Social Factors Affecting Innovation Cycle of Liquid Crystal Technologies : A Japanese Case Study

Narazaki, Yu
Department of Applied Science for Electronics and Materials, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Watanabe, Tomoaki
Green Asia Education Centre, Kyushu University

https://doi.org/10.5109/1929676

出版情報：Evergreen. 4 (4), pp.8-15, 2017-12. Green Asia Education Center
バージョン：

Social Factors Affecting Innovation Cycle of Liquid Crystal Technologies: A Japanese Case Study

Yu Narazaki[1,*], Tomoaki Watanabe[2,*]
[1]Department of Applied Science for Electronics and Materials, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan
[2]Green Asia Education Centre, Kyushu University, Japan

*Author to whom correspondence should be addressed,
E-mail: narazaki.y.195@s.kyushu-u.ac.jp (Y.N.), watanabe.tomoaki.384@m.kyushu-u.ac.jp (T.W.)

(Received August 12, 2017; accepted October 16, 2017).

This paper describes how to visualise and resolve the gap between nematic liquid crystal (NLC) technology and blue phase liquid crystal (BPLC) technology for liquid crystal displays (LCDs) based on their hype cycles and a comparative literature and patent search. In comparing the result of their hype cycles to the social and economic factors affecting technological innovation in Japan, the inadequacy of scientific advances in BPLC technology was ascertained. This insufficiency caused a reduction in the number of firms related to BPLC technology in Japan, as the driving force of technological innovation consists of the strength of the R&D work taking place in Japanese private enterprises. We concluded that the venture policies of the Japanese government would play an important role in resolving that inadequacy.

Keywords: Liquid crystal technologies, hype cycles, managing innovation.

1. Introduction

Why is there a technology gap between nematic liquid crystal (NLC) and blue phase liquid crystal (BPLC) technology for liquid crystal displays (LCDs)? NLC technology is utilised in conventional LCDs,[1)] liquid crystal (LC) lenses[2)] and other products. By contrast, BPLC technology is a strong candidate for next-generation LCDs because it consumes low energy and offers greater resolution compared with conventional LCDs.[3)] However, LCDs utilising BPLCs has never been commercialised, although scientific solutions for the application of its technology to LCDs have been reported, such as the large temperature range for BPLC available through polymer-stabilised BPLC (PSBPLC)[4)] and low voltage driven PSBPLC.[5)] There remains a technology gap in respect to the application to LCDs of BPLCs.

LCDs can become full-colour displays if they are utilised as a matrix optical shutter. There are two types of full-colour display systems, known as the colour filter system[6)] (CF system) (Fig. 1a), and the field sequential colour system[7)] (FSC system) (Fig. 1b). Commercial LCDs have currently been adopted to a CF system. This system divides white back light into three-colour light (red, green and blue) in pixels with RGB colour filters to produce full colour by mixing their divided light. This system mainly uses NLCs, fluorinated NLCs, as a matrix optical shutter. It possesses the great advantage that it is

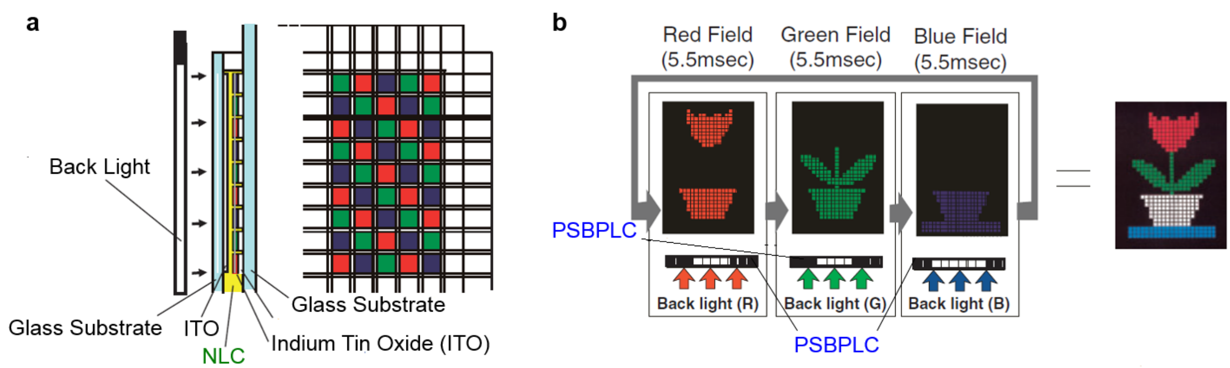

Fig. 1: Schematic illustrations of a (a) CF System and (b) FSC System {as schematically illustrated in Ref. 1}

easier to use with conventional LCDs, since it is a completed technology. There remain, however, several problems to be solved, such as the fact that the light transmittance is low due to the redivision of back light into three colours in a pixel and the manufacture of colour filters is complicated and requires advanced processing technology. On the other hand, a FSC system is also a colour display system that turns on RGB back light sequentially in a quick manner and simultaneously drives a rapid response in LC materials, resulting in a PSBPLC, as a matrix optical shutter. Moreover, the minimum response time for this system is required to be less than 5.5 milliseconds. Such a system has the three following considerable advantages due to its lack of need of colour filters: higher resolution and luminescence, low energy consumption and simplicity of manufacturing.[3,7] Hence, if BPLC technology can be developed for practical use in LCDs, novel LCD innovation might occur in the LCD field, because BPLC technology has potentially overwhelmed the above-mentioned disadvantages of NLC technology. Japanese private enterprises and research institutes are masters of far more advanced techniques in LC technologies than when they have been developed in Japan.[8] Furthermore, if BPLC technology able to be used with novel LCD technologies is newly developed in Japan, technological innovations in the LCD field are likely to be brought about in Japan. This innovation will have considerable impact on Japanese economy and society.

To date, considerable scientific research on BPLC technology has been reported in narrowing the technological gap between NLC and BPLC technology.[9] Besides, a prototype BPLC-mode LCD utilising an FSC system had been demonstrated by Samsung, in 2008.[10] However, social solutions for this technological gap and investigation methods have never been investigated.

In this study, we explore the causes of the technology gap. First of all, we identify this gap between technologies quantitatively, in terms of relevant articles and patents. Next, based on Gartner's technological hype cycle, we attempt to situate differences in technological development in several phases.[11] Furthermore, we examine social and economic factors behind each technological phase of each technology.

Here, we elucidate that the driving force of technological innovation depends on strength of the R&D work taking place in Japanese industries. However, the active attitude of Japanese enterprises toward investment in R&D has disappeared during the 'lost 20 years'. Thus, it is impossible to deduce the amount of technological innovation of the BPLC technology by emulating the successful past strategies. The Japanese government must, therefore, promote social solutions for its technology gap through its economic policy.

We present the evaluation methods for the visualisation of the technology gap between NLC and BPLC technology and graph their hype cycles in the following sections. The relationship between the role of the government and social factors in the induction of the latest LC technology, *i.e.* BPLC technology, is discussed through the results of the technological hype cycles in Chapter 3.

2. Evaluation Methods

2.1 Quantification of the technology gap between NLC and BPLC technology

The technology gap was quantified by the number of relevant articles and patents for each year. The period under investigation was classified into two: the earliest period, when fundamental LC research attracted much attention from 1888 to 1973, and the developing period, when LC research was mainly applying research to LCDs, lasers, thermometers, and more, from 1973 to 2016. The technology of the earliest period was quantified by a literature search based on the bibliography of Dumur and Sluckin.[10] That of the developing period was gauged by a patent search *via* a patent search engine on the official website of the European Patent Office.

2.2 Graphing the hype cycles of NLC and BPLC technology

The hype cycles of NLC and BPLC technologies were developed *via* the number of their relative patent applications which corresponds to expectations in the Y axis of a hype cycle. The expectations of these technologies were calculated from Equation 1.

$$E = (X - x_{min})/(x_{max} - x_{min}) \qquad 1)$$

where E is the expectation, X is the value of the number of their relative patent applications for each year, x_{max} is the maximum value of their relative patent applications and x_{min} is the minimum value of their relative patent applications. These hype cycles were smoothened with a moving average method of five years.[12] The investigation period of the NLC technology was defined to extend from 1968, when G. Heilmeier reported a novel display technology *via* the principle of dynamic scattering of NLC to 2007, when the world's LCD shipment volume exceeded that of cathode-ray tubes.[14] On the other hand, the period of BPLC technology was defined as extending from 2002 to 2016, when H. Kikuchi discovered PSBPLC[4] and opened new fields of applications in next-generation LCD such as blue-phase-mode LCD, to the end of the data.

3. Results and Discussion

3.1 Visualisation of the technology gap between NLC and BPLC technology

There is a clear technology gap between NLC and BPLC in the earliest and developing period, shown in Fig. 2a and b. it is possible that the crucial factors in the gap is recognition their LC materials, referring to a NLC and BPLC in their earliest periods. G. Friedel, Professor of Geology at the University of Strasbourg, recognised a certain kind of a LC as a NLC on the evidence of his experimental results and published an important review paper on the classification of LCs in 1922.[15] Articles related to this show the first tendency of increase, from 1926 to 1940, in Fig. 2a, because this recognition was a widespread fact and LC scientists (mainly European) at the time accepted it and were interested in it. On the other hand, a BPLC was accepted as a concept in 1973.[16] Research focusing on a BPLC was delayed by over 50 years approximately when compared with researches that centred on a NLC. Hence, the gap between them widened in the earliest period. Another factor was the globalisation of LC research. After World War II, two American chemists, G. H. Brown and W. G. Shaw, published the first review paper on LCs in English in 1957.[17] This paper breathed new life into LC research in the United States and other countries. Further, a liquid crystal institute was established in 1965 at Kent State University in the U. S. In the same year, the first official conference on liquid crystal research, called 'the first International Liquid Crystal Conference' was held at Kent State University. One year later, the first specialised journal on liquid crystal research, *Molecular Crystals and Liquid Crystal* began to be published. LC scientists had great opportunities to share their experimental results toward all over the world. This research began to be globalised from the time the LC research community was built. LC technology, therefore, developed rapidly from the 1960s to the present time. In particular, G. Heilmeier of the Radio Corporation of America (RCA) reported a novel display technology using the principle of dynamic scattering of a NLC in 1968.[13] LC researchers at the time came to know of this great breakthrough when RCA announced the first LCD utilising the advanced methods in May 1968.[10] Research focused on NLC technology for application in a display technology. Consequently, the number of articles of NLC technology increased from 1968 to 1973 and the technology gap between them was broadened. Hence, there are two causes of the gap in periodisation in these technologies and the higher demand for research NLC thanks to the globalisation of LC research in the earliest period.

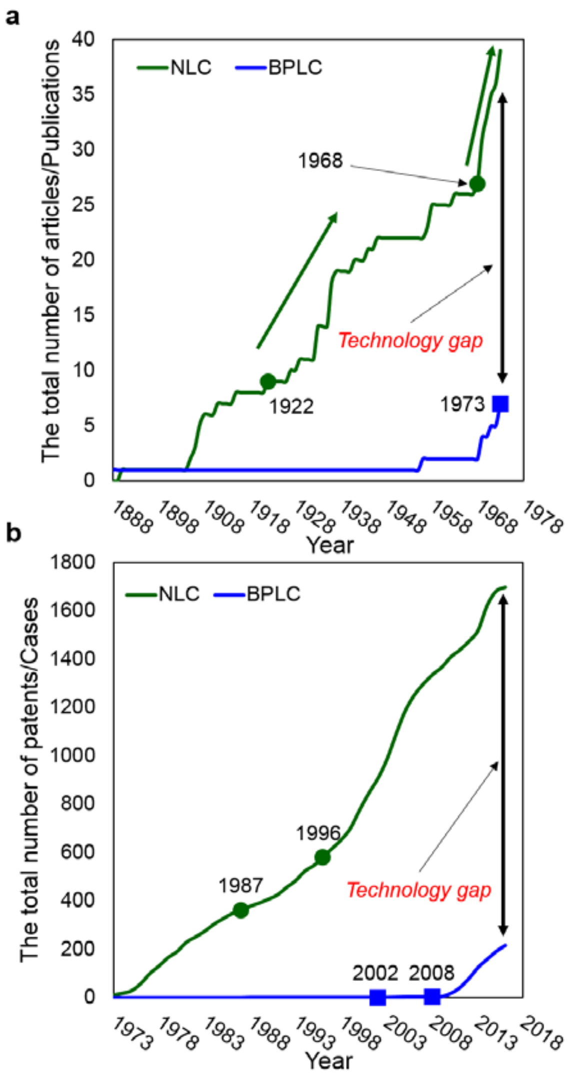

Fig. 2: The curves of the number of (a) relative articles in the earliest period and (b) patents in the developing period of the NLC and BPLC technology.

The data for the next point to be discussed fall in the developing period. From 1973 to 2016, a larger number of patents on NLC technologies were submitted by various universities and companies than those proposed on BPLC technologies. This behaviour is likely due to the commercialisation of the LCD utilising a NLC. Applied research on LCDs attracted greater attention since Heilmeier's breakthrough. A pocket calculator utilizing NLC technology was firstly put on the market by Sharp Corporation in 1973.[18] Moreover, Sharp then produced a full-colour TV, called Crystaltone, in 1987.[19] In 1996, there began to be produced large screen LCDs.[19] The commercialisation of LCDs had an impact on the field of LC research and the LCD market. By contrast, much effort was devoted to fundamental research on a BPLC, both theoretically and experimentally, in the 1980s.[20] However, few BPLC researchers were able to find a market value for its application, because it had the issue of a narrow available temperature range. Study of a BPLC was gradually disappearing from LC research. In 2002, applied research was revived by H. Kikuchi *et al*., who reported PSBPLC.[4] Six years later, market value arrived, because a prototype LCD utilising PSBPLC was demonstrated by Samsung.[10] After their enormous breakthrough, the number of patents in respect to the BPLC technology increased from 2009 to 2016. Thus, higher market values cause the expansion of the technology gap, since for several decades, NLC materials possessed higher value from due to its application in LCDs than a BPLC did.

3.2 Hype cycles of the NLC and BPLC technology

The hype cycle is shown in Fig. 3. It shows five phases: Technology Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment and Plateau of Productivity.[11] Technologies generally pass these phases. The phases are explained below.

- Technology Trigger: The hype cycle starts when a breakthrough, public demonstration, product launch or some other event generates press and industry interest in a technology innovation.
- Peak of Inflated Expectations: A wave of buzz builds, and expectations for this new technology rise above the current reality of its capabilities. In some cases, an investment bubble forms, as happened with the Web, social media and cloud computing.
- Trough of Disillusionment: Inevitably, impatience for results begins to replace the original excitement over potential value. Problems with performance, slower-than-expected adoption or a failure to deliver financial returns in the time anticipated all lead to disappointed expectations, and disillusionment sets in.
- Slope of Enlightenment: Some early adopters overcome the initial hurdles, begin to experience benefits and recommit efforts to move forward. Drawing on the experience of the early adopters, understanding grows about where and how the technology can be used to good effect and, just as importantly, where it brings little or no value.
- Plateau of Productivity: With the real-world benefits of the technology demonstrated and accepted, growing numbers of organisations feel comfortable with the now greatly reduced levels of risk. A sharp uptick (‘hockey stick’) in adoption begins, and penetration accelerates rapidly as a result of productive and useful value.

NLC went through all five phases, as shown in Figure 4a. Its Phase I, Technology Trigger, was from 1968 to 1973. Phase II, Peak of Inflated Expectations, was from

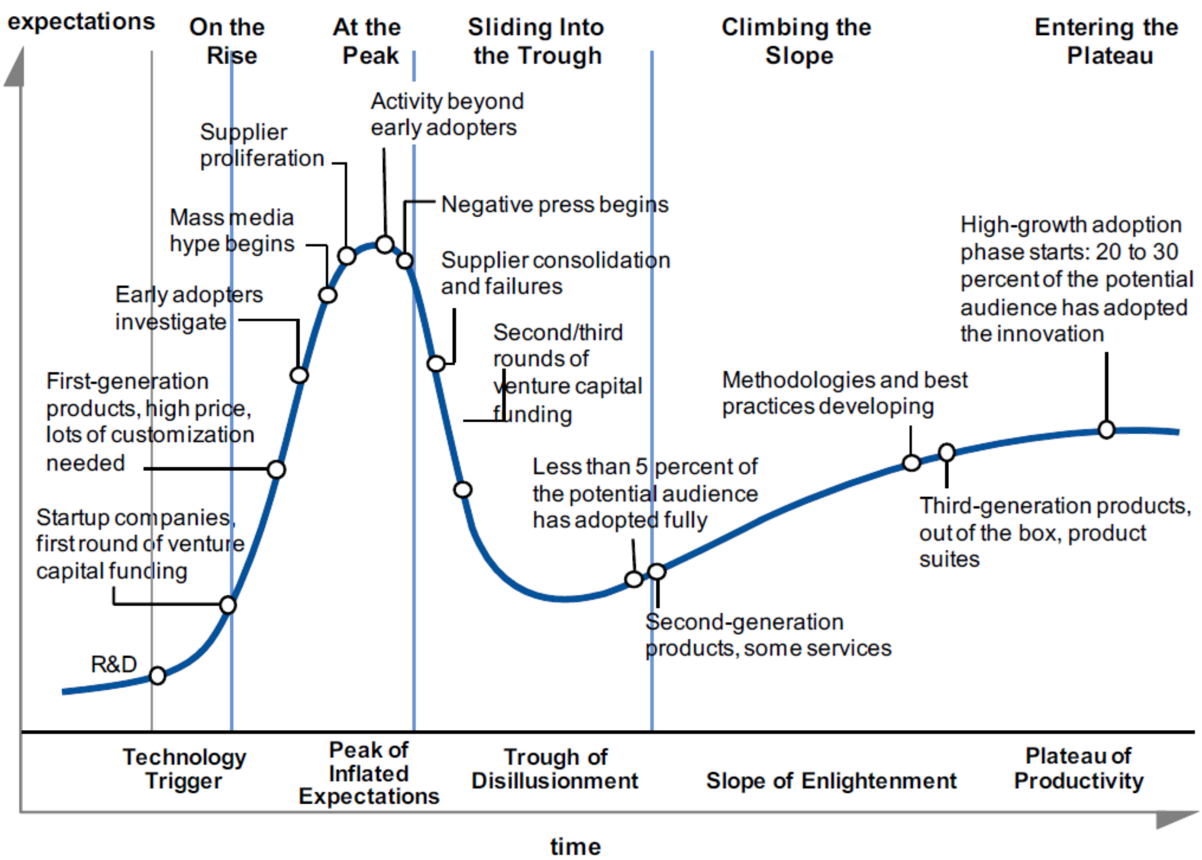

Fig. 3: Schematic explanation of the hype cycle {as schematically illustrated in Ref. 21}

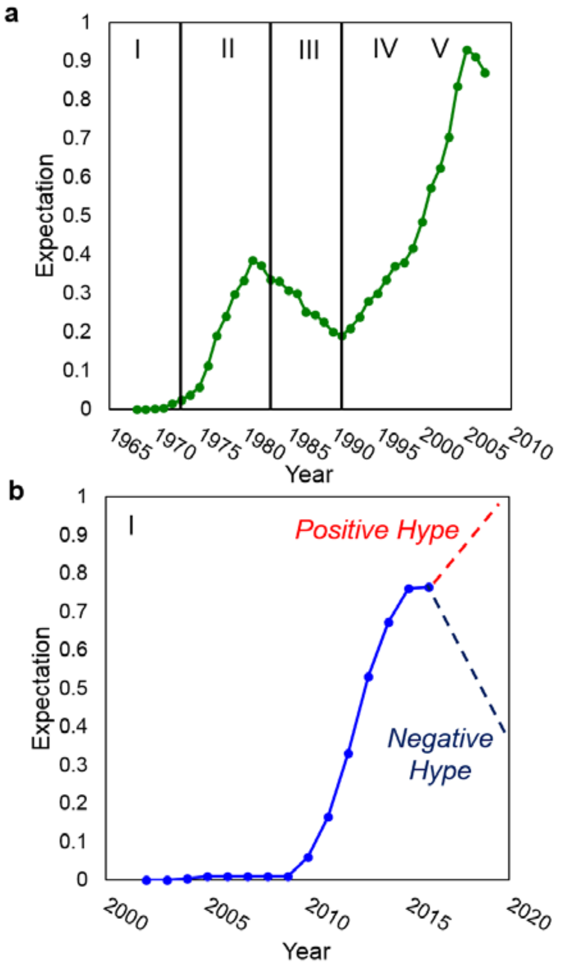

Fig. 4: The hype cycles of the (a) NLC and (b) BPLC technology. (I: Technology Trigger, II: Peak of Inflated Expectations, III: Trough of Disillusionment, IV: Slope of Enlightenment, V: Plateau of Productivity)

1973 to 1983. Phase III, Trough of Disillusionment, was from 1983 to 1990. Phases IV and V, Slope of Enlightenment and Plateau of Productivity, occurred from 1990 to 2007. However, the hype cycle of BPLC remains in Phase I, since first-generation BPLC-mode LCD products have never come on the market.

BPLC technology must accomplish phase transition, *i.e.* induction of positive hype, from Phase I to Phase II, because induction of negative hype in Phase I means technology death. If the hype cycle generally passes through the above-mentioned five phases, the hype cycle of BPLC one should also go through all five phases. The social and economic factors of NLC technology included a previously complete LCD technology; therefore, we found a lack of corresponding factors for BPLC to promote its phase transition. Here, we can assume several social and economic factors affecting innovation to move up to the next phase. When we look at the social environment surrounding the researcher community, the network and interaction among researchers (which we call the research alliance) plays a crucial role in advancing technology development. Along with social factors, economic factors can exert influence on technological innovation. In terms of capital for investment, government grants are important. Furthermore, the number of firm entries is also important from the viewpoint of the competitive market stimulating innovation. These factors are evaluated according to a three-grade evaluation (A, B and C) where A is better, B is average and C is worse. The investigation periods of their technology are defined from 1968 to 1978 for NLC and from 2006 to 2016 for BPLC, respectively.

The investigation results of the social and economic factors for ten years of the Phase I for each technology are shown in Table 1.

Table 1. Social and economic factors in Phase I

Influencing factor / Technology	Research alliance	Government grants	Relative firm entry
NLC (1968–1978)	B	B	A
BPLC (2006–2016)	B	A	C

A: better, B: average, C: worse

A research alliance for development of LCDs existed between Japanese companies, namely, Hitachi, Asahi Glass and Dai Nippon Toryo, under the guidance of the Ministry of International Trade and Industry (MITI).[22] In particular, the research achievement of NLC LCD technology was produced by research centres of Japanese companies rather than public research institutes from 1968 to 1978. There were 16 government grants for the NLC display technology from 1968 to 1978, and their data are to be found on the web site Grants-in-Aid for Scientific Research Database, KAKEN. In all, 13 Japanese companies were registered as researching NLC LCD technology during the same period.[22] The driving force for research on the NLC LCD technology was in the possession of the private companies rather than public institutes, since Japanese industries had enormous technological innovation capabilities (TICs) thanks to the periods of high and stable economic growth at this period in Japan. By contrast, there were several industrial–academic collaborations for the development of BPLC-mode LCDs between 2006 and 2016.[23,24) There were more than 30 grants for study of BPLC, as found on KAKEN, in that period. However, there were only three Japanese companies, JNC Co., Semiconductor Energy Laboratory Co., Ltd. and Advanced Film Device Inc.[23–25]. Characteristically, R&D on BPLC display technology would mostly be handled by public organisations, such as universities and public research institutes.

Considering the state of the NLC technology, if Japanese companies were to research BPLC technology for application in LCDs, it is likely that novel technological innovation for next-generation LCDs utilising BPLC materials would be induced. Thus, it is no exaggeration to say that the driving force for BPLC technological innovation is vigorously corporate research and collaboration between Japanese industries. However, Japan has long been faced with stagnation and deflation. Thus, most Japanese companies tend to avoid novel business investments and funding for R&D. Japanese industries do not possess TICs for a novel technological innovation. How can technological innovations be induced in Japan, given these circumstances? It is the hypothesis of Mariana Mazzucato that the government can play an important role in inducing technological innovation.[26] According to this idea, the government, instead of an enterprise, can play a role in taking the risk, *i.e.* an economic uncertainty, to exploit a novel market. The risk refers to the investment of fundamental research contributing to technological innovation and the uncertainty of profit based on technological innovation. A private enterprise tends to avoid taking these risks, since it puts most of its effort in applied research due to its economic rationality. The role of a government would be crucial where private companies are not taking risks for technological innovation. We can assume three areas where a government can help stimulate technological innovation: coordinating alliances among private enterprises, consolidating an arena conducive to collaborative research between academia and companies and providing financial support.

Let us consider these roles, drawing upon the example of the period of high economic growth between the 1970s and 1980s in Japan,[27] which was brought about by R&D and a financial loan policy under the initiative of the Japanese government. The first such R&D policy was titled R&D Projects for the Application to Industrial Technologies. It was established by MITI in 1966.[28] The idea was that the government, not private enterprises, would provide R&D funds, and it called for an alliance between Japanese industries, academic institutions and national R&D institutes to produce novel technology of importance to the national economy. The whole project was incapable of being spontaneously accomplished by Japanese private enterprise, since economic risk, enormous R&D funds and long-term fundamental research periods were required. Japanese private companies could undertake R&D activities with high economic uncertainty, ignoring their economic rationality. Various kinds of knowledge were widely spread through the strong alliances developed. The government also implemented a Fiscal Investment and Loan Program from the Bank of Japan and Postal Savings as a public loan policy for Japanese private companies.[26] They made major capital investments in R&D to improve arrangements in research environment. As a result, Japanese private enterprises possessed novel world-leading technologies and produced innovative products to which their technologies applied. The development of display technology based on NLC technology was conducted under a similar R&D project, funded by MITI. Many technological innovations, including NLC display technology, were induced by governmental R&D and monetary policy in the period of high economic growth.

LCD to BPLC technology is not expected to be induced in Japan in this way, even if the same governmental policies currently accommodate Japanese economy and society. There are two key matters, such as the situation of the Japanese economy and the lack of few firms entering the BPLC field, as shown in Table 1. First, Japanese industries do not have the TICs to induce novel technological innovation, due to deflation. Moreover, the Japanese government is currently attempting to become small government, reducing governmental intervention in the market by easing regulations.[29] Hence, government is currently reducing its role. Second, grants for BPLC development were superior to those of NLC, as shown in Table 1. Fundamental research on BPLC has been mostly undertaken in Japanese universities thus far. If these accumulated research results can be applied to corporate research, technological innovation for BPLC should be easier to induce. The reduced number of firms entering, however, limits its application in the LCD field. Here, we propose an R&D and monetary policy for the induction of BPLC innovation in Japan. We focus on smaller firms researching a BPLC. It is important for the induction of novel innovations to increase the relative size of an enterprise since innovations come about from active corporate research and knowledge sharing under alliances between relative corporations and institutes. Furthermore, entrepreneurial ventures have the potential for novel innovation in the present day, since innovation is required for differentiation.[30] We assume that if an R&D-oriented venture enterprise of BPLC technology is increased by governmental venture support policy under the Ministry of Economy, Trade and Industry (METI), novel innovation of LCDs utilising this technology will be induced. In fact, METI has an active policy of support. This policy allows for venture capital investment by the Innovation Network Corporation of Japan (INCJ), a tax-reduction policy and promotion of alliances between venture capital, large corporations, universities and public institutes.[31] There are two main problems with R&D-oriented ventures: the risk of money in a long-term research period and the difficulty in business expansion due to deficient alliances between large companies.[31] Risks of money are avoided by the endorsement of venture capital investment by the INCJ and the tax-reduction policy. Moreover, the promotion of alliances can lead to a large-scale venture corporations, long-term R&D and active knowledge sharing. Therefore, the government takes its investment risk and grants opportunities for long-term management by governmental venture support policy. If several venture firms that employ BPLC technology are supported by existing venture support policy, the current problem, that fewer firms are entering the field, is solved. Additionally, if newly established venture companies positively interact with large corporations, universities and public institutes, utilising the policy, they can learn the fundamental research results accumulated in universities and public institutes and conduct long-term management with the cooperation of large enterprises. They will accomplish novel LCD innovation for BPLC technology. Governmental policy, *i.e.* the role of government, is important for inducing novel innovation in Japan.

4. Conclusions

To summarise, there clearly remains a technology gap between NLC and BPLC technology. There are several causes of a technology gap: the different periods of recognition of their LC materials, the concentration of NLC research in the LC research society by the globalisation of LC research, and differences in their market values. BPLC technology has been limited in Japan by the fewer firm entries due to social and economic factors, for 10 years, remaining in Phase I (Technology Trigger). Moreover, Japanese industries have lost TICs due to deflation. Therefore, in the current structure, it is difficult to create innovation in Japan. Governmental R&D and monetary policy was effective in inducing novel technological innovation during the high economic growth of Japan (in the 1970 and 1980s). The Japanese government took economic risks and invested in high-uncertainty R&D projects, instead of requiring Japanese firms to exploit novel markets. These policies had the following characteristics: the creation of R&D funds; approval of strong alliances between Japanese industries, academic fields and national R&D institutes; and a Fiscal Investment and Loan Program as a monetary policy of the Bank of Japan and Postal Savings for the improvement of the research environment in the private sphere. Thanks to positive innovation policies by the MITI, Japanese enterprises produced innovative products by utilising their earned innovative technologies. LCD technology itself was developed in a similar R&D project of MITI in the 1970s. Japanese LCD enterprises, for example Sharp Corporation, possessed the world's leading LCD technology at that time. If it adapts a policy like the above mentioned for the induction of novel technological innovation, the policy will still not be satisfactory, for the Japanese government is currently becoming small government. We, therefore, focused on R&D-oriented ventures and the policies of their support under the METI to address application problems in BPLC technology. We propose the following possible policies: venture capital investment by INCJ, a tax-reduction policy and the promotion of alliances between ventures, large corporations, universities and public institutes for establishment of novel venture firms. Thus, two risk aversions for ventures, such as avoidance of risky investments and the prolongation of R&D venture business by the policies, can be ameliorated. It is expected that ventures will increase, since their business would be stabilised. Thus, if novel R&D venture corporations working on BPLC increase, discover fundamental research results accumulated in universities and public institutes and manage for the long term by utilising the policy, they will achieve novel LCD innovation using BPLC technology.

Acknowledgements

This work was supported by the Advanced Graduate Program in Global Strategy for Green Asia (Kyushu University).

References

1) T. Uchida, *Jpn. J. Appl. Phy.*, **53**, 03CA02, (2014).
2) S. Sato, *Jpn. J. Appl. Phy.*, **18**, 1679, (1979).
3) L. Rao, Z. Ge, S. T. Wu and S. H. Lee, *Appl. Phy. Lett.*, **95**, 231101 (2009).
4) H. Kikuchi, M. Yokota, Y. Hisakado, H. Yang and T. Kajiyama, *Nat. Mater.*, **1**, 64 (2002).
5) K. S. Bae, Y. J. Lee, C. J. Yu, H. Lee, J. H. Parka and J. H. Kim, *J. Appl. Phy.*, **51**, 072201, (2012).
6) T. Uchida, S. Yamamoto, Y. Shibata, *IEEE Trans. Electron Devices*, **30**, 503, (1983).
7) T. Takahashi, H. Furue, M. Shikada, N. Matsuda, T. Miyama and S. Kobayashi, *Jpn. J. Appl. Phy.*, **38**, L534, (1999).
8) H. Kawamoto, *Proc. IEEE*, **90**, 460, (2002).
9) MD A. Rahman, S. M. Said and S Balamurugan, *Sci. Technol. Adv. Mater.*, **16**, 033501, (2015).
10) D. Dumur and T. Sluckin, *Soap, science, and flat-screen TVs −A history of liquid crystals−*, OXFORD UNIVERSITY PRESS, Oxford, (2011).
11) E. W. Lajoie and L. Bridges, *Library Leadership and Management*, **28**, 1, (2014).
12) http://i-scover.ieice.org/proceedings/iscoverchallenge/2014/pdf/iscoverchallenge201407.pdf, (accessed 09/07/2017).
13) G. H. Heilmeier, L. A. Zanoni and L. A. Barton, *Proc. I.E.E.E.*, **56**, 1162, (1968).
14) T. Nagai, *management sensor*, **108**, 36 (2008).
15) T. J. Sluckin, D. A. Dunmur and H. Stegemeyer, *CRYSTALS THAT FLOW*, Taylor & Francis, London (2004).

16) D. Coates and G. W. Gray, *Phys. Lett.*, **45A**, 115, (1973).
17) G. H. Brown and W. G. Shaw, *Chem. Rev.*, **57**, 1049, (1957).
18) T. Geelhaar, K. Griesar and B. Reckmann, *Angew. Chem. Int. Ed.*, **52**, 8798, (2013).
19) http://www.sharp.co.jp/aquos/history/, (09/07/2017, accessed).
20) D. C. Wright and N. D. Mermin, *Rev. Mod. Phys.*, **61**, 385, (1989).
21) J. Fenn and M. Raskino, *Understanding Gartner's Hype Cycle, 2011*, Gartner's Inc., 1, (2011).
22) T. Numagami, *Ekisho Display no Gijutsukakushinshi*, Hakuto Shobo, Tokyo, (1999).
23) http://www.jst.go.jp/chiiki/shigen/hyouka/h23_hyouka.pdf, (accessed 13/04/2017).
24) https://www.innovation.hirosaki-u.ac.jp/sangakukan/jutaku/h24, (accessed 13/04/2017).
25) Y. Hirakata, D. Kubota, A. Yamashita, H. Miyake, M. Hayakawa, J. Koyama, S. Yamazaki, K. Okazaki, R. Sato, T. Cho, K. Tochibayashi and M. Sakakura, SID'11 Digest, **42**, 32, (2011).
26) Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, Japanese edition (translated by Akito Ohmura), Yakuji nipo sha, Tokyo, (2015).
27) M. K. Barai and B. B. Saha, *Evergreen - Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, **2**, 49, (2015)
28) M. Katsumoto, *J. Science Policy and Research Management*, **17**, 65, (2002).
29) D. Kajiwara, A. Kikuchi and S. Fujii, *J. Jpn. Soc. Civ. Eng. Ser. D3 (Infrastruct. Plan. Manag.)*, **70**, 1, (2014).
30) H. Onose, *Journal of creative management*, **1**, 133, (2005).
31) http://www.kantei.go.jp/jp/singi/keizaisaisei/miraitoshikaigi/venture_dai1/siryou3.pdf (accessed 09/08/2017).