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Patent and literature statistics – The case of optoelectronics ☆

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Abstract

The aim of this paper is to provide an overview of different statistical analyses from patent and literature databases that in combination are helpful for a variety of mostly strategic decision settings in firms. For the case of optoelectronics we assess the patenting and publishing activity of firms and individuals and their citation frequency.

The analyses identified leading players in the field, revealed technological dependencies, and the existence of patent clusters as patenting strategies. Co-citation analysis highlighted technological similarities between two firms involved in patent litigation trials. In this science-based technology field individuals combining characteristics of key inventors (a high activity and citation level in patenting) as well as core scientists (a high activity and citation frequency level in publishing) – therefore labelled ''R&D dualists'' – successfully bridge the gap between science and technology, but are exceptionally rare. Citation-weighted patent counts demonstrated the pivotal impact of one ''R&D dualist'' in an industrial R&D laboratory, severely affecting the laboratories' outcome when this individual left. An increasing level of R&D cooperation in particular technological subfields after the individual's departure could be found. However, patent analysis did not find evidence for long-term competence transfer in these subfields.

Keywords: Patent statistics; Technological cooperation; Knowledge acquisition; Citation analysis; Gallium nitride (GaN); Optoelectronics

1. Introduction

Statistical analyses of patent data offer a wide range of possible uses for strategic decision-making in corporations (see e.g. [1]). This paper gives an overview of different statistical patent and literature analyses that together provide in-depth insights into activities in research and development (R&D), such as knowledge protection strategies, the position of technology leaders as well as key personnel driving these developments. The spectrum of analyses covers what might be termed ''basic'' investigations of patenting and publishing activities both on the level of firms as well as individuals, but also presents the acquisition of external knowledge through cooperation, and highlights technology dependencies as well as protection of valuable technologies by means of patent thickets. The analyses were performed using both host- and web-based patent and literature databases, combined with a self-developed stand-alone analysis software package as a Microsoft Excel Add-In to produce visualizations of the results. The field of investigation is gallium nitride-based optoelectronic semiconductors, a relatively young technology field with great future potential. All analyses were conducted from an outside perspective, they were performed without in-depth (technical) knowledge about the developments in the field or the intentions and strategies of the companies whose names are mentioned in the following. Parts of our findings could be verified by other sources, particularly by means of searches in technology field-related news sites in the WWW.

The paper is organized as follows: first, we present some background information on the technology field. Second, we focus our analysis on the ten most active patentees in

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the technology field and further investigate their activities. Third, we look at key individuals driving the technology field and their patenting and publishing activities. Fourth, we pick out one leading firm from the technology field and investigate its R&D activities more thoroughly, including knowledge acquisition strategies through cooperation. Conclusions follow.

2. Technology field and data retrieval

Optoelectronic components such as light emitting diodes (LEDs) are a pivotal technology with high economic potential. White LEDs have already begun to replace electric bulbs, for example in cars, and will probably replace fluorescent tubes and electric bulbs in many more areas. The reason is that LEDs not only have a much longer lifetime, they also require only a fraction of the energy used by current light sources. The economic potential for savings in energy costs is estimated to be many billion dollars worldwide [2]. The technological roots of white LEDs lie in the blue-green spectral area of so-called group III nitride semiconductors [3]. The pioneering work in this technology field was done by Shuji Nakamura in the laboratories of Nichia Corp. in Japan. He not only developed blue and true green LEDs but also blue laser diodes that allowed the establishment of new standards for optical storage devices such as the blue-ray disc or HD-DVD. Nichia still holds virtually a monopoly[1] on blue laser diodes and the company holds a leading position in the LED market. Parallel to the work of Nakamura, Professor Isamu Akasaki together with Hiroshi Amano worked on a similar technological approach for Toyoda Gosei Corp. Due to similarities in both approaches Nichia and Toyoda Gosei were involved in a patent litigation trial that was settled in 2002 [5].

The technological scope of the case study covers semiconductor components in the blue-green spectral area based on GaN. For the patent priority years 1989–2004, patent searches were conducted in full-text patent databases from STN International, combining keyword searches with International Patent Classification (IPC) notations. The results were transferred to the Derwent World Patents Index (WPINDEX) and limited to patent families registered via the Patent Cooperation Treaty (PCT), at the United States Patent and Trademark Office (USPTO) or the European Patent Office (EPO). In the next step, the patent families were transferred to the Derwent Patent Citation Index (DPCI) to obtain patent citation data. Both databases allow patent family-wise data retrieval, i.e. all patent documents originating from the filing of a patent in various countries are assigned to one database record based on the priority date of the first patent in this family available to Derwent. Information on legal data was retrieved from INPADOC. Scientific publications were evaluated via keyword searches in Thomson ISI's Web of Science (WoS).[2] In total, 1885 patent families and 3112 papers were identified. The data was finally imported into Microsoft Excel and further analyzed through the self-developed tool PATONanalist [6]. For both patents and publications, full counts were used, assigning a patent or publication fully to each firm, institution, inventor or author.

3. Technology field analysis – companies

Our analysis revealed a steady growth of patent families in the technology field since the mid 1990s, of about 30% p.a. This growth rate is a good indicator not only of the novelty of the field but also of the relevance and potential of the technology. Fig. 1 presents the ten most active patent applicants; the majority from Japan. Three companies are clearly leading the field with more than 100 patent families: Matsushita, Sharp, and Toyoda Gosei. At the end of the ranking – on position ten – Nichia is to be found.

The next step was to investigate the patenting activity of these ten highly active companies for the time period 1995–2004. Here the three leading companies showed only a moderate increase in their activity level over time, while Samsung and Showa Denko, in particular, entered the field relatively late and demonstrated a steep patenting curve, which obviously catapulted both into the top ten patentees. Remarkable here is that these ten companies hardly cooperate with each other in the technology field. In contrast, such cooperation can be found on a larger scale among companies that are less active in patenting. This perhaps suggests that these ten highly active companies possess strong technological capabilities that allow them to pursue their research on their own in a highly competitive environment.

Fig. 2 highlights the different technology subfields (as defined by IPC notations) of the ten most active patentees. Patent notations shown are the ten most prevalent in the technology field. Showa Denko holds a striking position here because the firm's share of patents in technology subfields H01L033-00 (semiconductor devices for light emission) and H01L021-205 (processes for chemical deposition) is much higher than the share of its competitors. Furthermore, the firm is only active in five out of the top ten IPC notations. Thus Showa Denko seems either to clearly focus its R&D efforts, or to possess fewer competencies in other technological subfields.

There is a high level of interaction between science and technology in the field under consideration. Not only Professor Akasaki's work for Toyoda Gosei bridged the gap

[1] Sony also produces blue laser diodes under a cross-licensing agreement with Nichia. In November 2006 Sharp entered the market based on a different technology than Nichia's [4]. Other companies are about to follow.

[2] The full search strategy is not reproduced in this paper since it is lengthy, does not have an impact on the analysis and visualization techniques in general and involves the use of some proprietary know-how from PATON.

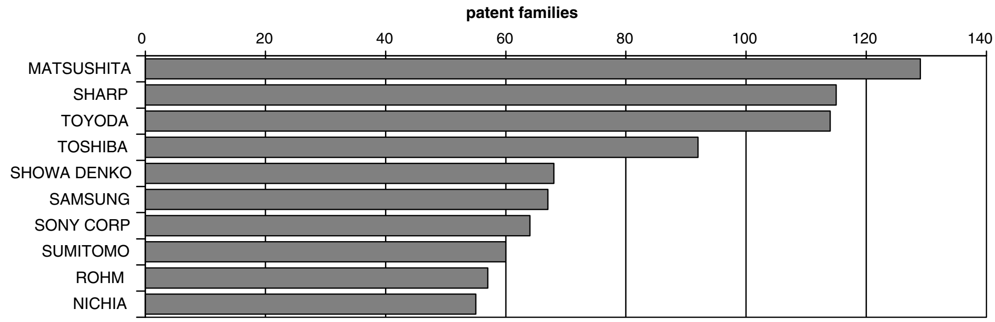

Fig. 1. The ten most active patent applicants in the technology field.

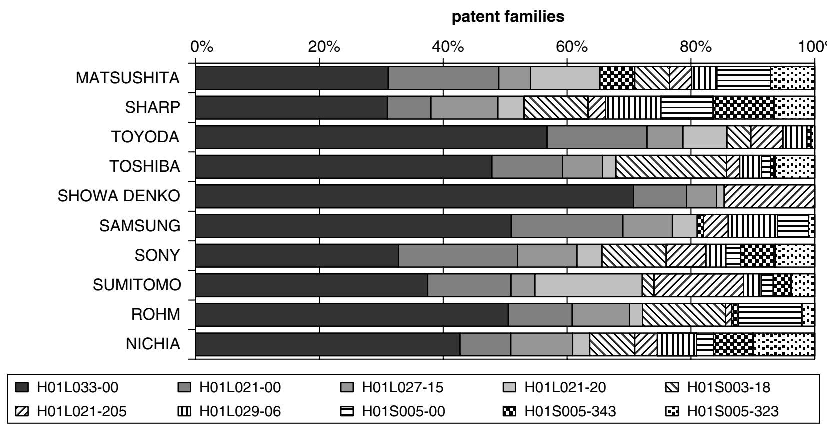

Fig. 2. Patenting activities of the ten most active patentees in the technology field in the ten most prevalent IPC notations.

between research and development. In 1999 Shuji Nakamura left Nichia for the University of California at Santa Barbara [7]. Before, he had published extensively many aspects of his work in leading scientific journals.

Fig. 3 therefore summarizes the publishing activity of institutions as covered in the Science Citation Index. The data retrieved from WoS was further analyzed to obtain information on citation frequency as is not accessible directly via statistical functions on the WoS website.

As Fig. 3 reveals, there are two companies among the ten most frequently publishing institutions. While Nichia holds third place, Samsung holds sixth. Samsung seems to pursue the strategy not only of patenting heavily in the field, but also of pursuing a research reputation. By publishing its research findings the firm encourages the acquisition of scientific knowledge, which seems to be intended, in return, to strengthen Samsung's capabilities in developing patentable technologies. In total, not many companies demonstrate a strong presence in the academic environment: Among the 25 most frequently publishing institutions there are only two more companies: S Epitaxy group from Taiwan ranks 14th; Sony comes on position 18. The former, however, is not very active in patenting and holds only five patents that in total received less than ten citations.

Up to this point we have only considered patenting and publishing activities. Citation analysis offers further insights into competencies of firms and their technological impact. Patent citations originate from references mainly to

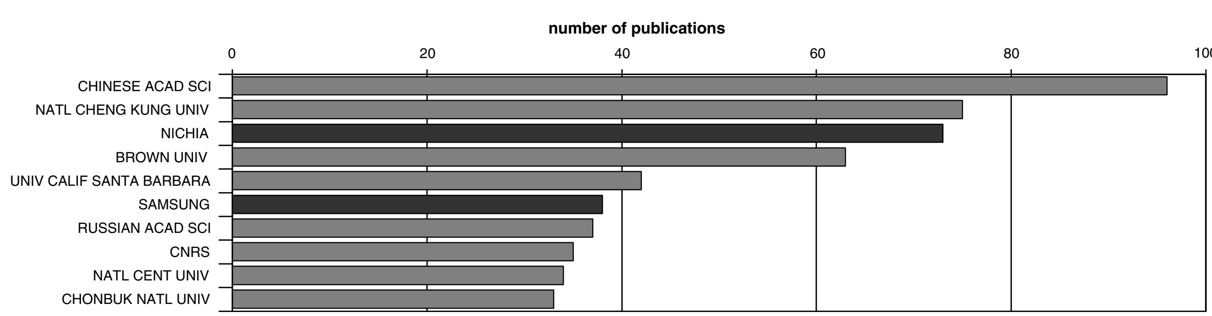

Fig. 3. The ten most frequently publishing institutions in the technology field.

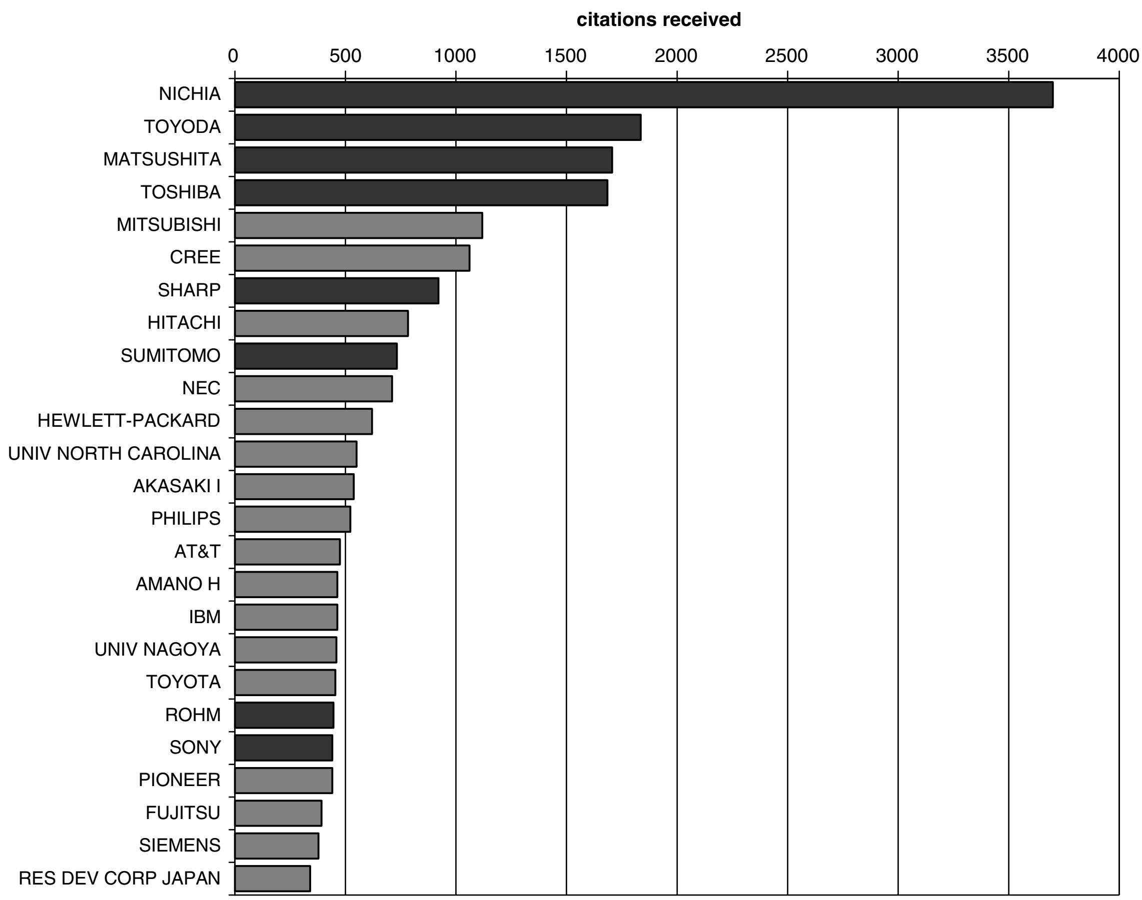

Fig. 4. The 25 most highly cited patent applicants in the technology field.

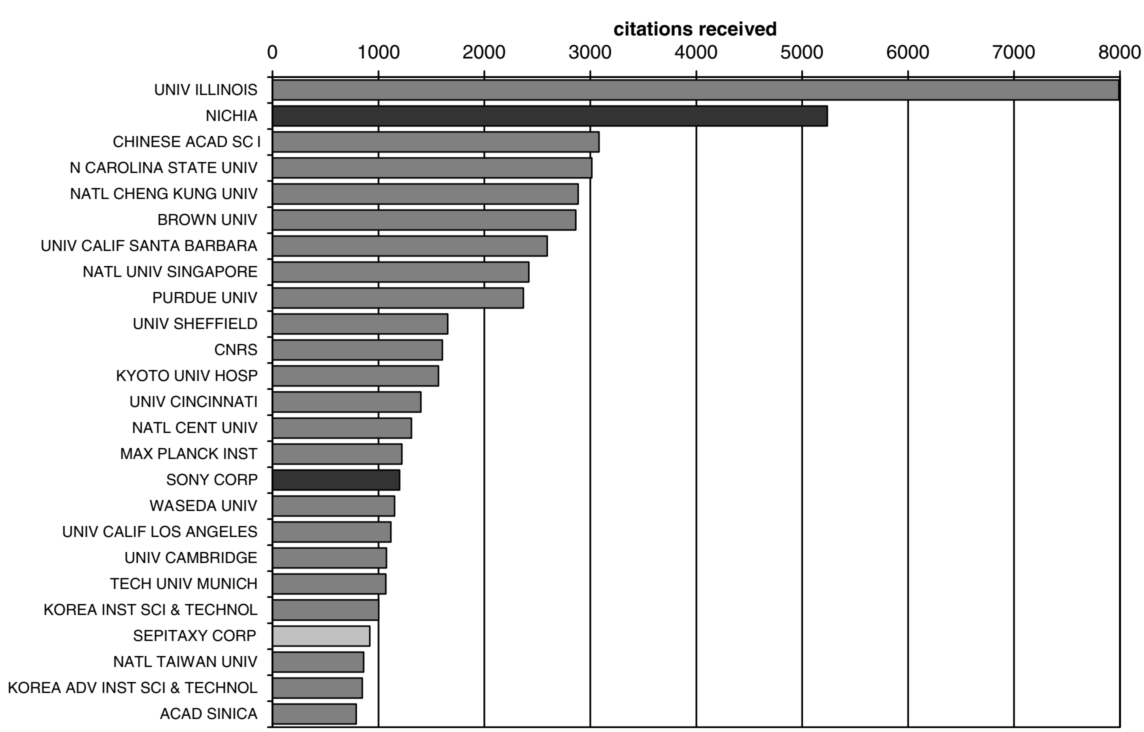

Fig. 5. The 25 most frequently cited institutions in the technology field.

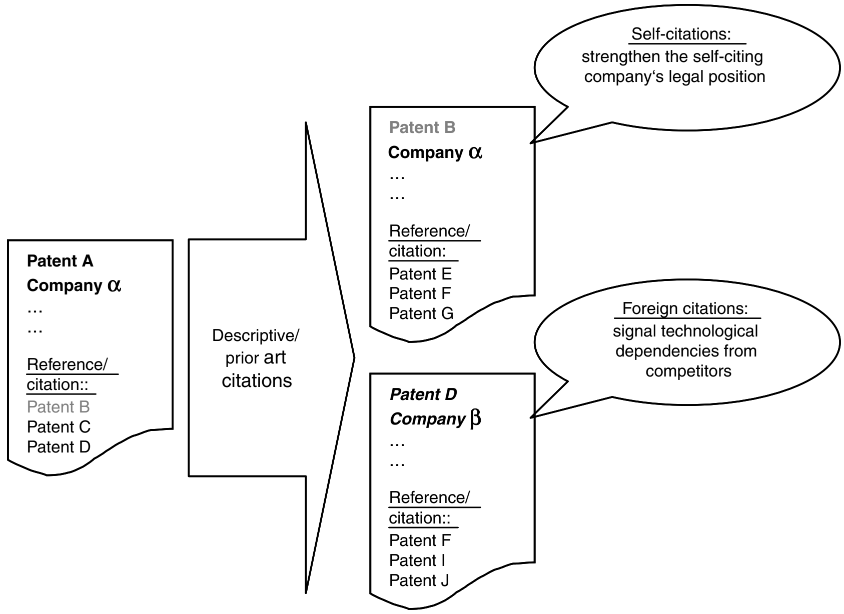

Fig. 6. Foreign and self-citations in patents.

prior art as stated by patent applicants or examiners. They limit the legal scope of the patent and indicate at least partially to which degree an applicant or inventor builds on knowledge of a priori developed technology, either by the applicant or inventor himself or by competitors or colleagues. Therefore the number of citations an applicant or inventor receives can be considered as a measure of his competence. Fig. 4 represents the 25 most frequently cited applicants in the technology field. Among them are six out of the ten most active patentees. The most highly cited patent applicant is Nichia, followed by Toyoda Gosei. In this case two firms that are well-known for their technological competence hold the leading positions. Taking only patenting activity into account would not have led to the conclusion that Nichia is indeed the key player in the technology field.

What is the position of the ten most active patentees in the technology field regarding their citation frequency in their scientific publications? As Fig. 5 indicates, Nichia occupies with its second place a leading position here as well. From the ten most active patentees there is only Sony among the 25 most frequently cited institutions, while only a third firm – S Epitaxy Corp. – stands its ground among universities and research institutions.

Patent citation analysis also allows the investigation of technological interrelationships and technology protection strategies. Fig. 6 gives an overview about different types of patent citations that originate from the reference section of search reports. So-called patent self-citations occur if a patent cites another patent of the same applicant, while "foreign citations" are references to patents from other applicants.

Self-citations are often found in patents positioned around particularly important patents (that are obviously cited) and thus create patent clusters or "thickets" [8–12]. Self-citations are considered as strength of one's own technological position [1] since they extend the legal scope of the cited patent and, at the same time, extend one's room to manoeuvre around one's own inventions. In contrast, foreign patent citations indicate to some extent technological dependencies from competitors since they represent (at least up to a certain degree) knowledge flows (for a discussion on this issue, see [13,14]).

For eight highly active companies in the technology field the manner in which they are linked through patent citations was assessed. Fig. 7 presents the results. Self-citations can be found on the diagonal.

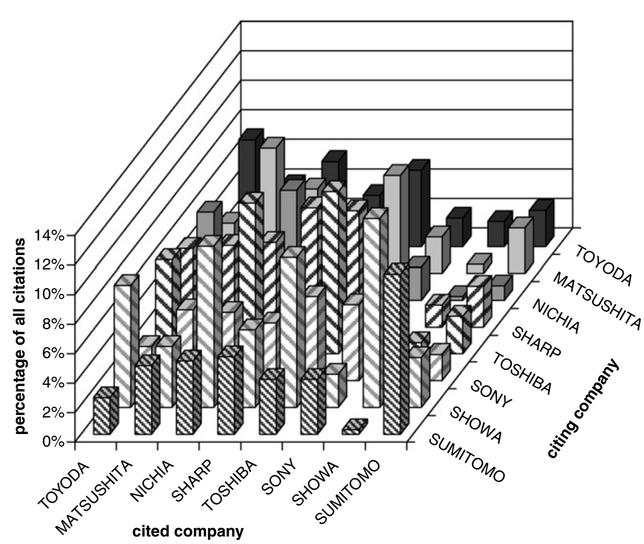

Fig. 7. Who cites whom? – Citation ties among eight highly active patent applicants in the technology field.

Table 1
Highly self-cited patent families of Sumitomo and Showa Denko

Sumitomo			Showa Denko		
Patent number (basic)[a]	Total citations[b]	Firm self-citations[b] absolute (percentage)	Patent number (basic)[a]	Total citations[b]	Firm self-citations[b] absolute (percentage)
EP1088914	23	6 (35%)	US6069021	28	16 (57%)
EP966047	36	5 (13%)	US2001036678	11	8 (73%)
WO9923693	17	5 (16%)	GB2316226	22	5 (23%)

[a] From Derwent.
[b] As of September 2006.

For example, Sumitomo is cited in 2% of all patents from Toyoda Gosei. Ten percent of all citations in Sumitomo's patents are self-citations. This number is only exceeded by Showa Denko. In comparison to all other applicants in the example, both companies show extraordinarily high self-citation rates. This might indicate the existence of patent clusters. To test whether this assumption holds true, we explored whether if either company possesses patents that they themselves cite frequently. Both companies hold three patent families that they cite themselves at least five times, as is shown in Table 1. Showa Denko holds three highly self-cited patent families with self-citation ratios beyond 50%, confirming the existence of patent clusters.

Fig. 7 furthermore reveals that Nichia and Toyoda Gosei are both cited with about equal frequency from Showa Denko and Toshiba. Calling back to mind the patent infringement trial as mentioned in Section 2 of this article, it becomes clear that the reason for this co-citation behaviour is rooted in the similarities of Nichia's and Toyoda Gosei's technologies.

Why do Toshiba and Showa Denko cite these patents? Toshiba cooperates (but does not patent together) with Toyoda Gosei [3], so Toshiba's patents appear to be a further development of Toyoda's (and Nichia's) technology, naturally citing the patents from these two applicants.

Showa Denko does not hold any patents in the technology field together with Nichia or Toyoda Gosei that would indicate R&D cooperation among them. Searching in the database INPADOC for patent oppositions against Showa Denko's patents did not result in any hits. However, since INPADOC only covers a selected range of countries, mostly from Europe where opposition has been registered, and Showa Denko mainly files its patents in Japan and the United States, this result needs be treated cautiously. The distinctive profile of Showa Denko's patent activities as discussed in Section 3 of this article leads us to the conclusion that the firm's technology is different from those developed by Nichia and/or Toyoda Gosei, so that neither cooperation nor infringement is an issue here. Searching the WWW confirms this finding. Our search revealed that Showa Denko's technology is clearly different from the one used by major competitors [15], validating the results found in patent analyses.

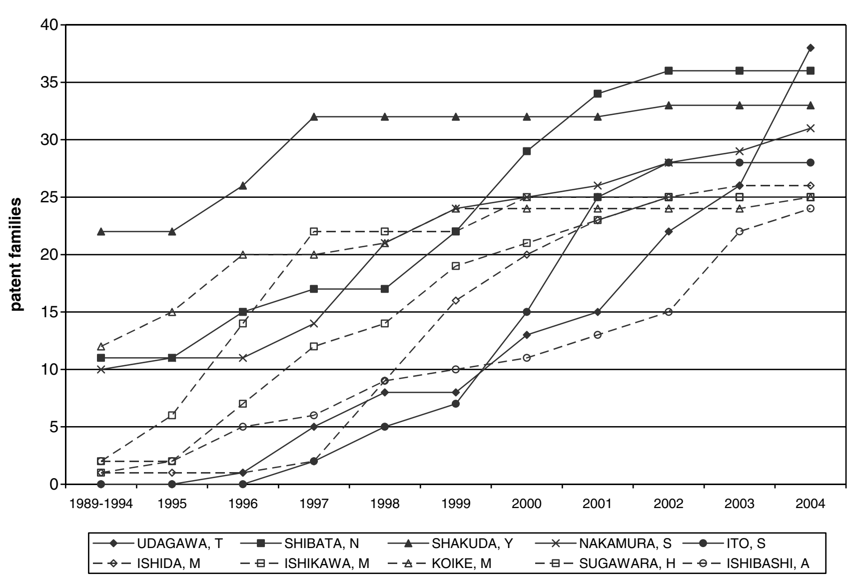

Fig. 8. Cumulative activities of the most active inventors in the technology field from 1995 to 2004.

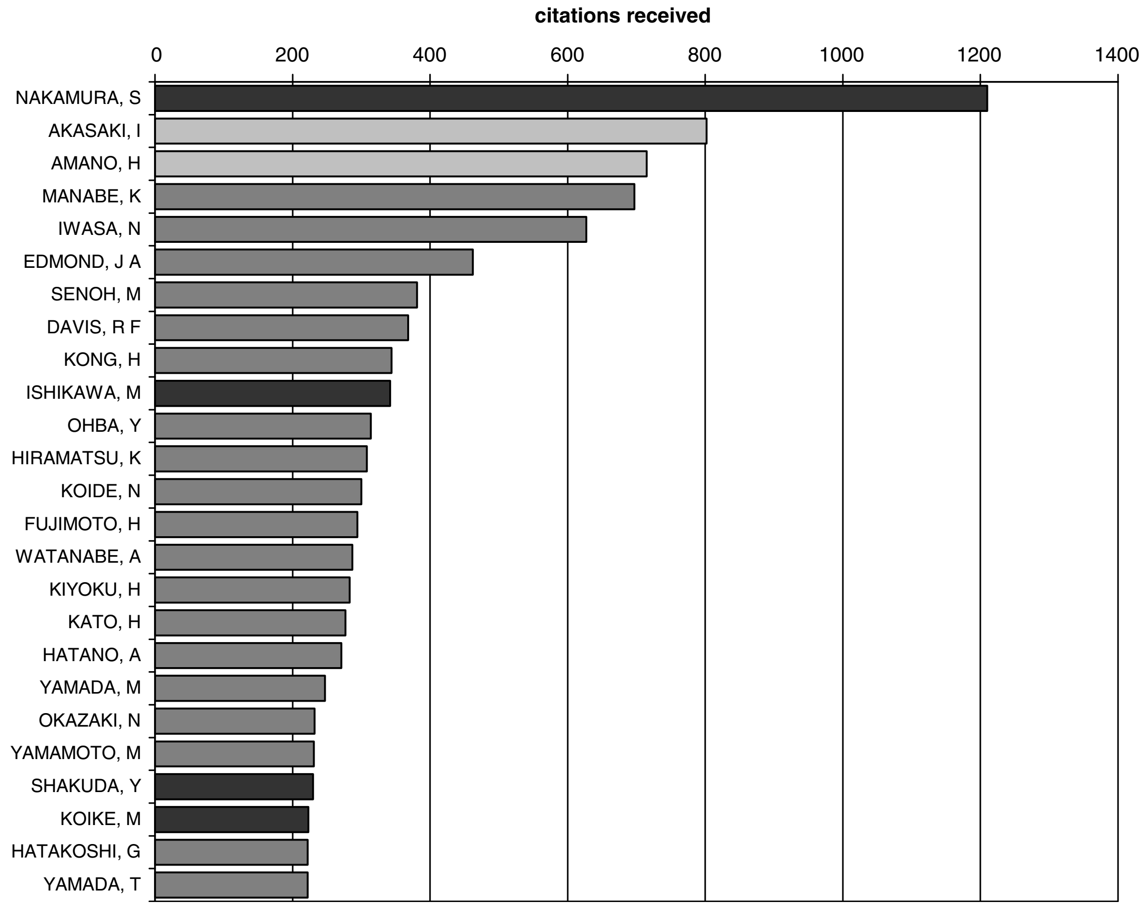

Fig. 9. The 25 most highly cited inventors in the technology field.

4. Technology field analysis – individuals

When introducing the technology field we highlighted the pivotal role of Shuji Nakamura from Nichia for developing group III nitride semiconductor technologies. Analyses as were shown in the previous section can be conducted for individuals as well. We will only present some of them, in order to assess the position of different individuals such as Nakamura in the technology field.[3]

Fig. 8 presents the cumulative patent activity over time for the ten most active inventors in the technology field. The graph shows that Nakamura is one of the most active inventors in the field. While another inventor, Shakuda, almost ceased to patent any longer in this technology field, Udagawa demonstrates just the opposite behaviour: in 1997 he was virtually not present in the technology field, but in 2004 he had become the most active inventor in the field.

[3] We did not control for homonyms. Both Derwent as well as Web of Science only provide individuals' last names plus first name abbreviations, making it difficult even in narrower fields to separate individuals with popular surnames. It can be expected that such biases can be found in our analyses as well.

A closer look at the most frequently publishing authors revealed that Nakamura holds the top position with about 80 publications. Ishibashi who ranks tenth among the most active inventors in 2004 occupies position 16. Professor Isamu Akasaki, not among the ten most active inventors, ranks 18th in publishing. Citation analysis again confirms the strong position of Nakamura and Akasaki/Amano as well. In patents, as can be seen in Fig. 9, Nakamura is the most highly cited inventor, defending his position undisputedly against Akasaki and Amano. Only three of the ten most active inventors belong to the 25 most frequently cited ones.

A similar picture can be seen in the citation ranking of authors (see Fig. 10). Besides Nakamura, who also leads the ranking unchallenged, no other "Top 10" patentee can be found among the 25 most highly cited authors. However, Akasaki and Amano are both present. Worth mentioning is the fact that Senoh and Mukai on position two and three in the author citation ranking are both coauthors of Nakamura. The citation frequencies in Figs. 4, 5, 9, and 10 are cumulative in nature, not taking into account if an institution or individual has received the majority of the citation counts maybe from only one or two documents. Fig. 11 takes the citation frequency of individual documents into account and demonstrates for

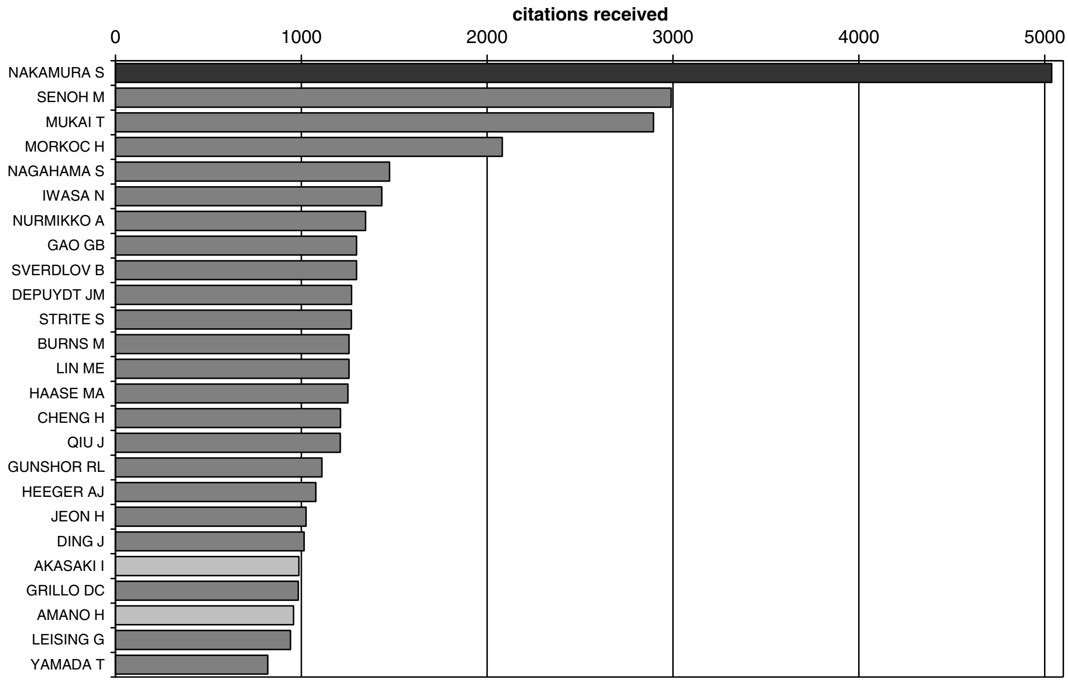

Fig. 10. The 25 most highly cited authors in the technology field.

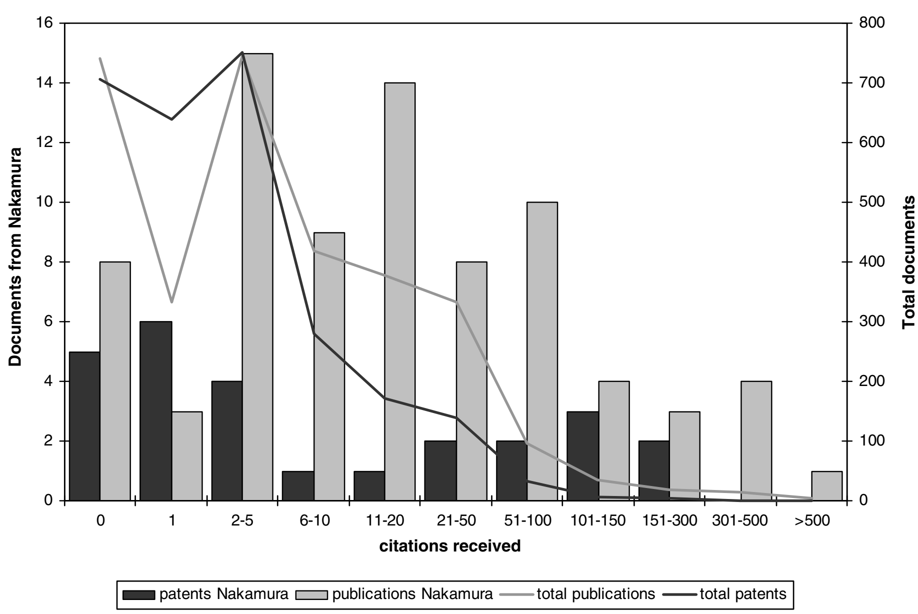

Fig. 11. Citation frequency of Nakamura's patents and publications between 1989 and 2004.

Nakamura that he published clearly higher cited documents than the population. In conclusion, analyzing publishing or patenting activity and citation frequency – both skewed distributions – of individuals has shown that activity and citation frequency of most individuals do not go hand in hand. At the same time, it can be seen that many inventors hardly publish and, similarly, that few authors patent heavily. However, there are some key people who not only possess the characteristics of key inventors [16] but also of core scientists [17]. These people, in our case Nakamura, Akasaki and Amano, can be described as key R&D dualists since they are not only highly active and highly cited in patenting but also in publishing, bridging successfully the gap between science and technology.

5. Analysis of companies – cooperation and knowledge acquisition

So far our analyses were all focused on a single technology field – the blue-green spectral range of group III nitride

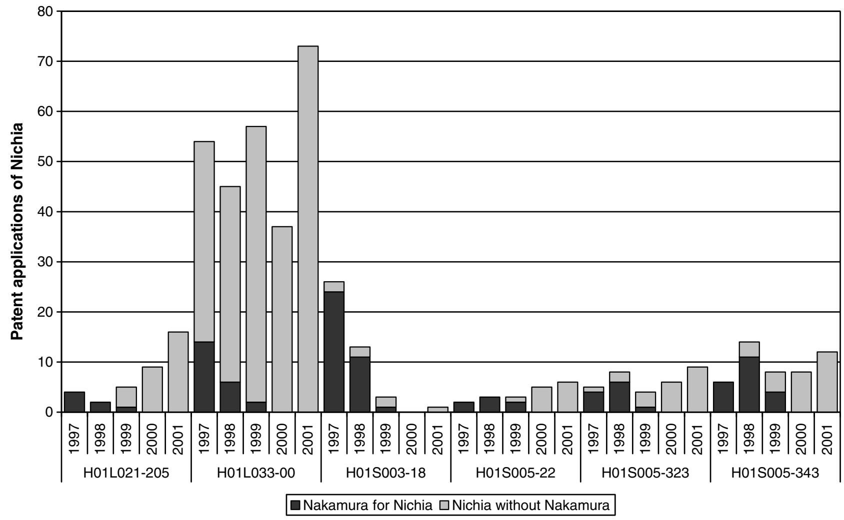

Fig. 12. Patent activity of Nichia and Nakamura between 1997 and 2001 regarding Nichia's ten most frequently assigned IPC notations.

semiconductors. This last section of our article is dedicated to a single firm, also from our technology field: Nichia. Therefore our analyses are based on all patent families from Nichia, not necessarily only those filed in the US, via the PCT, or at the EPO.

One of our goals in this paper is to investigate Nichia's cooperation behaviour and knowledge acquisition strategies. After several groundbreaking developments in the field of group III nitrides that secured Nichia a bright product portfolio, Nakamura left the firm for an academic career in 1999. It can be assumed that Nakamura's departure tore a hole in the firm's R&D department, clearly affecting the outcome of its R&D projects. One possible strategy to compensate for this loss at least partially would be external knowledge acquisition through cooperation, to enable the firm to enter complementary technology subfields, for instance, and strengthen its established technologies.

To assess the importance of Nakamura's work from Nichia's perspective, the extent to which he contributed to the firm's patent applications between 1997 and 1999 was investigated. The scope of analysis was limited to the firm's ten most frequently assigned IPC notations (“technological subfields”) that in total cover about 70% of Nichia's patent applications. In 1997 and 1998 he was named as (co-)inventor on about 50% of Nichia's patent applications in these “Top 10” technological subfields. This number fell to about 12% in 1999, certainly due to a departure in the first or second quarter of this year. However, in four out of the ten technological subfields he was not active at all. Therefore our further analyses were limited to those fields where Nakamura was indeed active.

Fig. 12 shows how Nakamura's activity was distributed over time and technological subfield. It becomes clear that due to Nakamura's high level of involvement his departure certainly has affected Nichia's technological capabilities. One could have expected that Nichia would have experienced a decline in patenting activity in these fields after Nakamura's departure. This, however, is not the case in five out of the six technology fields. Only in IPC notation H01S003-18 (semiconductor material for lasers) did the firm's patenting activity significantly decline; in the remaining technology fields it increased.

Nichia seems to have compensated for the loss of Nakamura's work with respect to the patent activity level. But could the firm also maintain the quality or importance of its patents? Since patent citations indicate the importance of patents [18,19], the firm's patent activity per technology field and year was weighted with the number of citations received. As suggested by Trajtenberg [20], the number of citation-weighted patent counts per technology field is calculated as follows: $P_{\mathrm{wc}} = \sum_{i=1}^{n} \mathrm{Pat}_i * (\#_{\text{cit-per-pat}_i} + 1)$, where Pat_i is the patent under consideration, and $\#_{\text{cit-per-pat}_i}$ is the number of citations received by this patent, and n is the number of patents in the technology field. Self-citations were not eliminated as is frequently done in analysing citation rates in scientific publications since, as was noted in Section 3 of this article, they rather represent a patent's technological strengths. Not for all patent families citation data was available. The number of patent families with missing data was distributed about equally over the technological subfields. More than 95% of the documents without citation data were registered only in Japan.[4]

Since the database DPCI from which citation data was retrieved provides the cumulative number of citations received until the retrieval date, older patent families, especially, could have received significantly more citations than younger patent families. However, Trajtenberg [20] found that the impact of a patent's age is in many cases overestimated; that is the bias originating from a patent's age is less

[4] For patent families with citation data those only registered in Japan received on average 2.5 citations, while patent families registered in more than one country had an average citation frequency of 6.9.

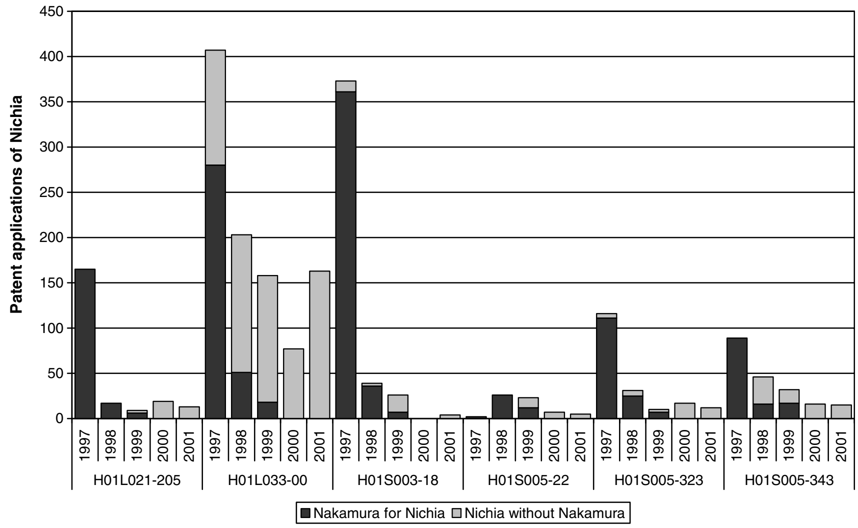

Fig. 13. Citation-weighted patent activity of Nichia and Nakamura between 1997 and 2001 regarding Nichia's ten most frequently assigned IPC notations.

severe than expected. The reason is that for most patents the number of citations received per year peaks shortly after the patent was published, and declines steadily thereafter [21,22]. Therefore, after a couple of years (depending on the technology field) many patents already have accumulated a major share of all citations they will ever receive, allowing a timely comparison of truncated citation data. The bias occurring here is reciprocally proportional to the time difference from publishing the patent to the point of observation, and the shorter the time period during which the sample of patents under consideration was published.

Fig. 13 presents the citation-weighted patent activity for the six main technological subfields in which Nakamura worked for Nichia. Here the outstanding performance of Nakamura becomes apparent. He is responsible for 88% of the firm's citation-weighted patent counts in 1997, for 47% in 1998, and for 26% in 1999. Since the ratio of the time periods "publishing the first patent to observing the citation data" to "publishing the oldest patent to publishing the newest patent" is in the order of 2, there is certainly a bias that should be taken into account. However, this bias should be negligible in comparison to the steep decline in citation-weighted patent counts as can be found in Fig. 13. In conclusion, it became obvious that Nakamura's departure certainly hit Nichia's R&D department hard.

Could Nichia have tried to compensate Nakamura's knowledge through cooperation?[5] Fig. 14 provides an overview about Nichia's patent families over time originating from cooperation. It can be seen that during Nakamura's time at Nichia there were hardly any cooperations, but after his departure, in 2001 and 2002, the number of patent applications from cooperation peaked. This might be an effect of Nakamura's departure, driving Nichia towards

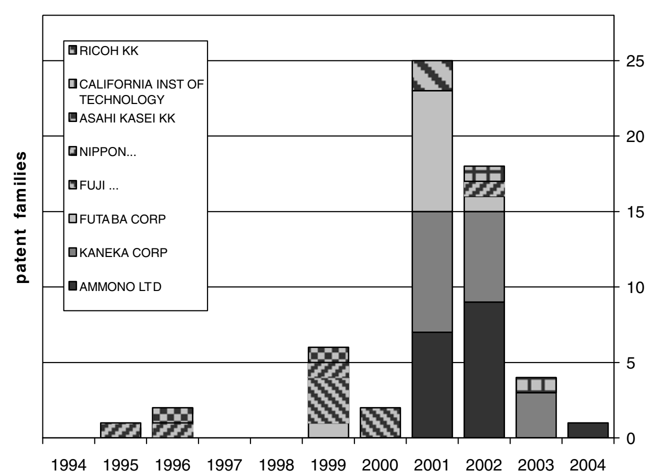

Fig. 14. Patent families from Nichia resulting from cooperation.

acquisition of externally available knowledge. Fig. 15 presents the four technological subfields in which Nichia patented through cooperation since 1997. The clear technological focus on a few subfields can be interpreted as strategic intention to access external technological competencies in other areas. Included in the graph were only

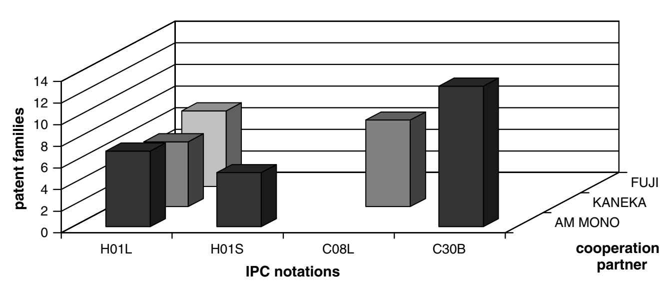

Fig. 15. Nichia's cooperation partner and patenting activity in technological subfields.

[5] Cooperation is defined as joint patent applications with another firm.

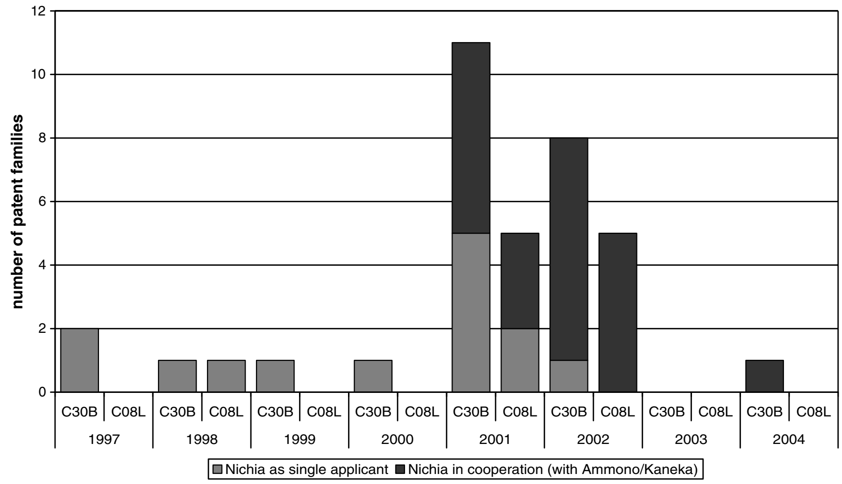

Fig. 16. Patenting activities with and without cooperation in technological subfields C30B and C08L.

those partner companies that filed for at least three patent applications with Nichia, and only technological subfields (4-digit IPC notations) with at least three patent families. In IPC notation H01L033-00 there are 15 applications resulting from cooperation in 2001, or about 20% of all patent families from 2001. Nakamura's activity in this technological subfield was in about the same order of magnitude.

In a further step it was investigated to what extent Nichia accessed ''new'' technology subfields by means of these cooperations. The results can be found in Fig. 16. For the subfields C08L and C30B Nichia's patent activity was plotted for the years 1997–2004. In C08L (compositions of macromolecular compounds), a part of Nichia's chemicals business, the firm had only filed for a single patent previously. In C30B (single-crystal growth), relating to Nichia's semiconductor business, Nichia patented earlier, but on a very moderate level. During the time of cooperation in both technological subfields Nichia' patent activities skyrocketed. But not all of Nichia's patent families from this time originate from cooperation, the firm also filed some patents on its own, maybe benefitting from technological spillovers from cooperation. However, in the years thereafter Nichia's patenting activity here ceased. It cannot be said if the firm intended to learn from these cooperations and use that knowledge on own projects in the long run, a strategy which perhaps failed, or if these cooperations were only intended to solve particular technological problems, with no intent to acquire related knowledge for long-time use.

6. Conclusion

This case study presented several different patent and literature analyses for the technology field ''semiconductor components in the blue-green spectral area based on GaN'', and gave insights into a variety of issues in business firms with strategic background.

First, statistical analysis of patenting and publishing activities as well as citation data was performed on a technology field level. The results confirmed the leading role of one company in the field: Nichia. Patent clusters around frequently cited patents could be detected for Sumitomo and Showa Denko. Co-citation analyses revealed technological similarities among Nichia and Toyoda Gosei – both companies were involved in patent litigation trials. Second, two individuals – Nakamura and Akasaki – were identified as key players or R&D dualists in the field. It became obvious that only very few individuals bridged the gap between science and technology successfully, as Nakamura and Akasaki do since they are highly active and highly cited in both domains. Third, closer examining one company in the field – Nichia – revealed that the firm obviously suffered technologically from Nakamura's departure. Patents developed after his departure are of less impact. The firm also increased its cooperation level thereafter, but these cooperations did not result in many subsequent patent applications by Nichia on its own, implying either that knowledge acquired through cooperation might not have been absorbed successfully, could not have been further developed into own technological capabilities, or the aim of the cooperation was to solve particular technological problems with no long-term impact.

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