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Technovation 26 (2006) 13–29

technovation

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There's a new man in town: the paradigm shift in optical technology

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Abstract

The contribution gives a short introduction into the enabling character of modern optical technology and tries to trace the paradigm shift from bulbs to opto-electronics and photonics in quantitative terms using science and technology indicators. As an example of the economic potential of the new optical technology, the impact on foreign trade is investigated and discussed. As it turns out, there seem to be different strategies of nations concerning adoption of modern optical technology. Most of the countries considered follow the strategy to start from the traditional strength in their homebase and differentiate from there to the prosperous new product lines. But also newcomers are observed which do not follow this traditional path. Overall, the contribution adds evidence to the notion that the evolution in changing areas of technology is nation-specific.

Keywords: Optics; Paradigm shift; Patents; Evolution; Foreign trade

1. Introduction

In the 1990s Optical Technology (OT) achieved a great eminence as an enabling technology—and this development is still going on. Today, optical technology is more than just lenses, lighting or photography. Lasers next to the operating table, diodes for energy-efficient lighting or projectors and flat screens are only some of the recently developed products applying optical technology, whereas glasses, lenses and cameras have not ceased to be well-known and established products in use. The decreasing size especially of lasers and an increase in power and efficiency makes it hard to imagine what this technology enables us to do and to expect in the future.

Today, optical technology is an important factor in the development of new products and processes in many branches of industry and continues to offer them invaluable development potential. It has established itself as a driving force for technological and economic development in many industries, like the Information and Communication Sector (ICT), medical equipment manufacturing or energy and lighting, to mention only some. For the ICT sector it can be expected, that optical technology will be the main technology inside the next generation of computers—optical computers. Where the mechanical world has come to certain limits the optical world promises new dimensions. A broadly known example is the problem of hard drives, which physically cannot be pushed very much further, not only due to mechanical limits, but also due to a decrease in the speed of processing the electronic data. Optical storage systems work at the speed of light and use the whole light spectrum, so much more information can be stored on a much smaller space, and the speed is still high enough to serve the purposes of future tasks. Whereas optical components like infrared interfaces or CD and DVD drives are standard equipment in modern computers, the future will bring us—from today's viewpoint—even more components on the basis of optical technology up to complete optical computers.

In the operation theatre optical technology will gain importance not only by the substitution of the traditional scalpel by the laser scalpel, which has already become reality in many modern hospitals. The surgeon of the future is—at least in part—a machine, guided by a computer.

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0166-4972/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.technovation.2004.07.007

And the input signals to it will stem to sensors, which are also based on optical technology.

Since the first bulb was brought into being by Thomas Edison, the development of lighting has dramatically changed—though in most parts the principle is still the same. But in some parts the principle is completely different, as can be seen in the use of diodes for lighting: it is not only to achieve a close similarity to daylight, which is healthy for man's eyes, but also to achieve a higher energy efficiency, which helps to establish a responsible and sustainable use of resources.

The 'new' optics expected in the near future is sometimes called 'photonics'. Photonics is the combined use of microelectronics, opto-elelctronics, integrated optics and micro-optics, in which particular consideration is given to the requirements of parallel signal processing. In view of the large number of technologies combined in photonics, it is understood as a general concept, even though the segments operating together are not strict subdivisions of photonics. Behind this lies the conviction that, by the start of the 21st century, the subject matter, the use of the concept and the economic aspects of photonics will increasingly come to the forefront. Beams of light can cross in a plane or in space without affecting each other. This can produce parallel and highly networked systems, so that photonics is particularly well suited to all types of pattern recognition, associative storage, parallel search procedures, etc. and especially artificial neural networks. What is behind this obvious change in understanding optics?

In the 1960s, important contributions towards the understanding of research and development (R&D) processes emerged from science theory. Kuhn (1962) and Lakatos (1974) criticized the prevailing cumulative description of scientific development and gave a central position to the paradigm change which comes in as discrete patterns of further development in the sciences. In innovation research, this logic soon metamorphosed into technology and led to the postulation of technological paradigms (Dosi, 1982, 1988). The term technological paradigm is understood to be a specific pattern of search-and-solve methods which belong to a well-defined science principle, in which this knowledge is channelled to appropriation and its immediate dissemination. Expressly material or production engineering aspects belong to the paradigm (Dosi, loc. cit., p. 1127).

Initially euphoric expectations of a new technology (mostly on the part of the scientific community) tend to be followed by increasingly cautious development phases before the market is finally penetrated. The use or rejection of innovative products on commercial markets often leads to new demands on R&D, which is why it generally makes sense to speak of 'feedback processes'. The cyclical development of science-intensive technologies results in a long time-scale for the observation of the efforts made to incorporate both important fundamental science areas and major application systems (for a review of this literature see Grupp, 1998).

In economic classification, present-day optical technology is part of:

- conventional consumer goods such as optical lenses and photographic equipment
- modern products such as CD players and optical memory as well as
- capital goods such as measuring instruments and lasers for use in manufacturing and medicine.

A more or less drastic change in the leading paradigm is always a chance for new actors; the cards are shuffled anew. But do the big players from the old branches of the economy have a higher chance of winning the new game? This is the question, which we try to answer on the basis of empirical evidence stemming from R&D indicators—namely scientific publications, patents, R&D expenditure and foreign trade statistics.

We attempt to show, that, indeed, the big players have good chances in the new game. But also some new players may find their way to mastering modern optics. One of the most important reasons for this is, that such a change in the technological foundations is a rather radical affair, which also devaluates traditional knowledge and skills. Another reason is the fact, that an increase in importance and a gain in market shares also leave space for specialisation and differentiation. As it is the case in most of the upcoming technologies, there is a rather asymmetric distribution of the emphasis of such new technologies over countries. Again, it seems that the formerly known and leading industrial nations are also on the top of the wave.

For the purposes of this study, we chose a classification system containing eight items for delineating optical technology. These are based on systems used in Lenkungskreis (2000, p. IX) and COSE (1998):

- Optics in information and communications technology (ICT)
- Optical technology in biomedicine (Biomedicine)
- Measurement, testing, sensor technology (MTS)
- Optical technology in production engineering (Production)
- Lighting and energy (L+E)
- Manufacture of optical components and systems (Components):
  - ○ Conventional optics
  - ○ Modern optics and
  - ○ Television engineering.

In most of the statistics presented in this article, we aggregated these classes—just to get the assumed paradigm change clearer-into two categories: traditional and modern optics. Traditional optics contains the groups 'Measurement', 'Lighting and Energy', 'Conventional Optics' and 'Television engineering'.

Nevertheless, the discussion of the results will still be given on the level of the eight categories, where appropriate.

2. Basic research in optics

2.1. Bibliometric methodology

Scientific research plays a particularly important role in high-tech, science-based branches of industry like optical technology. In these sectors basic plus applied research done by public institutions as well as R&D by business enterprises is needed to establish new technologies and products. Therefore, an international comparison of scientific articles provides information about this sector's scientific positioning and technological potential. Though not all scientific and especially technological findings will be (immediately) published, scientific publications can be seen as one implication for the strength of national scientific and-to a certain extend-of national innovation systems.[1]

One source for a systematic analysis of scientific publications is the Science Citation Index (SCI), provided by the Institute for Scientific Information (ISI). This database is available online[2] and can—besides others—also be used for statistical purposes. It covers a range of international scientific journals from different disciplines ranging from mathematics over engineering to sciences like biology or chemistry, with more than 600,000 articles added newly each year. It also contains some of the most important scientific journals in the field of optics.[3]

In this article, as a national publication each publication is counted where at least one author with an address in the specific country was involved. Therefore, multiple counts are possible, if several authors from different countries are responsible for the publication. Another way of assigning publications to countries would have been to count only the first author for each publication as an indication of main authorship. Because in many cases the authors are named in alphabetical order, this would not have been appropriate. A second reason for accepting multiple counts is the fact, that each author involved has a certain knowledge or expertise, which just is intended to be assigned to his or her country.

The examination of scientific publications can first of all be done via absolute numbers or shares of publications. These figures are not independent of influences of a country's size, so for elimination of size effects relative measures are more appropriate. One of these measures is the number of publications relative to the number of inhabitants or employed population. Due to the fact that the number of employees is also 'biased' by some other factors like economic structure, productivity and cultural influences, we decided to use the absolute number of inhabitants to calculate relative publication figures. The so called specialisation index[4] allows an assessment of the standing of a certain scientific discipline within a country relative to its standing in the world (defined by all publications in the database). The figures are standardised, so a direct comparison of the values between countries irrespective of their size and statements about the specialisation of their national research systems are possible.

The question as to whether there is a natural order concealed in science and technology which could be used as a basis for its subdivision into 'optics' and 'not optics' is readily answered in the literature by stating that technology at the start of the 21st century cannot be subdivided in this way. However, different the individual lines of R&D may be, they will all ultimately act in combination. Therefore, the choice of a generic heading like optics is somewhat arbitrary, since some subject areas will inevitably fall under more than one such heading (Grupp, 1994). This may be checked by looking for the interlocking of different fields of science or technology, respectively. For an enabling technology like the OT it is important to know in which other fields it has an impact and also how this impact changes over time. In this study this is done by analysing the citations of articles from optics in other scientific or technological fields (in journals dedicated to these fields).

First, all publications in the SCI were grouped into 26 scientific fields (following Grupp et al., 2001). Next, it was investigated how many articles are published in each discipline per year and how many of these cite at least one article from an optics journal. These examinations were done on two levels: world-wide absolute values of optics cited within these disciplines by year as well as the articles for each country (under investigation).

For the purpose of international comparability and independence of size effects, impact specialisation is computed on the basis of these figures, too, and thus the comparability between different scientific fields and between different countries is made possible.

2.2. Publications in optics

As shown in Table 1, the share of US researcher's output in the field of optics decreased rapidly in the course of

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[1] For a detailed discussion of scientific publications as an indicator for scientific and technological strength see for instance van Raan (1988).

[2] For the analysis conducted for this study we used the online version available through the host STN.

[3] For a list of these journals see http://www.isinet.com.

[4] $\mathrm{RPA} = 100\tan h\ln[(Pkj/\sum jPkj)/(\sum kPkj/\sum kjPkj)]$. P_{kj} is the number of publications of country k in field j. By using the natural logarithm an arrangement around zero is achieved. The Tangens Hyperbolicus—multiplied by 100—forms the boundaries of -100 and $+100$ (Grupp, 1998).

Table 1
Share of published articles in optics by selected countries, 1990–2001

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
US	32.8	31.6	30.5	31.3	30.2	28.3	26.6	25.8	24.4	24.5	24.4	24.2
JP	7.3	7.5	7.0	6.3	7.5	8.0	8.2	8.0	9.4	9.2	9.0	8.3
DE	5.4	6.1	7.7	7.2	7.8	7.9	8.1	8.3	8.0	8.8	8.8	9.0
FR	4.4	4.8	5.1	5.0	5.4	5.3	6.1	7.0	6.7	6.2	6.2	6.9
GB	7.7	7.5	7.8	7.7	8.1	8.0	8.0	7.6	7.3	7.2	7.3	6.0
CH	1.0	1.1	0.9	1.1	1.1	2.4	1.4	1.5	1.7	1.6	1.4	1.4
CA	2.7	3.0	3.3	3.5	3.0	2.8	2.7	2.7	2.3	2.3	2.4	2.3
SE	0.7	0.8	0.8	1.1	1.2	1.0	1.1	1.2	1.3	1.3	1.5	1.7
IT	2.0	2.4	2.7	2.6	2.8	2.9	3.3	3.3	3.5	3.7	3.8	4.2
NL	1.2	1.5	1.7	1.4	1.8	1.4	1.4	1.6	1.5	1.5	1.6	1.6
KO	0.2	0.3	0.4	0.6	0.6	1.2	1.0	1.3	1.5	1.6	1.9	2.2
TW	0.7	0.8	1.1	1.2	1.1	1.2	1.8	1.7	2.0	1.8	2.0	2.3
IN	2.1	2.3	2.1	2.0	1.9	1.6	1.8	1.8	1.8	1.8	2.0	2.3
CN	2.8	3.0	3.2	3.9	3.3	4.0	3.9	4.1	5.1	5.7	6.9	8.0
PL	1.2	1.4	1.1	1.2	1.3	1.3	1.5	1.4	1.3	1.5	2.2	2.2
all countries	72.3	74.2	75.4	76.2	77.1	77.2	76.8	77.3	77.9	78.8	81.2	82.5
Top ten	65.2	66.3	67.5	67.3	68.9	68.0	66.8	67.0	66.1	66.4	66.2	65.6

Sources: SCISEARCH; Fraunhofer ISI calculations.

the 1990s. The reason: other countries such as Japan, France and Italy expanded their activities during the same period. Despite this, the lion's share of articles in optics originate from the USA. Germany's share grew noticeably, from some 6% world-wide at the start of the decade to 9% at its close. As a result, Germany became increasingly specialised in optics and joined the front ranks of the world's industrialised nations in this field by the late 1990s. Publicly-funded R&D facilities account for the bulk of Germany's output of published scientific articles although the overall capacity of such facilities has not increased in Germany during the period under review. This evolution seen in optics research has been the result of a shift in the primary activities pursued by the publicly-funded research sector—which is largely self-determined. The scientific foundation in favour of optical technology appears to have improved considerably in Germany in recent years to the disadvantages of other areas.

The development of China was the most noticeably in this group of countries. The Chinese scientists have been able to increase their share from some 3 to 8%, while the world-wide number of publications in optics nearly doubled within the same period. Also some other emerging countries like Korea, Taiwan and Poland have been able to increase their share in optics in the course of the 1990s as did French, Swiss, Swedish and Italian researchers; whereas British and Canadian researchers lost parts of their good position.

In the year 2001, 15 countries under consideration account for nearly 83% of all scientific publications in optics, covered by the Science Citation Index, whereas this share was about 72% in the year 1990, which is first of all due to the growth of the five emerging countries, whereas the 10 leading countries still account for about 65 percent.

As already mentioned, these figure are dependent on the size of a country. The relative measurement of scientific

Table 2
Publications per 1,000,000 inhabitants in the field of optics in the 1990s

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
US	8.4	9.1	9.5	9.4	10.9	10.4	9.9	10.3	10.0	9.4	10.8	10.5
JP	3.8	4.4	4.5	3.9	5.6	6.2	6.4	6.7	8.2	7.5	8.6	7.2
DE	5.4	5.6	7.6	6.9	9.0	9.4	9.7	10.8	10.8	11.2	13.1	11.5
FR	5.0	6.1	7.1	6.6	8.5	8.5	10.0	12.4	12.5	10.8	12.4	12.1
GB	8.6	9.5	10.7	10.2	13.0	13.2	13.3	13.8	13.7	12.6	14.9	12.6
CH	9.5	11.6	10.3	12.7	14.5	32.6	19.4	23.1	26.2	23.9	23.0	20.6
CA	6.4	8.1	9.1	9.5	9.7	9.4	8.9	9.7	8.6	7.9	9.5	10.1
SE	5.4	6.6	7.7	9.5	12.4	10.6	12.4	14.0	15.8	15.6	20.6	19.8
IT	2.2	3.1	3.7	3.6	4.6	5.0	5.6	6.2	6.8	6.7	8.1	9.5
NL	5.3	7.4	8.7	7.3	11.1	8.7	8.6	11.0	10.3	10.0	11.9	11.4
KO	0.4	0.5	0.7	1.0	1.2	2.5	2.1	3.1	3.7	3.5	5.0	6.2
TW	2.4	2.8	4.2	4.7	4.8	5.5	8.1	8.3	10.2	8.5	10.8	12.9
IN	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CN	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.7	0.8
PL	2.0	2.7	2.3	2.4	3.1	3.2	3.8	4.0	3.7	4.1	7.1	6.9

Sources: SCISEARCH, OECD—Main Science and Technology Indicators; Fraunhofer ISI calculations.

publications per 1,000,000 inhabitants is given in Table 2. As can be seen, Great Britain and the United States have high indices nearly over the whole period under observation, which is to a small extent also due to a language bias favouring English speaking countries (Grupp et al., 2001). But also smaller nations like Switzerland, Sweden, the Netherlands and Taiwan are ranked highly by using this indicator. This can be explained by the fact, that they do not have a large own readership by language and therefore directly write in English which is still the most important language in the sciences. On the other hand, countries like France or Germany also reach good positions in the international comparison on the basis of publication intensities, having a large circulation in their indigenous language. The amounts of China and India are qualified due to their large size in respect of population. This indicator shows, that these countries are not as active in optics, as could be expected by the fact that they account for about 1/3 of the world population.

What also can be seen in Table 2 is that in all countries there is a positive trend in the course of the 1990s, so the per-capita publications in the field of optics increase nearly everywhere. American researchers have not been able to push their position very much further; in the United States optics was important already in the 1980s. Late adopting countries like Japan, Germany, Italy, Korea or Poland have been able to reach high growth rates, starting from a lower level.

The indicators used so far do not take into account the specialities of the national research systems, indicating the rank of optics within the system. The specialisation index (Fig. 1) sets the share of national activities in the field of optics in relation to the activities in this field throughout the world. Positive values—which indicate activities above the world-wide share—are reached by France, Japan, Germany and the emerging countries Korea, Taiwan, China and Poland. Besides that a negative development can be seen in the United States, Great Britain, Canada, The Netherlands and also China.[5]

2.3. Science spillovers of optics

Attention should be directed to the question of the scientific areas into which optics 'spill over'—in other words, for which areas does it or could it have an enabling function. Strong influences of new knowledge in optics already exist for several scientific disciplines like electronics, telecommunication, nuclear sciences and of course in the related fields of measurement or physics (Table 3).

In the course of the 1990s optics gained more and more importance for data processing, basic chemicals and materials research, but also for fields like medical equipment or thermal processes a positive development can be seen. Besides a development over time there may also be some differences over countries in their structures of using optics in other disciplines. The impact of optics in electronics is high all around the world with slight disadvantages for Korea, Taiwan or Poland (Table 4). In the field of telecommunications the picture is a little bit more diffuse. Whereas nearly all countries show positive values Great Britain, Japan, Italy and India reach especially high figures. Concerning data processing, the advantages lie in the United States, Great Britain, Canada, Sweden and the Netherlands for example. Weak spillover processes are visible for Germany, France, Italy and China.

The field of measurement is split between the traditional industrialised countries showing a high impact of optics on their research system and the emerging countries (except India) showing lower values. The medical equipment field is diversified and shows also an interesting pattern. Though all countries reach only negative values—indicating a citation rate below average of all optics citations of the respective country—Canada, the United States, Great Britain and Switzerland reach significantly lower negative figures.

3. Invention and innovation in optical technology

3.1. Patent statistics: methodology

Patents are the most important output indicators of innovation activities for the manufacturing sector. This is also valid for the field of optical technology, though not all inventions find their way to official filing and may not be found in patent databases afterwards.

Form the viewpoint of the analysis of innovation systems, patents are an indicator for the codified knowledge of (mostly) companies and in a broader perspective of national economies (Grupp, 1998, pp. 144). Different to brandmarks, which can be seen as an innovation indicator which include the service sector (Schmoch et al., 2002), patents are focused on technological innovations, which are first of all created in the manufacturing sector.[6] It can be assumed that every patent—especially in the R&D-intensive branches like OT (see below)—is preceded

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[5] For the English-speaking countries this may also be based on the fact, that in the second half of this decade more and more non-English speaking journals were covered by the Science Citation Index. But the overall trend should not be perverted by this fact. A comparison of the articles in the field of optics shows that 7.8% of all articles of the years 1993–1995 are published in journals, which did not exist in the database in the years 1998–2000. Vice versa 13.2% of the articles in the years 1998–2000 are published in journals, which have not been included in the years 1993–1995. So the difference of 5.5% may be classified as 'artificial' growth. Relative to the overall growth of 33.4%, this is a rather small part of the total growth. A difference in the distribution over countries has not been examined here.

[6] In some cases also companies from the service sectors apply for patents. But their share of alle patents at the EPO lies below 5% (Blind et al., 2003).

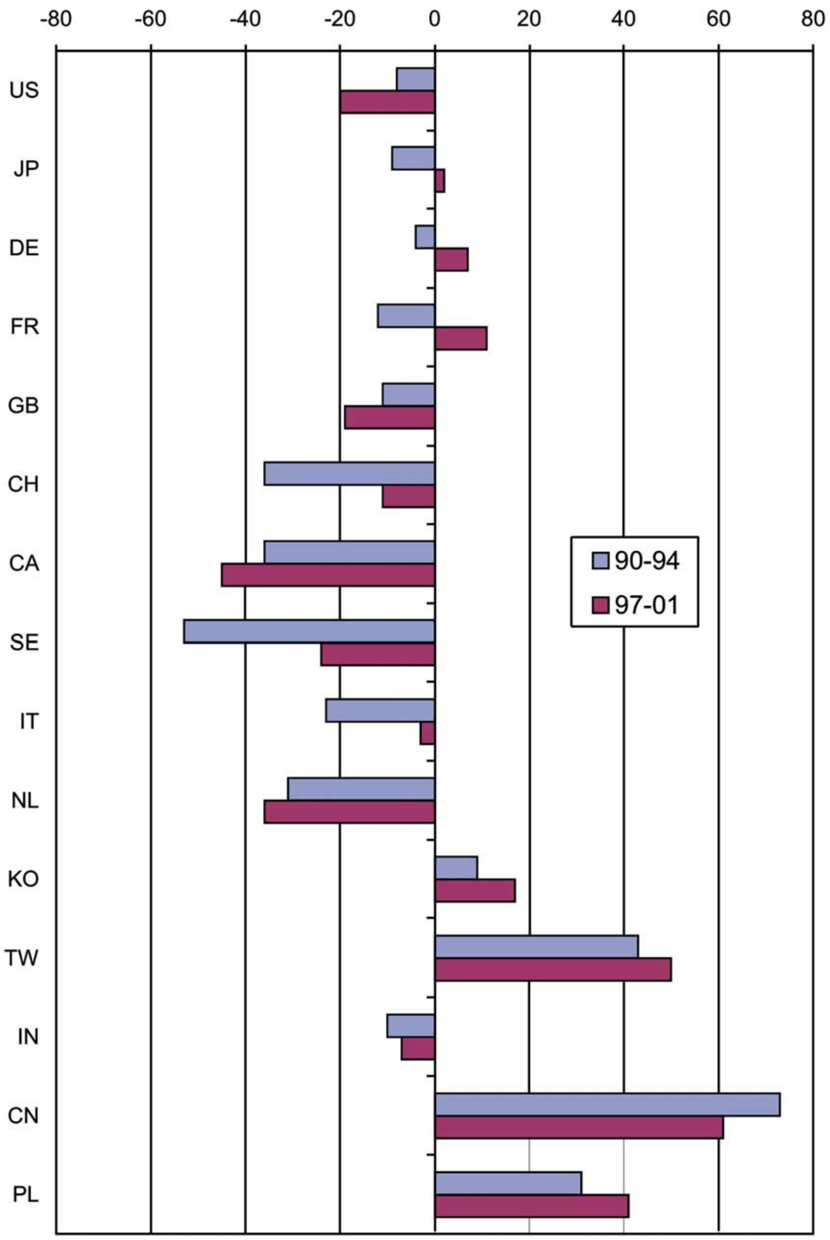

Fig. 1. Specialisation index for selected countries 1990–1994 vs. 1997–2001. Sources: SCISEARCH; Fraunhofer-ISI calculations.

by a large amount of investment in R&D (Kash and Kingston, 2001). So patents can be interpreted as a success or output indicator of the R&D process (Kleinknecht and Oostendorp, 2002; Grupp, 1998; Grupp et al., 2002).

Which application at which patent office is used for the statistical analysis is of crucial importance for the interpretation, actuality and coverage of the patent indicator. For international comparative studies one could use applications at different national offices, but this would lead into a broad range of problems with comparability and availability of data, first of all due to different patent laws and also due to different ‘cultures‘ in applying for patents. This kind of approach would make sure that every nation under consideration has a certain home advantage, but would be an enormous endeavour. As far as we know, nobody tried it so far.

In times of global markets and international competitiveness patent offices covering the largest and most important markets are used for statistical analyses of patent applications. These offices are the Japanese Patent Office (JPO), the US Patent Office (USPTO) and the European Patent Office (EPO). One further way of applying for international patents is under the Patent Cooperation Treaty (PCT) administrated by the World Intellectual Property Organisation (WIPO) in Geneva.

For the analysis conducted for this article, applications at the European Patent Office and under the PCT procedures were used. These figures were chosen because of

Table 3
World-wide importance of optics for other scientific disciplines (specialisation index) 1990–2001

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Electrical engineering	82	80	79	75	76	78	80	81	79	81	77	77
Telecommunications	52	37	30	31	46	45	50	52	45	51	41	26
Data processing	−39	−46	−24	−25	−23	−15	−15	9	−7	10	0	−1
Optics	100	99	99	99	99	99	99	99	99	99	99	99
Measurement and control	90	88	88	86	84	84	82	79	85	84	82	85
Medical technology	−80	−78	−71	−74	−71	−78	−67	−73	−72	−52	−63	−67
Nuclear technology	61	73	46	58	65	69	57	60	63	62	46	52
Organic chemistry	−99	−99	−99	−99	−99	−98	−94	−93	−90	−90	−84	−84
Polymers	−26	−14	−28	−21	−11	−16	−16	−27	−29	−8	−18	−13
Pharmaceutics	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100	−100
Biotechnology	−98	−98	−99	−98	−99	−98	−98	−98	−98	−97	−97	−98
Food processing	−100	−100	−100	−100	−100	−100	−100	−100	−100	−99	−100	−100
Basic materials chemistry	−4	−2	5	−1	−2	8	10	21	18	21	21	14
Processing	−90	−86	−66	−66	−80	−87	−83	−86	−79	−78	−72	−76
Materials	−2	−6	10	16	18	18	24	26	26	30	30	23
Environmental technology	−42	−91	−96	−86	−96	−93	−87	−87	−88	−91	−87	−91
Mechanical machinery	−42	−16	−23	−28	−37	−36	−46	−46	−42	−43	−44	−54
Thermal processes	−67	−63	−71	−51	−59	−56	−61	−65	−40	−56	−35	−58
Construction technology	−88	−91	−84	−80	−88	−95	−98	−95	−97	−93	−92	−93
Physics	92	92	92	92	91	91	92	91	92	91	91	89
Medicine	−98	−98	−98	−98	−98	−98	−97	−98	−98	−97	−98	−98
Biology	−97	−96	−98	−96	−97	−97	−97	−98	−97	−97	−97	−98
Ecological and climate research	−40	−60	−62	−53	−62	−55	−59	−50	−49	−54	−58	−62
Mathematics	−39	−5	−28	−17	−9	−6	−28	−63	−62	−65	−71	−73
Geosciences	−19	−31	−29	−44	−55	−47	−44	−53	−15	−23	−28	−28

Sources: SCISEARCH, Fraunhofer ISI calculations. The disciplines were classified using the subject categories in Grupp et al. (2001).

international comparability and high actuality of data, yet a summary about the application process and the relevant features of the proceedings at the EPO and at the WIPO cannot be given in the frame of this contribution; see for instance Grupp and Schmoch (1999).

In the statistical use of patents it is a special advantage, that in the respective databases all patents are published[7]—after a certain time lag—and then are also available for statistical purposes. So the whole population is represented and not only a sample of patents. At the EPO[8] the time lag between the first application (priority) and the publication is 18 months. In this article, only priorities are used, because on one hand this leads to higher actuality and on the other hand it can be assumed that before every patent application represents a certain inventive activity, whether it will be granted or not. Another reason to use priorities is the close connection to the time of invention or the innovation expenditures (R&D expenditures for instance).

Inventors have the chance to apply for a patent in some or even all of the more than 120 countries via the WIPO as the central institution using a uniform procedure. For the patent statistics of the European Patent Office the patents applied for under the PCT procedure get into the databases with a certain postponement. It is a rather young procedure,[9] which was and still is discovered by more and more applicants (Schmoch, 1999). The patent figures at the WIPO show very high growth rates in the course of the 1990s and today these growth rates are still high. To some extent this growth is due to a real growth of inventions, but to a certain extent, this growth is also due to a shift of more and more applicants towards this procedure. What makes it hard to distinguish between the real and the procedural growth is the fact, that these growth rates differ widely over countries, technological fields or branches and to some extent also over firm size, to mention only these. So a pure usage of PCT data seems not appropriate (yet).

Patents are not directly connected to products, but can be distinguished by their technological implications. The International Patent Classification (IPC) is regularly revised every 5 years. With about 65,000 symbols in its deepest disaggregation a very sophisticated classification is reached. Each patent is classified by the examiner, who normally is an expert in his/her field, to one main and several secondary codes. This classification then can—besides other purposes—be used for statistics. On the basis of this classification, the assignment of patents to the eight classes of optical technology was done.

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[7] The American Patent Office (USPTO) does not publish the applications but only the grants. There, the non-granted applications are not accessible.

[8] The target or destination countries represented by the EPO go beyond the member countries of the European Union.

[9] Though it was established in the year 1978, it reached a high attractiveness in the 1990s, first of all because much more countries signed the treaty at that time.

Table 4
Country specific impact of optics on other scientific disciplines 1999–2001

	World	US	JP	DE	FR	UK	CH	CA	SE	IT	NL	KO	TW	IN	CN	PL
Electrical engineering	79	79	81	78	78	89	87	82	83	74	89	55	61	70	72	64
Telecommunications	39	47	72	25	46	81	41	49	36	68	49	29	−1	56	27	29
Data processing	3	17	−4	−44	−41	26	2	27	34	−15	17	−7	12	10	−44	−72
Optics	99	100	99	99	99	100	99	100	100	99	100	99	99	99	98	99
Measurement and control	83	86	84	80	85	85	72	88	83	72	84	46	47	87	43	62
Medical technology	−62	−41	−88	−79	−84	−50	−46	−14	−72	−85	−60	−94	−91	−94	−85	−77
Nuclear technology	53	62	49	41	43	53	29	51	41	14	77	−56	4	45	−3	24
Organic chemistry	−86	−81	−95	−78	−90	−85	−4	−64	−95	−84	−84	−100	−98	−96	−98	−90
Polymers	−13	18	−30	−19	−22	21	38	−20	16	26	−5	−33	−34	−86	−54	−73
Pharmaceutics	−100	−100	−99	−100	−100	−100	−99	−99	−100	−100	−97	−100	−100	−100	−100	−100
Biotechnology	−98	−96	−99	−97	−99	−96	−96	−98	−96	−98	−97	−100	−100	−99	−99	−98
Food processing	−100	−100	−100	−100	−100	−99	−99	−92	−100	−100	−100	−100	−100	−100	−99	−100
Basic materials chemistry	18	53	0	23	17	35	48	58	58	16	58	−17	0	−23	−52	−8
Processing	−76	−6	−65	−62	−52	−19	−43	−53	−19	−60	−7	−46	−90	−91	−92	−93
Materials	27	29	2	10	40	40	34	23	27	50	41	10	2	15	−30	10
Environmental technology	−90	−75	−97	−70	−97	−93	−65	−97	−92	−86	−92	−43	−100	−98	−99	−93
Mechanical machinery	−48	1	−40	−24	−10	−21	20	−40	−40	−16	−6	−63	−50	−76	−81	−76
Thermal processes	−50	17	−60	22	−13	−66	−13	−82	17	−33	6	−34	−76	−89	−75	−64
Construction technology	−93	−86	−88	−79	−74	−85	−63	−88	−99	−71	−87	−100	−96	−96	−96	−100
Physics	90	90	84	83	84	90	81	95	91	83	88	78	81	88	75	71
Medicine	−98	−95	−99	−98	−99	−96	−96	−92	−99	−99	−97	−100	−99	−100	−100	−100
Biology	−97	−96	−99	−96	−99	−96	−96	−96	−97	−97	−95	−100	−99	−99	−99	−98
Ecological and climate research	−58	−25	−60	−41	−48	−67	−53	−51	−70	−37	−42	−65	−83	−87	−95	−79
Mathematics	−70	−56	−71	−79	−85	−49	−81	−59	−62	−74	−87	−97	−97	−58	−95	−88
Geosciences	−26	18	−43	−31	−36	−51	−40	−28	−39	−19	7	−51	−19	−79	−87	−43

Sources: SCISEARCH, Fraunhofer-ISI calculations. Discipline classification as in Table 3.

The analysis of patent statistics is done similarly to the analysis of scientific publications in Section 2.3. Next to absolute and relative figures, intensities (patents per 1 million inhabitants) and specialisation indices are calculated, to reach a better international assessment of the figures. The specialisation index (RPA) is calculated with the same formula where P_{kj} is now the number of patents of country k in the technological field j.

3.2. Patents in optics

Table 5 contains the absolute number of patent applications, the patent intensities, the growth rates and the specialisation index in the area of optical technology for the selected countries. As can be seen, the total number of applications nearly doubled[10] within the period under consideration. In the year 2000 the United States account for about 1/3 of all applications in the field of optical technology at the European Patent Office, followed by Japan and—with some margin—Germany. The Netherlands reach a higher number of patent applications than the larger European countries France and Great Britain, giving them rank 4 under the 15 countries under consideration here.

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[10] Within the same period the overall patent applications at the EPO doubled, too. Therefore, a doubling in the number of applications in the field of optical technology does not give any evidence for an respective increase of relevance of OT.

Table 5
Indicators based on patent applications in optical technology for selected countries

	N of patents in 2000			Patents per 1 mio. inhabitants			Applications 1990 vs. 2000 (in per cent)			Specialisation index (1996–2000)		
	OT	Trad.	Mod.	OT	Trad.	Mod.	OT	Trad.	Mod.	OT	Trad.	Mod.
Total	10,363	6310	4052	–	–	–	195.4	182.1	220.7	–	–	–
US	3337	1844	1493	12.1	6.7	5.4	237.5	199.8	309.7	4	2	8
JP	2869	1700	1169	22.6	13.4	9.2	139.7	131.2	154.4	44	40	51
DE	1372	920	452	16.7	11.2	5.5	206.3	211.4	196.7	−38	−31	−50
FR	542	365	177	8.9	6.0	2.9	174.7	186.1	155.1	−26	−23	−31
GB	491	308	184	8.2	5.1	3.1	152.6	145.8	165.5	−14	−14	−14
CH	201	136	65	28.0	18.9	9.0	254.2	266.5	231.8	−31	−35	−26
CA	153	74	78	5.0	2.4	2.5	508.8	337.8	979.2	−27	−47	3
SE	149	68	81	16.8	7.6	9.1	708.2	563.3	901.4	−54	−71	−26
IT	195	116	79	3.4	2.0	1.4	162.3	144.7	197.4	−48	−52	−41
NL	584	458	126	36.7	28.8	7.9	358.5	448.8	207.3	49	61	13
KR	156	83	73	3.3	1.8	1.6	445.0	285.0	1218.1	28	17	43
TW	35	29	7	1.6	1.3	0.3	587.2	714.3	333.2	15	45	−74
IN	1	0	1	0.0	0.0	0.0	100.0	n.a.	n.a.	−99	−100	−96
CN	37	24	13	0.0	0.0	0.0	1853.3	n.a.	1300.0	−18	−6	−41
PL	2	2	0	0.1	0.1	0.0	n.a.	n.a.	n.a.	−76	−71	−85

modern OT: optics in ICT, Biomedicine, Production and modern components; traditional OT: optics in Lighting and Energy, Measurement, classical components (lens, photography etc.) and Television; Source: PATDPA; values for 1999 and 2000 are projected; Fraunhofer ISI calculations.

When looking at the patent intensities, the Netherlands reach the highest values, first of all due to Dutch activities in the more traditional[11] parts of optical technology,[12] namely Lighting and Television. Also smaller European countries like Switzerland or Sweden are ranked highly, with the former having a certain strength in traditional but also in modern OT and the latter with laying an emphasis on modern OT. Japan with high intensities has a pretty good diversification between traditional and modern optical technology, still laying a certain emphasis on the traditional parts of photography, lenses and television. The Japanese figures are the more astonishing as the European Patent Office and the European market are not that important for Japanese enterprises as for example the US market and therefore having a kind of 'home disadvantage' at the European Patent Office.

It can be seen that most of the countries experienced a growth rate, which is above the overall patent growth of 195% between 1990 and 2000, but some countries remain on a lower level, namely Japan, Great Britain, France and Italy. These countries are overtaken by some developing countries like Korea,[13] Taiwan and China, when looking at the growth rates. Thus, these countries produce higher absolute patent numbers than the developing ones, but the latter are catching up. The economic crisis in Asia within the 1990s explains—to a certain extend—the rather low growth rate in Japan. In the last years the development of Japanese patent applications got back its dynamics of the 1980s or even goes beyond. One will see if the Japanese firms are able to convert their newly reached technological strength into returns on the world markets again.

The most impressive values—in terms of growth—are reached by Sweden, Taiwan, Canada and Korea. Besides Taiwan these countries extremely specialise in modern optical technology. This underlines our hypothesis that also smaller and 'younger' countries are able to put a foot in the door of photonics. The United States-on the other hand-show a pretty interesting development as US companies are able to keep their good position in traditional OT as well as showing high growth rates in the more modern part of optical technology at the same time, namely ICT and Biomedicine.

The specialisation indicates the position of optical technology within the national innovation systems. Positive values are reached by the United States, Japan, the Netherlands, Korea and Taiwan. It is pronounced by this index that the 15 countries under examination are on different trajectories in the paradigm change in optics. Whereas Germany, France, The Netherlands or Taiwan do better in traditional OT, countries like Switzerland, Sweden, Canada or Korea focus on modern OT. Some countries show a rather similar pattern in both parts. These are the United States, Japan, but also Great Britain and Italy, whereas India and Poland are not really assessable yet. China also holds a singular position as the values are not stable enough to be finally assessed.

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[11] For the demarcation of 'traditional' see the introduction and the legend to Table 5.

[12] The intensities in traditional and modern optical technology (rows in Table 5) are not directly comparable as the patent applications in traditional OT are still higher than in modern OT. But the ranks within the columns-compared over countries-give indications for the position relative to the overall activities.

[13] One may ask if it is still appropriate to label the OECD member country Korea as a developing country instead of an industrialised country. Anyway, it is a rather 'young economy' in the premier league of world-wide important economies.

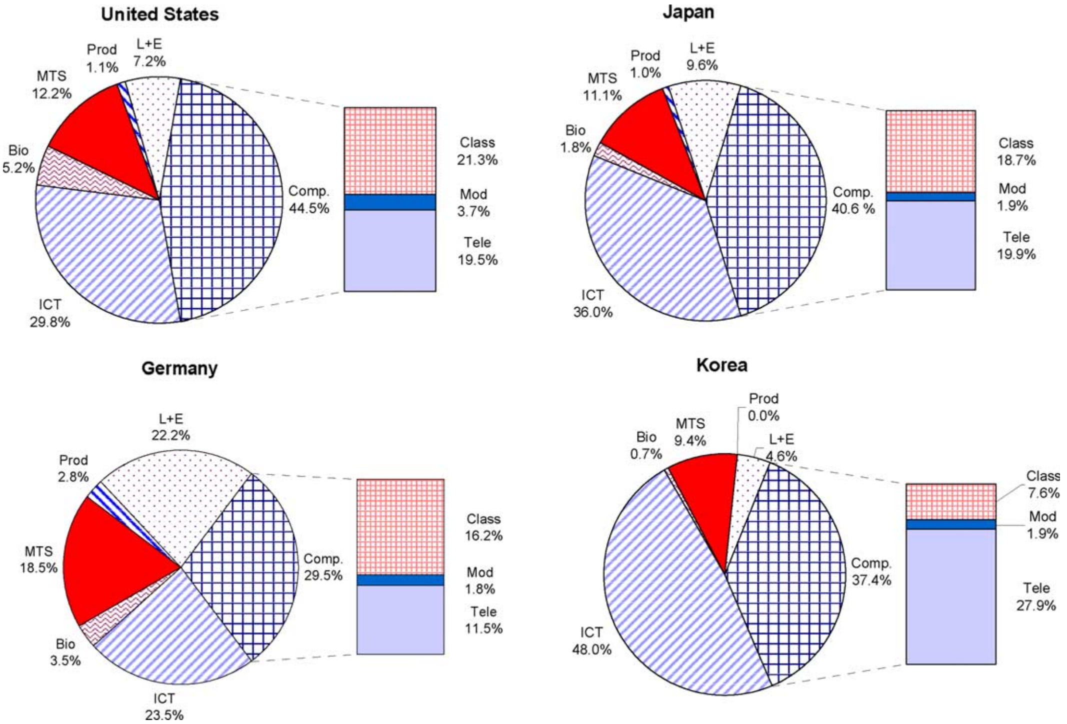

Fig. 2. Patent applications involving optical technology for selected countries, broken down by subfield, 1998–2000. Key to the acronyms: ICT: OT in ICT; Bio: OT in Biomedicine; MTS: Measurement, Testing and Sensors; Prod: OT in the Production Process; L + E: Lighting and Energy; Comp: Optical Sources: PATDPA; Fraunhofer ISI calculations; the values for 1999–2000 are extrapolated.

Fig. 2 shows the different distribution of patent applications within the big three and the rather 'young economy' of Korea in an exemplary fashion. Here, patent applications are split up in six, respectively, eight categories, underlining the diversified alignment of these four countries in the changing optical technology. It also shows the different sizes within the two parts of OT. The modern applications of optical technology in Information and Communication Technology take up a pretty large share of the patent applications in OT in all countries. This also holds for the optical components at the side of traditional OT (except the small field of modern components). Also MTS (traditional) is a rather large part of OT concerning the patent applications as is Lighting and Energy. The rather modern applications of optical technology in Biomedicine, in the Production Processes and the modern components have still restricted shares at the overall patent applications in the field of OT. But these patent applications are the most promising ones and also define the enabling function of optical technology for other technological fields.

Germany's rather 'bad' position in the part of modern OT can now be qualified, for example. The German position is mainly defined by its low activities concerning the ICT activities. But the German firms do very well in the younger applications of Biomedicine, Production and modern components. So Germany is in a pretty good position for future tasks of optical technology, even though the position in modern applications seems to be below average. Japan's patent intensities nearly doubled during the 1990s and are markedly higher than those reported by the USA and seem to focus on certain niches of optical technology, which is obscured by the large application segment of optical technology in the ICT sector. This assumption of niche activities also holds for some other countries like the US, for example. The US focus-so it seems—on Biomedicine and Medical Equipment in general also affects the activities in optical technology in Biomedicine of 5.2%. Two conclustions may be learned from Fig. 2: first, focusing on traditional or modern applications of optical technology does not imply to clearly give up one part and second, some countries seem to have a certain specialisation strategy, which is not directly obvious at the aggregated level.

To sum up the results of the examination of patent applications: four groups of nations can be identified by their different pattern of patenting at the European Patent Office in the field of optical technology. Whereas all countries under consideration do pretty well in optics research, as the analysis of scientific publications could show, they widely differ in their patent activities:

- The first group of countries (still) lay a certain emphasis on traditional OT. These are The Netherlands, Germany and Taiwan. A sub-group is constituted by France, Italy and maybe also Great Britain, falling off their former successes by not showing a similar positive trend like other countries do.
- The second group are more or less engaged in both traditional and modern OT. These are the United States,

Table 6
Dynamics of the relevance of optical technology for other areas of technology (from multiple patent classifications 1990–1994 as compared to 1995–1999)

	Electrical eng.	ICT	Instruments	Chemistry	Process eng.	Mech. eng.
OT in ICT	0	+	0	−	+	−
Biomedicine	−−	0	−	++	+	++
MTS	0	−	0	0	0	+
OT in Prod.	−	−	−	++	+	0
L+E	0	+	−	+	0	+
Opt. comp.**	++	+++	0	0	+	0
Television	0	+	−	*	+++	0

Key to symbols: 0 = change smaller than +/−10%; + = change between 10 and 50%, ++ = between 50 and 100%, +++ = more than 100%; the same for '−' and '−−'. *Patents without corresponding secondary classification; **classical and modern optical components without television. Source: PATDPA; calculations by Fraunhofer ISI.

Korea, Switzerland and in the last years Japan. Also China may be summarised under this heading, but not acting constantly enough for being finally assessed.

- The third group of countries specialises on modern optical technology, namely Canada and Sweden.
- The fourth group has not (yet) been able to convert its research excellence into technological innovations or patents, respectively. These countries are India and Poland.

3.3. Spillovers of optical technology

The optics field as a whole is so heterogeneous that it calls for a closer examination. By statistical analysis of main and secondary patent classes, increasing spillover potentials of modern OT can be assessed (Table 6). Optical technology increasingly stimulates the ICT field, for example. The compact disc has already superseeded magnetic storage media. We will also see optical storage media replacing the magnetic hard disk sooner or later. Other areas where ICT can make use of optical technology applications include wireless data transmission via infrared interfaces. Optical elements will also be important components inside computers (optical computers) in the future. In this connection, monitors and displays—which can also be classified as products of optical technology—already play an important role in consumers' everyday life.

4. R&D activities related to optical technology

4.1. R&D branch statistics: methodology

The relative R&D figures used here stem from OECD[14] databases, namely ANBERD and STAN. These figures are only available at a two-digit sector level and therefore do not allow a sharp demarcation of optical technology. Nevertheless, the data are used to get some insights into the national R&D expenditures in sectors closely related to optical technology. The R&D expenditures are the only data used in this article which are based on a sector demarcation. Whereas it is rather easy to classify optics on the basis of scientific publications, patents or products, a classification on the basis of sectors or branches is more difficult; the reason lies in the nature of the sector differentiation. A firm is normally assigned to that sector, in which its main activity in terms of value added or number of employees is located (gravitation principle). Especially for firms with a high diversification this is a rather artificial assignment. Sector data base are included here, first of all, because R&D expenditure are investments in the future and therefore may explain how stringent the path into the future development is pursued.

Actually we are using R&D intensities—defined here as R&D expenditure relative to the production value within a certain sector, as this indicator is independent of size effects, currency exchange rates or structural effects due to a over-specialisation in some relevant sectors, as it would be the case, if absolute R&D expenditures were used. The interpretation of R&D intensities has one main disadvantage, as an increase in the R&D intensity may rely on a 'real' extension of R&D expenditures or on a decrease of production values—and vice versa. It can be assumed—and empirical results proof this assumption (see, e.g. Grupp et al., 2002), that R&D expenditure is less elastic as production, turnover or value added. However, with these restrictions in mind, a subjective assessment of the figures presented her should be possible.

In some cases, optical technology plays only a subordinate role for optics users (and at their R&D facilities). Companies in other sectors—whose total R&D expenditures on optics are not known-probably account for the lion's share of Optical inventions. This is a further reason, why the figures used here allow only a restricted assessment of the R&D activities in optical technology within the different countries. It must also be pointed out that gross output varies greatly between individual areas of application in the optical technology field. In Germany for example, this

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[14] This is the reason why China and India are not included in the following tables. They are not members of the OECD.

Table 7
R&D intensities in selected OECD countries 1991–2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
US	6.7	7.2	7.6	8.5	8.3	8.2	9.1	9.4	12.1	11.3
JP	6.0	6.8	7.6	8.2	9.0	9.1	9.7	10.6	n.a.	n.a.
DE	6.4	5.8	6.1	6.1	6.7	6.1	5.5	5.5	5.6	5.1
FR	13.7	11.7	11.6	11.8	10.3	9.1	9.3	6.5	6.5	n.a.
GB	3.8	3.7	4.0	3.3	3.4	3.1	3.4	3.4	n.a.	n.a.
IT	0.9	1.0	0.8	0.6	1.4	1.1	2.2	1.6	1.6	1.6
SE	1.5	6.9	10.3	10.8	10.3	9.6	7.8	7.4	8.1	n.a.
KR	n.a.	n.a.	n.a.	n.a.	1.2	1.3	1.6	1.8	1.2	n.a.
PL	n.a.	n.a.	n.a.	0.6	0.4	0.4	0.4	0.7	0.5	n.a.

ISIC 33: Manufacture of medical, precision and optical instruments, watches and clocks. Data for Canada, Switzerland, the Netherlands, China, India and Taiwan are not available. Source: OECD: STAN, ANBERD; Fraunhofer ISI calculations.

field accounts for nearly 12% of the manufacturing sector's gross output. ICT applications are responsible for half of this, while OT in the Production Process, Lighting and Energy, and Measuring and Control technology generate about 10% each. All other areas contribute single-digit shares.

Actually we examine the sectors 33 (Manufacture of medical, precision and Optical instruments, watches and clocks) and 32 (Manufacture of radio, television and communication equipment and apparatus) of the International Standard Industrial Classification (ISIC), as it can be assumed, that these are 'closest' to the optical technology.

4.2. R&D intensity related to optical technology

Virtually in all countries these sectors (and thus also OT) exhibit intensities that exceed the level reported for the manufacturing sector as a whole, so it can be called a R&D intensive technology. Although invention activity has grown rapidly in the optical technology in most of the countries analysed here R&D intensities in the Optical Industry are stagnating or even shrinking in the course of the 1990s in most of the countries for which data are available (Tables 7 and 8).

Concerning sector 33 'medical, precision and Optical instruments, watches and clocks', three groups of countries can be identified. A first group, comprising the United States, Japan and to some extend also Italy and Sweden, have been able to increase their share of R&D expenditures within the second half of the 1990s. A second group of nations has been able to keep their shares more or less stable, namely Great Britain and—on a lower level-also Korea and Poland. In the third group the R&D activities are partly extremely decreasing in the course of the 1990s (France and Germany).

Concerning the activities in sector 32 (see Table 8), this picture changes decisively. Germany is the only country, which has been able to increase its R&D intensity. Though this is partly a publicly funded investment, Germany's business sector keeps the lion's share of this expenditure. For France a similar development can be seen, but at the close of the decade, the figures decrease here, too. The second group of stagnating countries consists of the United States, Japan, Canada and—on a lower level-of Korea and Poland. The third group is formed by Great Britain, Italy and Sweden, whereas at least for Sweden the reason for the dramatic decrease lies in an increase of production and not in a decrease of R&D expenditure.

Table 8
R&D intensities in selected OECD countries 1991–2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
US	9.1	8.5	7.9	7.8	7.9	9.3	8.9	9.5	6.9	8.6
JP	5.6	6.4	5.9	6.1	6.2	5.7	5.9	n.a.	n.a.	n.a.
DE	12.1	12.5	12.8	12.1	12.4	14.0	15.1	15.5	13.0	10.7
FR	8.4	10.9	11.3	11.8	10.4	10.2	9.3	9.1	8.7	n.a.
GB	6.1	6.0	6.2	4.6	4.5	4.7	4.2	4.5	n.a.	n.a.
CA	12.1	11.1	12.9	13.9	12.8	13.1	13.1	14.3	12.4	n.a.
IT	8.0	8.5	8.6	8.8	7.9	6.9	6.7	6.5	9.2	n.a.
SE	28.2	26.9	20.5	15.7	12.6	10.8	9.8	9.9	8.3	n.a.
KR	n.a.	n.a.	n.a.	n.a.	4.5	5.1	5.7	4.3	5.1	n.a.
PL	n.a.	n.a.	n.a.	1.8	1.2	1.1	1.0	1.4	1.2	n.a.

ISIC 32: Manufacture of radio, television and communication equipment and apparatus. Data for Switzerland, the Netherlands, China, India and Taiwan are not available. Source: OECD: STAN, ANBERD; Fraunhofer ISI calculations.

When taking into account the results of the analysis of patent applications as an output indicator of the innovation process, one may ask if a connection between R&D and patents really exists or at least if it is stable over time in times of a changing technological paradigm. A first answer to both questions would be ‘No’. To some extend this is due to the measurement problems on the R&D side.

One explanation why patent output is rising while R&D intensities are stagnating or even shrinking is the fact that production has been greatly expanded—most significantly, through new products-at least since the mid-1990s. Research and development have not kept up with the pace of this growth. This captures a characteristic aspect of a shift in technological paradigms. R&D expenditure pertains to future products whereas R&D intensities are measured on the basis of turnover that is currently being generated. When an industry is navigating in calm waters, these figures signal stable conditions. In other words, a particular sector is by nature either R&D intensive or not. However, when a company conducts R&D on a large scale to adopt a new technological paradigm and consequently produces successful innovations that cause its production and turnover levels to rise very rapidly, its R&D quotients will fall until conditions return to normal for this particular sector. From the observed relations we may conclude, all other things being equal, that firms are progressed considerably into modern Optical production.

5. Foreign trade—an exemplary economic output of technological activities

The values of the foreign trade statistics do not only give an indication of the economic success of products in a foreign country and—based on this—how it contributes to the national welfare, but it can be interpreted as an indicator for the international ‘strength’ of a sector. The maintenance of one’s position on a foreign market, where companies directly meet their competitors without a specific ‘home advantage’, tells much about the state of this company and in a wider perspective the competitiveness of the national economy.

5.1. Foreign trade statistics: methodology

One of the mostly used sources for the assessment of export data is the so called ‘International Trade by Commodities Statistics‘ (ITCS) provided by the OECD.[15] In this statistics all commodities are counted in US $, which leave the economic area of one country (exports) or enter the respective economic area (imports). Commodities, coming in from one country and which are directly forwarded to a third country, are not counted in this statistics.

The commodities are firstly classified on the basis of the so called Harmonised System (HS) and then reclassified with the help of the Standard Industrial Trade Classification (SITC) used here. Though the respective figures are reported by the national statistical offices the OECD figures are not completely comparable to the national statistics, because in some cases the national definition of foreign trade deviates from the OECD definition and is therefore recalculated to ensure international comparability.

The different foreign trade indices can be seen both as output indicators of national economies, but also as indicating the international competitiveness of countries or industries. In this article, basically three indicators are used: (1) the national share of the world[16] trade (WTS); (2) the relative share (RTS) indicates the relevance of a countries exports with the respective commodities relative to the world-wide exports of these commodities and is calculated similar to the specialisation index used for scientific publications and patents; (3) the Revealed Comparative Advantage (RCA) compares the relation of exports to imports of a specific country (with the respective commodities) with the relation of all imports and exports of that country. It is also calculated like the specialisation index mentioned above. Positive values indicate an export surplus and negative values indicate an import surplus in the considered product group.

5.2. International competitiveness in optical technology

The overall foreign trade indicators in the area of optical technology (see Table 9) show evidently that Japan dominated the world-wide market with optical commodities over a long period in the 1990s. This strong position was first of all based on large market shares in television, photography (cameras) and partly in ICT. But Japan’s position dramatically dwindled in the second half of the decade with the share of OECD-wide trade nearly cutting to half in the year 2000, compared to 1991. The Japanese export-import relation (RCA) is still positive, but also decreased clearly within these 10 years. Other countries, which lost world market shares, are some of the traditional Western European nations like Germany, France, Italy and also Switzerland. Winner of this re-distribution within the Optical paradigm change are the United States and Great Britain and the smaller industrialised countries Canada, Sweden and the Netherlands. Whereas all these nations have been able to convert their increased share into specialisation, the US increase goes hand-in-hand with a decrease in the specialisation indices. This indicates that the growth of the market share was still below the average growth (RTS) and that the Americans increased their imports of optics commodities even more than their exports. Again, the most noticeable development can be assigned to Korea—though

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[15] Again this is the reason why China and India are not included here.

[16] World covers in this case all OECD member countries.

Table 9
Indicators based on foreign trade statistics in the area of optical technology for selected countries, 1991 and 2000

	Share of World Trade (WTS)		Relative Trade Share (RTS)		Revealed Comp. Adv. (RCA)	
	1991	2000	1991	2000	1991	2000
USA	16.5	17.5	6	−2	−24	−27
Japan	31.5	18.6	69	45	88	23
Germany	13.1	9.0	−25	−33	−30	−36
France	6.4	5.3	−30	−27	−31	−21
United Kingdom	8.0	8.9	11	34	10	18
Italy	4.4	2.3	−45	−72	−39	−59
Canada	1.3	3.3	−82	−46	−84	−49
Sweden	1.6	2.4	−32	19	−46	11
Netherlands	5.7	7.2	14	52	−12	−6
Switzerland	1.4	1.2	−53	−47	−53	−42
Korea	n.a.	4.7	n.a.	9	n.a.	8

Source: OECD, Lower Saxonian Institute of Economic Research and Fraunhofer ISI calculations.

it was not in the OECD in the early 1990s and therefore no data are available for that period, reaching a share of world-wide trade with optical commodities, which is nearly as high as that of France and even higher than the shares realised by Canada, Italy or Sweden. As could be seen already in the analysis of patent data, the Korean firms are specialised in traditional optical technology (television) and therefore explain to a large amount the Japanese losses.

These overall developments in the optical technology can be further qualified when looking at the foreign trade differentiated by traditional and modern OT (Tables 10 and 11).

Table 10 displays the foreign trade indicators for the traditional optical technology between 1991 and 2000. The increase in the overall world trade share of the US—as indicated by Table 9— is not backed by an increase in the part of traditional optical commodities as their share declines by more than 2%. Their relative world position in traditional optics consequently shrinks as well as their export-import relation (RCA). More or less the same holds for Japan-but on a much higher level-and also for other traditional industrialised countries like Germany, Italy, France and Switzerland, while the latter two could increase their relative position parallel to a decrease in their share of the world trade. The upcoming countries in the part of traditional optics are Canada, Sweden, the Netherlands and Korea again. But also ‘other countries’ have been able to double their share of the world-wide ‘cake’ of optical products in the course of the 1990s, showing that the group of producers of traditional optical technology became and maybe still becomes larger.

It seems that those countries holding higher shares in the traditional sub-fields of the optical technology loose (or give up?) their positions for the benefit of the smaller and upcoming nations. The only exception from this rule is the UK, which has been able to push its standing a little bit further.

Concerning the modern applications of optical technology (Table 11) the results look somehow different. The only nations which have been able to gain in their positions are the US and Canada, whereas all other countries under consideration have lost world trade shares, even the ‘promising’ ones like Sweden and Korea. This is due to an extensive increase of ‘other countries’, which could not be analysed in detail here. The increase by 12% of this country group spreads over the remaining 19 OECD

Table 10
Foreign trade indicators in traditional optical technology 1991–2000

	WTS			RWA			RCA		
	1991	1994	2000	1991	1994	2000	1991	1994	2000
USA	22.8	21.5	20.5	36	33	14	8	7	−10
Japan	24.4	20.9	12.9	52	39	12	72	46	−21
Germany	12.9	11.6	9.1	−27	−23	−32	−31	−32	−39
France	6.4	6.4	5.6	−30	−20	−22	−29	−22	−14
United Kingdom	9.2	9.4	10.6	24	36	49	11	16	27
Italy	4.0	3.4	1.6	−52	−57	−86	−43	−24	−80
Canada	1.8	1.8	3.9	−72	−74	−34	−77	−80	−42
Sweden	2.1	1.4	3.0	−4	−37	37	−26	−59	27
Netherlands	5.0	6.5	8.6	0	38	64	−20	−1	−1
Switzerland	1.7	1.4	1.4	−37	−47	−31	−44	−58	−32
Korea	n.a.	3.6	4.6	n.a.	5	9	n.a.	28	−3
Other countries	9.7	12.1	18.2						

Source: OECD, Lower Saxonian Institute of Economic Research and Fraunhofer ISI calculations.

Table 11
Foreign trade indicators in modern optical technology 1991–2000

	WTS			RWA			RCA		
	1991	1994	2000	1991	1994	2000	1991	1994	2000
USA	8.4	8.7	11.7	−54	−52	−40	−73	−72	−62
Japan	40.8	33.4	29.6	80	71	74	97	87	70
Germany	13.4	11.4	8.9	−24	−24	−35	−30	−26	−29
France	6.4	5.5	4.7	−31	−35	−38	−34	−34	−35
United Kingdom	6.5	5.7	5.4	−10	−13	−15	6	6	−15
Italy	5.0	4.8	3.9	−35	−29	−38	−34	−9	−17
Canada	0.8	0.9	2.3	−93	−93	−70	−92	−91	−64
Sweden	0.9	0.9	1.4	−73	−66	−35	−76	−74	−36
Netherlands	6.6	5.9	4.5	28	29	9	−4	4	−24
Switzerland	1.0	0.9	0.7	−74	−73	−77	−68	−68	−67
Korea	n.a.	6.5	4.7	n.a.	57	10	n.a.	88	32
Other countries	10.2	15.4	22.2						

Source: OECD, Lower Saxonian Institute of Economic Research and Fraunhofer ISI calculations.

and associated countries for which we have no detailed, stable and long term data. There seems to be no individual ‘Goliath’ among these countries, but when the results of the patent analysis are taken into account, China and also Poland may have some advantages.

Japan previously had enormous strengths in the global market for modern applications of OT, first of all backed by its good position in information and communications technology. In the course of the Asian crisis the former strength has suffered, but Japan still holds the ‘pole position’ in modern applications. If the Asian crisis was the immediate cause or only an opportunity for other countries cannot be assessed finally here. But what can be said is, that first of all the United States, Canada and Sweden have benefited from the Japanese weakness. This also holds to some extend for the Netherlands. Optical technology in the ICT sector plays an important role in this country’s economic structure even though the Netherland’s foreign trade specialisation in this field is no longer backed by a correspondingly high level of patent activity, particularly in recent years. Thus, Dutch firms have remarkably been able to enhance their world trade shares in the ICT sub-sector, but at the same time they lost their former good position in Modern Components, which explains why their overall world trade shares in modern applications was shrinking (Table 12).

5.3. Sub-sectors of opics

The US backed the changes in competitive positions first of all by strengthening the efforts in the fields of Modern Components and in Biomedicine starting from a ‘home base’ in ICT. Most other larger industrialised countries are loosing their standing in traditional optical technology for the benefit of the smaller industrialised countries. But at the same time no one is really able—except the US and Canada—to weigh up these losses with gains in modern applications of optics. Here seem to be much more players on the playground and strategy and tactics are not yet visible. It looks like soccer of 6-year-old children: They all crowd around the ball and no one cares about his or her individual tasks.

This impression of chaos may somehow be disentangled when looking at the sub-sectors of modern OT (Table 12).

Table 12
World trade share in the sub-sectors of OT in the year 2000

	ICT	Bio-medicine	Production	Measuring	Lighting and energy	Classical components	Modern components	Tele-vision	Total OT
USA	18.2	32.6	21.0	29.0	13.5	14.8	45.8	5.5	17.5
Japan	12.9	11.2	21.2	15.7	6.4	41.2	6.6	34.6	18.6
Germany	7.4	16.5	15.3	17.2	17.0	8.5	29.8	3.7	9.0
France	5.7	6.0	2.8	2.9	8.1	3.4	3.7	4.3	5.3
United Kingdom	12.1	4.6	3.4	8.5	5.3	5.4	3.9	4.9	8.9
Italy	1.2	2.6	6.1	1.5	9.3	5.1	1.2	0.6	2.3
Canada	4.5	0.7	2.2	2.0	2.8	4.5	3.4	0.5	3.3
Sweden	3.0	2.3	6.1	3.6	1.9	0.4	1.2	1.6	2.4
Netherlands	9.2	7.2	2.2	5.0	3.1	6.2	1.7	3.7	7.2
Switzerland	0.9	2.2	10.8	4.8	0.8	0.6	0.3	0.1	1.2
Korea	5.5	1.0	1.4	0.2	1.3	3.1	0.1	8.4	4.7
Other countries	19.4	13.1	7.5	9.6	30.5	6.8	2.3	32.1	19.6

Source: OECD, Fraunhofer ISI calculations.

Then individual strategies appear. The US focus on ICT, Modern Components and Biomedicine, as already mentioned. Japan still has to cope with the consequences of the Asian crisis, but seem to focus on ICT as a sign of former strength and also optics in the production field. Germany missed the train in ICT and may only have chances in some special niches. On the other hand German companies, when acting in the optics field, are prepared for future tasks in Production, Modern Components and to some extend also in Biomedicine. The Netherlands, Canada and Sweden put more or less an exclusive emphasis on ICT applications, which is the largest market under consideration here but also the most overcrowded one. Completely new players have high chances in the newer fields of modern applications of optical technology, as the gains of 'other countries' in world market shares indicate. Concerning traditional OT applications the 'retreat' of the traditional industrialised countries is used by 'traditional newcomers' like Korea, Sweden or Canada and some niches are available for complete newcomers.

6. Discussion and conclusions

The notion of a technological path that is defined by catchwords such as 'data transmission via light,' 'Optical computers' and 'plastic light-guide fibre' is growing. The term Photonics has been coined for the pin-pointed manipulation and processing of light for transmitting information and data: photonics will emerge as a natural extension of opto-electronics. Today's technology transforms electrical signals into light signals at interfaces and then back into electrical signals at their destination—a process that involves various losses (see Grupp, 1994). This method offers enormous advantages for fast parallel processing because problems with conducting signals and short-circuits do not arise when light is used.

Optical technology is a so-called enabling technology which serves as an input for other technical applications and products. Despite the fact that optical technology directly accounts for only a small share of value added in some product groups (the lasers used in conventional CD players cost only one or two US $ to make), it is frequently essential to the particular product's functioning. A shift from conventional applications to modern applications is underway. Optical technology builds increasingly on the latest scientific findings. In keeping with its large variety of possible applications and its wealth of different technical implications, Optical technology influences many jobs in the manufacturing sector and is also responsible for a large share of the economic development.

In the optical technology—or better to say, in many technologies with the help of optical technology—a change in the leading technological paradigm is underway, shifting from traditional to modern applications. Parallel to this shift the connection between the latest scientific findings and the fate of the economic development also increases. The science system in many countries has already made an 'advance payment' in the optics field. During the 1990s the number of scientific articles in most countries has reached a high growth rate. Now it is necessary for most nations to catch up with the economic system so that this 'know-how lead' can be translated into marketable products. Since small and medium-sized enterprises are the pillars supporting economic activity in the optical technology field, steps must be taken to support the two-way transfer of knowledge given the difficulties that usually arise in this connection. Regional inter-linkage offers the greatest potential here. The modern applications of OT in ICT, the life sciences or production appear to be particularly suited for this because the technological revolution in these fields offers good opportunities for 'new entrants': The cards are being reshuffled as the sector is making the transition from opto-electronics to photonics. But as can be seen from the analysis above, some countries—especially the 'developing' ones—are still not able to convert their scientific excellence into economic advantages. The promotion of this transfer of knowledge between scientific institutions and economic entities seems to be the challenges for the policy makers also in the field of optical technology.

As it turns out, there seem to be different strategies of nations concerning the OT. Some remain in conventional optics, some master modern applications and others do both. At the same time some of the considered countries seem to specialise in certain applications of OT and seem to occupy individual niches with the help of optical technology. Most of the nations-if actively changing their position and specialisation in OT-follow more or less the same strategy: starting from the 'home-base' of traditional strength in the manufacturing sector, they increase their effort in related parts of OT. This can be seen in the case of Germany, where the dynamics of the OT in production engineering is tied to the machinery and equipment sector. Another example are the US, where the impressive development in biomedical optics is based on preceding successes in overall Biomedicine. These examples highlight another important result of the analysis: except the field of OT in the ICT sector, the modern applications of optical technology are undertaken by traditional industrialised countries and not—as hypothesised in the introduction—by new players in the game. In part, a path for newcomers can be seen, going from traditional to modern applications, and not directly into modern parts of OT. But there seem to be chances for complete newcomers from the side entrance especially in modern applications of optical technology, which do not follow this traditional path.

In the event that the optics field is actually undergoing a paradigmatic shift from 'lens grinding' to Photonics, the question must be raised of how national innovation systems with their existing economic structure plan to respond to this shift. In Germany, for example, the way industry is organised continues optics to be viewed as a sister to precision instruments—in other words, as somewhat more advanced lens grinding. Cohesive basic and continuing training courses, occupational designations and product classifications that correspond much more to this new paradigm are needed. The signs of the times are as clear as a laser show in the sky. It is vital that many countries lay the groundwork for a development path by resolutely pursuing structural adjustments. The world's major economies-the USA, Japan and in some cases even France and Great Britain-have already started getting their private sector 'into shape' for the technological challenges that the future will bring in the optics field. For enterprises that operate globally, the R&D infrastructure is an important factor in decisions on whether to invest in a particular country-because being efficiently incorporated into R&D networks makes it possible to create and safeguard jobs.

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