers, if successful, a simple and less expensive manufacturing method (printing) for new applications. The potential applications of electric circuits using polymers and organic semiconductors are flat panel displays, electronic tags, smart cards, anti-counterfeit devices, medical diagnosis tools, memory, sensors, disposable electronics and wearable computing. Among the companies and universities doing leading research in conducting polymers and electronic circuit are Elecon^{21,22)}, Plastic Logic^{23,25)}, Lucent Technology / Bell Labs^{26,27)}, Rolltronics Corporation^{28,29)}, FlexICs^{30,31)}, MIT's Media Lab^{32,33)} and Alien Technology.³⁴⁾

2.3 Solar Cell³⁵⁻³⁹⁾

The first application of the photovoltaic solar cell was for satellites in the 1960s. In the 1970s, ground-based applications started. Though the market is growing, price and energy conversion efficiency are key for the wide use of solar cells. Solar cells are clean and offer infinite energy. On the other hand, solar energy has wide fluctuation and low density as drawbacks. Most of the solar cells used in practice are silicon-based. New type solar cell called Graetzel cell started attracting a great deal of attention in the 1990s. Graetzel cell uses dye-sensitized titanium dioxide. Its use of liquid electrolytes is one of the major disadvantages because of the lack of stability and operation temperature. University of Cambridge's Cavendish Laboratory and the Max-Planck-Institute for Polymer Research reported a new photovoltaic thin film or self-assembling solar cell that uses the combination of crystalline dye and discotic liquid crystal. Photodiodes made from the films

show external quantum efficiencies of 34% around 490 nm wavelengths. The film can be made directly from solution. Among the companies and universities are Konarka⁴⁰⁾, Sharp Corporation⁴¹⁾ and University of Cambridge.⁴²⁻⁴⁵⁾

2.4 Electrophoresis Display

The concept of electrophoresis displays has been known for years. Many other display technologies are proposed for potential use such as electronic books. Among those new technologies are the polymer dispersed liquid crystal (PDLC) display, polymer network (PN) liquid crystal display and cholesteric liquid crystal display. Electrophoresis display started attracting researchers as a potential application for electronic book especially because of bistability (low power consumption) and high contrast. Among the organizations doing leading research in electrophoresis display are E Ink⁴⁶⁻⁵⁰⁾ and Gyricon.⁵¹⁾ The E Ink electronic display is a reflective electronic display that uses electrophoretic ink. The principal components of electronic ink are microcapsules that contain positively charged white particles and negatively charged black particles suspended in a clear fluid. A black and white image can be achieved by electro migration of black and white particles. E Ink's first commercial product is a display called Ink-in-Motion™. It is a motion display with preset content for advertising at the point of purchase.

2.5 Fabrication Process

The fabrication process is important in the manufacture of products. Process innovation has played an important role in many manufacturing industries. Patterning technology is also important in the manufacturing of many devices. Photolithography, which uses photo mask and photo resist, is the dominant method for patterning used in the semiconductor industry. There are many technologies for patterning. Among those are nanomachining such as STM and AFM, printing, imprinting, soft lithography and near-field phase-shifting photolithography.^{52,53)}

Soft lithography⁵⁴⁻⁵⁶⁾ is a non-photolithographic method based on self-assembly that has the potential to fabricate nano- and micro-scale structures and allows two-dimension structure control, and micro patterning or three-dimensional control of device structures. There are some shortcomings, however, such as deformation of the stamp, defects in the pattern and difficulty of precision registration. Cost is expected to be reduced (much lower cost). Traditional performance is not as good as current lithography because soft lithography may have poorer lateral dimensional stability and more defects compared to the conventional fabrication methods such as photolithography and CVD (chemical vapor deposition). Soft lithography is not probably a direct competitor to photolithography. Ancillary performance is better because soft lithography process produces smaller features than photolithography. Bioassay for the pharmaceutical industry is an example

Table 1 Selected Technologies and Products

Technology	OLED	Electrophoresis	Conducting Polymer	(Semi-) Conducting Polymer/Organic Chemicals	Graetzel Cell
Product	Display	Display	Circuit (ITO substitute)	Circuit (organic transistor)	Organic solar cell
Cost	Down (in future)	Down (in future)	Down (in future)	Down (in future)	Down (in future)
Traditional Performance	Up	Depends on application	Up & down	Up & down	?
Ancillary Performance	Up (vs. LCD)	Up (vs. LCD)	Up (vs. ITO)	Up (vs. inorganic)	Up (vs. inorganic)

of application of soft lithography. Surface Logix produces advanced miniature bioassays based on the work of Prof. George Whitesides in soft lithography.⁵⁷⁾

3 Analysis from the Viewpoint of Disruptive Technology and Business Model

Products, including proposed products that have not yet been commercialized, examined in this study show the general trends outlined in Table 1.

1. There are great uncertainties in traditional performance.
2. Most of the technologies and products focus on low price and better ancillary performance such as low cost of manufacturing in organic electric circuit and flexibility in conducting polymer for electrode.
3. Companies that are active in the fields studied are different from the existing incumbent companies in many cases.
4. Most of the technologies and products are not focusing on expensive and better traditional performance to compete with existing technologies and products.

It is not easy to discuss disruptive technology because there are many new technologies that compete with existing products in many different ways and because there are many possible disruptions in one category of technologies and products. For example, many companies are pursuing different approaches to organic light emitting diode.^{58,59)} Whether or not there is replacement or disruption of companies depends on the performance the company achieves and the strategy it takes.

If we compare liquid crystal display with organic light emitting diode, for example, organic light emitting diode has a potential to become disruptive technology. The definition of traditional and ancillary performance depends on the applications for organic light emitting diode. It is reasonable to conclude that organic light emitting diode do not have better traditional performance with respect to color reproduction and lifetime at this point. However, organic light emitting diodes offer better performance with respect to a wide visual angle, a high response time and a thinner

structure than liquid crystal display. This performance allowed organic light emitting diode to be used in applications such as audio appliance for automobiles and PDA, while they are competing with liquid crystal display in terms of traditional performance. Whether or not there is a disruption of technologies depends on the performance of the products. It is important for organic light emitting diode to create a market such as lighting and very different product such as a display for clothes because the market may be limited if the product is a replacement of existing liquid crystal display.^{60,61)}

It is interesting that the liquid crystal display has been widely accepted as a display even though liquid crystal display is generally more expensive and has lower visual performance than CRT. This is because the ancillary performance of liquid crystal display, size and low power consumption, is essential for mobile applications. In other words, mobility of display is more important than traditional performance in the case of applications for mobile applications. If the market values the ancillary performance or if the ancillary performance opens a new market as in the case of liquid crystal display, then organic light emitting diode have great potential to successfully create value.

It is interesting that organizations that are active in the development of new technologies studied in this paper are quite often different from the incumbent companies in the industry itself. For example, Cambridge Display Technology (CDT), Universal Display Corporation (UDC), Uniax, and Kodak are actively developing organic light emitting diode material, however, these companies are not major players in the liquid crystal display market. On the other hand, IBM and Lucent Technologies are developing new technologies (organic electric circuit) in addition to developing current technologies (silicon base technologies).

Performance /cost is an important factor for organic electronics for diffusion. Main analyzed the performance/cost and advantages for light emitting polymers. She suggested that light-emitting polymer for TV, computer monitor is a revolutionary innovation, and that for wireless application is an architectural innovation.⁶²⁾

In conclusion, the possibility that the above technologies or products may become disruptive

technologies cannot be excluded because the overall observation fits the definition of a disruptive technology.

1. The companies believe that products such as organic light emitting diode, electric circuit and organic solar cells are less expensive when the products are in full production (organic light emitting diode, electric circuit by coating or self-assembly).
2. The companies are focusing on ancillary performance (for example flexibility).
3. Traditional performance is probably not as good as that for current products.
4. Active research groups are different from mainstream groups in the industry.

However, whether or not a new technology becomes a disruptive technology strongly depends on the performance of a new product; in other words, it depends on the existence of innovation and scientific discoveries.

The business models vary by company and in some cases is still not clear. The business models include most of the possible models for chemical and materials companies including the following:

1. Manufacturing and sales of materials
2. Manufacturing and sales of components
3. Manufacturing and sales of final products
4. Technology licensing

Many strategic partnerships are observed in the areas studied. For example, CDT has formed partnerships and alliances with various companies such as materials, components and OLED panel manufacturing companies. Incumbent companies also have similar alliances and partnerships. Among the models, licensing-only business model seems to be the least attractive business model among the companies studied.

Fig.1 shows the source of the key technology for the companies studied. The original source of technologies is not clear for some of the start-up companies. However, many start-up companies started with a technology originally developed at a university or national laboratory. Professors and researchers from the organizations where the original research was conducted are sometimes involved in the start-up companies. Large companies have several choices; internal R&D, equity investment, alliances and

acquisitions. Evaluation of the source of the key technology for incumbent companies was not clear in some cases because internal research activities have not been studied. The fact that companies pursued sources of new technologies outside their organizations does not necessarily mean that they weren't also conducting in-house research at the same time.

4 Conclusion

Followings are the summary of general observations in the fields studied.

1. New technologies for, and companies producing, organic light emitting diodes (OLED), organic solar cells, conducting polymers for electric circuit, organic transistors, single molecular memory, and manufacturing architectures are emerging.
2. The new technologies compete with existing technologies.
3. The new technologies are focusing on inexpensiveness and ancillary performance.
4. Many of the new technologies are immature.
5. New concepts of manufacturing technologies are also emerging.
6. New technologies tend to emerge from organizations other than mainstream technology companies.
7. Scientific research plays an important role.
8. The key technologies of start-up companies tend to originate from academic institutions and national

Source of key technology	Outside company	A, B, C, D, E, F, G, H	I, J, K, L, M, N, O, P, Q, R, S, T, U, V
	Inside company		W, X, Y, Z, AA
		Start-up	Incumbent
		Company	

Fig.1 Matrix analysis of source of key technology for start-ups and incumbent companies. (Company names are shown by alphabet.)

laboratories.

9. Leading technology development companies are for the most part seeking strategic partners.

10. Start-up companies and incumbent companies are developing similar technologies in many cases.

11. It is not clear whether new technologies are disruptive technologies in the beginning stages.

Observing the new technologies studied reveal the following general trends.

1. They focus on inexpensiveness.

2. Initial product performance may not be as good as that of the current product.

3. New technologies are not emerging from mainstream research groups.

While the above three trends suggest the technologies studied may be disruptive technologies, it is too early to make a definitive claim. Ultimately, it will depend on the performance achieved. It seems that disruption of technologies is “ a result ” and is hard to predict when the technology is immature. In the case of organic light emitting diodes (OLEDs), the fact that OLEDs started taking off as a business in some applications, such as car audio displays for example, and that over all observations follow the concept of disruptive technology suggests the possibility that a disruption of technology (from liquid crystal displays to organic light emitting diodes) cannot be excluded. Whether or not OLEDs become a disruptive technology, however, depends on the future innovation.

Current information technology is based on silicon-base integrated circuits, CRTs, and liquid crystal displays. The transistor was invented by Dr. John Bardeen, Dr. Walter Brattain, and Dr. William Shockley at Bell laboratories in 1947 in the US. The transistor replaced the vacuum tube, which was invented by Sir John Ambrose Fleming (University College) in 1904 in England. The integrated circuit was invented by Mr. Jack Kilby at Texas Instruments in 1958 in the US. The integrated circuit market has grown considerably since Kilby’s discovery and in 2000 stood at \$177 billion. The end equipment market is worth nearly \$1,150 billion.⁶⁵⁾ The CRT was invented by Dr. Karl Ferdinand Braun in 1897 in Germany. CRT sold 240 million sets (\$25 billion) in 1997.⁶⁴⁾ Liquid crystal display was invented by RCA in the 1960s in the US. Liquid crystal displays sold 32 million sets (910 billion yen, approximately \$9 billion) in

1997.⁶⁵⁾ Those data show that silicon-base integrated circuits, CRTs, and liquid crystal displays have created great value.

Dr. Gordon E. Moore, of Fairchild Semiconductors (now Intel Corporation), predicted that the number of transistors per integrated circuit would double every two years and that this trend would continue through 1975.⁶⁶⁾ Moore’s Law has been maintained for far longer than initially predicted because of continuous innovations. The number of transistors per chip increased from 5,000 (Intel 8080) in 1974 and had reached 42,000,000 (Pentium 4) by 2000.⁶⁷⁾ However, the cost of manufacturing plants has also increased significantly. Each plant cost \$3 billion in 1998.⁶⁸⁾ It is estimated that the cost of a plant will increase to \$50 billion in 2010 assuming that the cost continues to increase at the same rate in the past.⁶⁹⁾

Although silicon technology continues to improve, it is not clear how much further it can improve. Is there a possibility that new technologies such as plastic electronics could replace some part of the silicon technology or create a new market that would result in silicon technology having difficulty creating value in the future? Those questions are hard to answer. However, the possibility cannot be excluded because there is much research and development attempting to create value in the area of organic light emitting diodes (OLED), organic solar cells, conducting polymers for electric circuits, organic transistors, molecular memory, and manufacturing architectures.

本報はマサチューセッツ工科大学スローンスクールに提出した論文の一部を加筆修正したものである。

References

- 1) Allan Afuah, *Innovation Management* (New York, NY: Oxford University Press, 1998), p.13.
- 2) Clayton Christensen, *The Innovator’s Dilemma* (Boston, MA: Harvard Business School Press, 1997).
- 3) Ibid., p. P121.
- 4) Clayton Christensen, “ Discovering new and emerging markets ” , Chemtech (September 1997), p. 42.

- 5) Ibid.
- 6) Sony, home page
(<http://www.sony.co.jp/SonyInfo/News/Press/200102/01-007/>).
- 7) Samsung, home page
(<http://www.samsung.co.jp/news/group/ng011101>).
- 8) Nikkei Electronics On Line
(<http://ne.nikkeibp.co.jp/FPD/2001/11/1000008786>).
- 9) International Display Technology Inc., home page,
(<http://www.idtech.co.jp/en/news/press/20030312.html>)
- 10) Cambridge Display Technology, home page
(<http://www.cdtltd.co.uk>).
- 11) The Japanese Research Association for Organic Electronics Materials, *Yuki LEDsoshi no nokosaretajyuuyokadai to jitsuyokasenryaku* [Important issues and commercialization strategies of organic LED devise] (Tokyo: Bunshin Publishing Co., 1999), p.145.
- 12) California Council on Science and Technology, vol. 6, issue 1 (January 2001),
(<http://www.ccst.ucr.edu/ccst/pubs/nwsltr/v6i1/v6i1.html#ucsb>).
- 13) Uniax, home page (<http://www.uniax.com>).
- 14) Universal Display Corporation, home page
(<http://www.universaldisplay.com>).
- 15) V. Bulvoc, R. Deshpande, M. E. Thompson, S. R. Forrest, " Tuning the color emission of thin film molecular organic light emitting devises by the solid solvation effect " , Chemical Physics Letters vol. 308 (1999), pp. 317-322.
- 16) Kodak, home page (<http://www.kodak.com>).
- 17) The Japanese Research Association for Organic Electronics Materials, *Yuki LEDsoshi no nokosaretajyuuyokadai to jitsuyokasenryaku* [Imprtant issus and commercialization strategies of organic LED devise] (Tokyo:Bunshin Publishing Co.,1999), p.1.
- 18) C. W. Tang and S. A. VanSlyke, " Organic electroluminescent diodes " , Applied Physics Letters, vol. 70 (1987), p. 913.
- 19) C. W. Tang and S. A. VanSlyke, " Electroluminescence of doped organic thin films " , Journal of Applied Physics, vol. 65 (1989), p. 3610.
- 20) C. W. Tang, " Two-layer organic photovoltaic cell " , Applied Physics Letters, vol. 48 (1986), p. 183.
- 21) Elecon, Inc., home page
(<http://www.eleconinc.com>).
- 22) Elecon Technical Report, PIN-EF02-02-28.
- 23) Plastic Logic, home page
(<http://www.plasticlogic.com>).
- 24) Chemical and Engineering News, vol.79 no. 1 (January 2001), p. 26.
- 25) Tracy Staedter, " Plastic Logic " , Technology Review (September 2001),
(<http://www.technologyreview.com/magazine/sept01>)
- 26) Bell labs, home page (www.bell-labs.com).
- 27) Barbara Goss Levi, " New Printing Technologies Raise Hopes for Cheap Plastic Electronics " , Physics Today vol. 54, no. 2 (2001), p. 20.
- 28) Rolltronics Corporation, home page
(<http://www.rolltronics.com>).
- 29) Wade Roush, " Flexible transistor on a roll " , Technology Review (January 2002).
- 30) FlexICs Inc., home page (<http://www.flexics.com>).
- 31) Mark LaPedus, " Here come plastic ICs from startup FlexICs " , Semiconductor Business News (September 26, 2001),
(<http://www.siliconstrategies.com/story/OEG20010926S0027>).
- 32) MIT Media Lab., home page
(<http://www.media.mit.edu>).
- 33) Brent A. Ridley, Babak Nivi, and Joseph M. Jacobson, " All-Inorganic Field Effect Transistors Fabricated by Printing " , Science, vol. 286 (1999) pp. 746-749.
- 34) Alien Technology, home page
(<http://www.alientechnology.com/>).
- 35) The New Energy and Industrial Technology Development Organization (NEDO), home page
(<http://www.nedo.go.jp/taiyo/eng/intro/index.htm>)
- 36) Sharp Co., home page
(<http://www.sharp.co.jp/sc/library/sun/sun4-5.htm>).
- 37) CEA/DCom - INTERNET WEB SITE
(<http://www.cea.fr/gb/>).
- 38) Nippon Keizai Shinbun, April 19 (2002).
- 39) Solar Cell, Kinozairyō [Functinal Materials] vol. 16, no. 4 (April 1996) p. 57.
- 40) Konarka, home page
(<http://www.konarkatech.com>).

- 41) Nippon Keizai Shinbun, April 19 (2002).
- 42) Nippon Keizai Shinbun, April 19 (2002).
- 43) Jenny Nelson, " SOLAR ENERGY: Solar Cells by Self-Assembly? ", Science, vol. 293 (2001), pp.1059-1060.
- 44) L. Schmidt-Mende, A. Fechtenkter, K. Mlen, E. Moons, R.H. Friend, J.D. MacKenzie " Self-organized discotic liquid crystals for high efficiency organic photovoltaics " vol. 293 (2001), pp. 1119-1122.
- 45) Pamela Zurer " SELF-ASSEMBLING SOLAR CELLS-Crystalline dye and liquid crystal self-organize into photovoltaic thin film ", Chemical & Engineering News, vol..79, no.33 (August 13, 2001), p. 9.
- 46) E Ink, home page (<http://www.eink.com>).
- 47) Barrett Comiskey, Jalbert, Hidekazu Yoshizawa, and Joseph Jacobson, " An Electrophoretic Ink for All-Printed Reflective Electronic Displays " , Nature, vol. 394 (1998), p. 253.
- 48) *Flat Panel Display 2001 part 1 and part 2* (Tokyo: Nikkei Business Publications, Inc., 2001).
- 49) Toppan Printing Co., Ltd., home page. (<http://www.toppan.co.jp/aboutus/release/article474.html>).
- 50) Steve Ditlea, " The Electronic Paper Chase " Scientific American (November 2001).
- 51) Xerox Parc, home page (<http://www2.parc.com/dhl/projects/gyricon/>)
- 52) Younan Xia, John,Rogers, Kateri Paul, and George Whitesides, " Unconventional Methods for Fabricating and Patterning Nanostructure " , Chem. Rev., vol. 99, no. 7 (1999), p.1823-1848.
- 53) National Institute of Advanced Industrial Science and Technology (AIST), press release (http://www.aist.go.jp/aist_j/press_release/pr20020121/pr20020121.html).
- 54) David H. Gracias, Joe Tien, Tricia L. Breen, Carey Hsu, and George M. Whitesides, " Forming Electrical Networks in Three Dimensions by Self-Assembly " , Science, vol. 289 (August 18, 2000), pp. 1170-1172.
- 55) Younan Xia and George Whitesides, " SOFT LITHOGRAPHY " , Annu. Rev. Mater. Sci. vol. 28 (1998), pp. 153-184.
- 56) Surfacelogix, home page (<http://www.surfacelogix.com>).
- 57) Surfacelogix, home page (<http://www.surfacelogix.com>).
- 58) *Flat Panel Display 2001 part 1 and part 2* (Tokyo: Nikkei Business Publications, Inc., 2001).
- 59) Tsuyoshi Numagami, *Ekisho dhisupurei no gijyutsukakushinshi* [History of technological innovation of liquid crystal display] (Tokyo: Hakutoshobou, 1999), p. 351.
- 60) Asahi News Paper (<http://www.asahi.com>).
- 61) Arpad Bergh, George Craford, Anil Duggal, and Roland Haitz, " *The Promise and Challenge of Solid-State Lighting* " , Physics Today, vol. 54, no. 12, (December 2001), p. 42.
- 62) Elicia M A. Main, " Innovation and Adoption of New Materials " , Ph.D. Thesis, (September 2000), p.97.
- 63) Texas Instrument home page (<http://www.ti.com/corp/docs/kilbyctr/jackstclair.shtml>)

- 64) *Denshibuhinnenkan 1998* [Annual report of electronic parts 1998] (Tokyo: Chunchisha, 1998), p. 197.
- 65) Ibid., pp.139-140. Number of sets includes middle and large size panels and excludes small size panels.
- 66) Intel home page
(<http://www.intel.com/research/silicon/mooreslaw.htm>)
- 67) Ibid.
- 68) Michael Brooks, “ *Quantum Computing and Communications* ” (London, Springer Verlag, 1999), p.66.
- 69) Ibid.



本社 技術部
課長
小尾 直紀
OBI Naoki