Bibliometric mapping as a science policy and research management tool
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9   Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes[*]

A bibliometric study on recent developments in Micro-Electronics, and on the performance of the Interuniversity Micro-electronics Centre in Leuven from an international perspective

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Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes

A bibliometric study on recent developments in Micro-Electronics, and on the performance of the Interuniversity Micro-electronics Centre in Leuven from an international perspective

Abstract

The general aim of the paper is to demonstrate how the results both of a structural analysis, and of a research performance assessment of a research field, can be enriched by combining elements of both into one integrated analysis. In addition, a procedure is discussed to select and analyze candidate benchmark institutes to assess the position of a particular research institute, in terms of both its cognitive orientation and its scientific production and impact at the international research front.

The combined method is applied in an evaluation of the research scope and performance of the Inter-university Centre for Micro-electronics (IMEC) in Leuven, Belgium. On the basis of the comments of an international panel of experts in micro-electronics, the method was discussed in detail. We concluded that the method provides a detailed and useful picture of the position of the institute from an international perspective. Moreover, we found that the results of each of the two parts are an added value to the other.

9.1   Introduction

In evaluative bibliometrics, two main procedures have been developed in the past decades. These two have, until now, always been used separately. The performance analysis, based on publication output and received citations, is used to assess the research performance of countries, universities, departments or persons. Early examples of these kinds of evaluative studies on a national level are Narin (1976), ABRC (1986), on the level of research institutes Martin and Irvine (1983) and Irvine and Martin (1985), and on the level of individual researchers Garfield (1983). Since the early years of these kind of science studies, the techniques have been improved and have gained an increasing role in policy support. An extensive overview and discussion of the state of the art is presented in Kostoff (1996), Narin and Hamilton (1996), Martin (1996), Van Raan (1997), Glänzel (1996), and Baird and Oppenheim (1994).

Mapping of science is the second procedure in evaluative bibliometrics, mostly aiming at displaying structural and dynamic aspects of scientific research (Braam, 1991). Maps of science have been created with different techniques. The co-citation

technique was initiated by Henry Small at the Institute for Scientific Information (ISI) and further developed in the early seventies (Small, 1973; Small and Griffith, 1974; Griffith et al., 1974; and Garfield, Malin & Small, 1978). In the early eighties the co-word technique was introduced and further developed (Callon et al., 1983; Callon, Law & Rip, 1986, Law et al., 1988; Tijssen, 1992). The technique in general, as a tool for policy purposes, had to withstand severe criticism (e.g., Hicks, 1987; Oberski, 1988; Healey, Rothman & Hoch, 1986). A persistently returning point of criticism has been that the maps lacked of expert validation. At the start of this decade, combinations of both co-citation and co-word were developed (Braam, Moed & Van Raan, 1991; and Peters and Van Raan, 1993), partly to deal with the criticism. The main idea was to use one technique to validate the results obtained by the other.

In the present study, this idea is further developed, in the sense that results from one bibliometric approach are used to validate the results of another. We present the results of a combined performance/mapping study, used to evaluate a Belgian research institute in micro-electronics. At first, the combination was implemented to assess the activity and performance of the institute from both points of view. In a later stage, the combination was used to address the comments from experts to the study. As a result, we managed to use either procedure to validate the results of the other.

The Inter-university Micro-Electronics Centre (IMEC) in Leuven (Belgium) was founded in 1984 by the Flemish Government as an institute to perform scientific research which is five to ten years ahead of industrial needs. To fulfil this mission statement, IMEC has developed a strategy based on four guiding principles:

i.   The establishment of an internationally recognized 'Centre of Excellence' in the field of micro-electronics;

ii.   The performance of fundamental and strategic research in close collaboration with the Flemish universities;

iii.   The performance of dedicated and flexible training programmes in the field of micro-electronics to both educational institutions and industrial companies;

iv.   The reinforcement of industrial activities of companies based in Flanders.

In view of the renewal of the framework agreement for 1996 to 2000, the Flemish Government commissioned an audit of IMEC's activities from 1984 until 1995. In order to provide background material for the Government in its negotiations with IMEC regarding the further elaboration of the new framework agreement, a bibliometric analysis of the research activity was conducted. It consisted of two main parts:

1. A study focussing on the worldwide trends in micro-electronics, and an assessment of the activity of IMEC in the field;

2. A study focussing on the research performance of IMEC in the field as compared to the performance of selected benchmark institutes.

The main objective of the study was to explore the potentials of a combination of these two aspects. The information added from one study to the other was expected to enhance the quality and applicability of both.

9.1.1 IMEC's organizational structure

IMEC was founded as a non-profit organization. Given its mission statement, IMEC's aim to match its long-term research strategy to the future needs of the (Flemish) industry is of crucial importance. To assist its scientific management in formulating this strategy, the IMEC has established a scientific advisory board. It is composed of ten members working either in academic institutions or in industry in Europe, Japan and the United States. This advisory board annually discusses IMEC's research strategy.

IMEC has a typical matrix structure. The study of basic technologies is organized in divisions:

- VSDM: design methodologies for Very Large Scale Integration (VLSI) systems;

- ASP: Advanced Semiconductor Processing;

- MAP: Materials and Packaging.

Each division contributes to the basic development of these technologies in collaboration with international partners. Many projects carried out at IMEC, however, make use of the technologies and are jointly executed by two or three divisions. A fourth division, Department for Industrial Training (INVOMEC), is responsible for IMEC's training activities.

The research and development activities of the Information Technology (INTEC) Laboratory of the Faculty of Applied Sciences at the University of Ghent (RUG), are fully coordinated with IMEC's activities in such a way that from a scientific point of view this research group can be considered as a division of IMEC. INTEC's research efforts are directed towards broadband communication, including opto-electronics and high-speed/ high-frequency circuits. In this study we investigated the three research divisions mentioned, plus INTEC, in as far as its research (output) is formally (addresses in publications) linked to IMEC.

9.2   Data, method and results

9.2.1 Publication data

In collaboration with the staff of IMEC, a database was created containing full bibliographic information (title, name, initials and working address of each author, source, volume, page, publication year) of all publications published during 1985-1994. The research output was represented by all publications in the IEE database on Physics, Electronics and Computing (INSPEC) and the Science Citation Index (SCI) with at least one IMEC address. We started with all the IMEC publications in INSPEC, which contains the addresses of the first author only. The database was completed by the IMEC staff with data from their own internal publication database. Part of these completing publications were covered by INSPEC as well, but were not selected before because the first address is not the IMEC. The INSPEC[17] information was added to these publications.

9.2.2 Citation data

For each publication, we collected data regarding the number of times it was cited until September 1995. This citation data was extracted from the on-line version of the SCI, produced by the Institute for Scientific Information (ISI). We determined the number of times a publication is cited per year. In addition, we counted the amount of self-citations separately. A self-citation is defined as a citation in a publication of which at least one author (either the first author or co-author) is also author of the cited publication.

9.2.3 Selection of benchmark institutes

In this evaluative performance analysis, IMEC's results are compared to those of benchmark institutes. The data collected regarding these reference institutes is used for two different purposes. First, it enhances the standard performance analysis results based on IMEC's publications and on the received citations. Normally, these analyses compare the results of a given institute to the world average. The present analysis compares the results of an institute with those of other, particular institutes. Secondly, the output of the benchmark institutes and their impact are used to characterize IMEC's publication activities. In this section, IMEC's scientific output will be presented from an international perspective. The objective is to identify significant trends in the field, as defined by the publications of the IMEC and the benchmark institutes, and to analyze how IMEC's activities fit into this overall picture.

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[17] I.e. information added by the database producer, e.g. classification codes, and indexed terms.

The identification of benchmark institutes is a complex process. In view of the two applications mentioned above, there are several factors to be taken into account. On the one hand, a selected benchmark has to be active in the same field as the IMEC. On the other hand, the inclusion of benchmarks should allow us to have a somewhat broader view of the domain, in order to identify topics in which the IMEC is not, or hardly, actively pursuing. In addition, the size of the selected benchmarks should be comparable to the IMEC's.

We selected candidates using bibliometric techniques. In other words, the selection was made by comparing publication characteristics of institutes with those of the IMEC, in as far as they were included in the INSPEC database. The characterization of the IMEC's output was done by structuring its publications into areas of research. These areas were defined by clusters of classification codes. These clusters were obtained by co-occurrence clustering of the most frequent classification codes in publications of the IMEC in the period 1991 to 1994.

In the next step, we determined the number of publications produced by other institutes in these sub-domains, in as far as they were included in the INSPEC database in 1993[18].

The data per institute was enriched with three additional figures:

1. The number of sub-domains in which it has at least one publication;

2. The number of publications in each domain in which the IMEC is active;

3. The total number of publications of that institute in INSPEC (1993).

The ratio of figures 2 and 3 gives an indication of the scope, as compared to the IMEC's scope, and figure 1 indicates the 'output profile' similarity of an institute with the IMEC. Finally, the number of publications in INSPEC, gives an indication of the research capacity of the institute.

Based on a combination of these indicators, and taking a certain geographical spread, and a spread in the type of organizations (academic, firms etc.) into consideration, the following institutes were selected:

*   NTT LSI Labs. at Kanagawa, Japan   (NTT)

*   Department of Electronic Engineering, National Chiao Tung University at Hsinchu, Taiwan   (NCTU)

*   Department of Electrical & Computer Engineering, University of Texas at Austin, TX, USA   (UTA)

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[18] As the INSPEC database includes data of the first author's address only, a publication of which the address of the second or third author is of a particular institute, is not assigned as such.

- Department of Electrical Engineering & Computer Science, University of California at Berkeley, CA, USA   (UCB)

- Fraunhofer-Institut Für Angewandte Festkorperphysik at Freiburg, Germany   (FHGF)

- Philips Research Laboratories at Eindhoven, The Netherlands   (PHIL)

All of the institutes have a scope, which is more than 50 similar to the IMEC's scope. Three institutes have a scope of more than 85 overlap, two of about 65 overlap. The IMEC has about 100 publications per year. Four of the institutes have a similar output per year, two institutes have a publication output somewhat below this number. One of these institutes has increased its production during the period to match the IMEC's level[19].

9.2.4 Analyses

The publication database used in our analyses consists of two parts. One contains papers from INSPEC (database years 1989-1995) with one of the benchmark institutes in the address field, while the other part contains the earlier described the IMEC papers published in INSPEC (see section 9.2.1). Together, this data represents the research output of all those institutes within the field. From this database, we selected all papers published during the time period 1988 to 1994. In order to monitor trends in the field during these years, we broke them down into three 3-year blocks: 1988 to - 1990, 1990 to 1992, and 1992 to 1994.

9.2.4.1 General trends in micro-electronics and actor analysis

To provide a visual representation of a large collection of publications (bibliographic data), the 'cognitive maps' are used, developed at the Centre for Science and Technology Studies (CWTS) (e.g., Braam, Moed & Van Raan, 1991; Van Raan & Tijssen, 1993; Peters & Van Raan, 1993, and Noyons & Van Raan, 1998). In such maps the vast amount of knowledge written in (scientific) publications is structured by means of a two-dimensional representation. The structure is generated from the
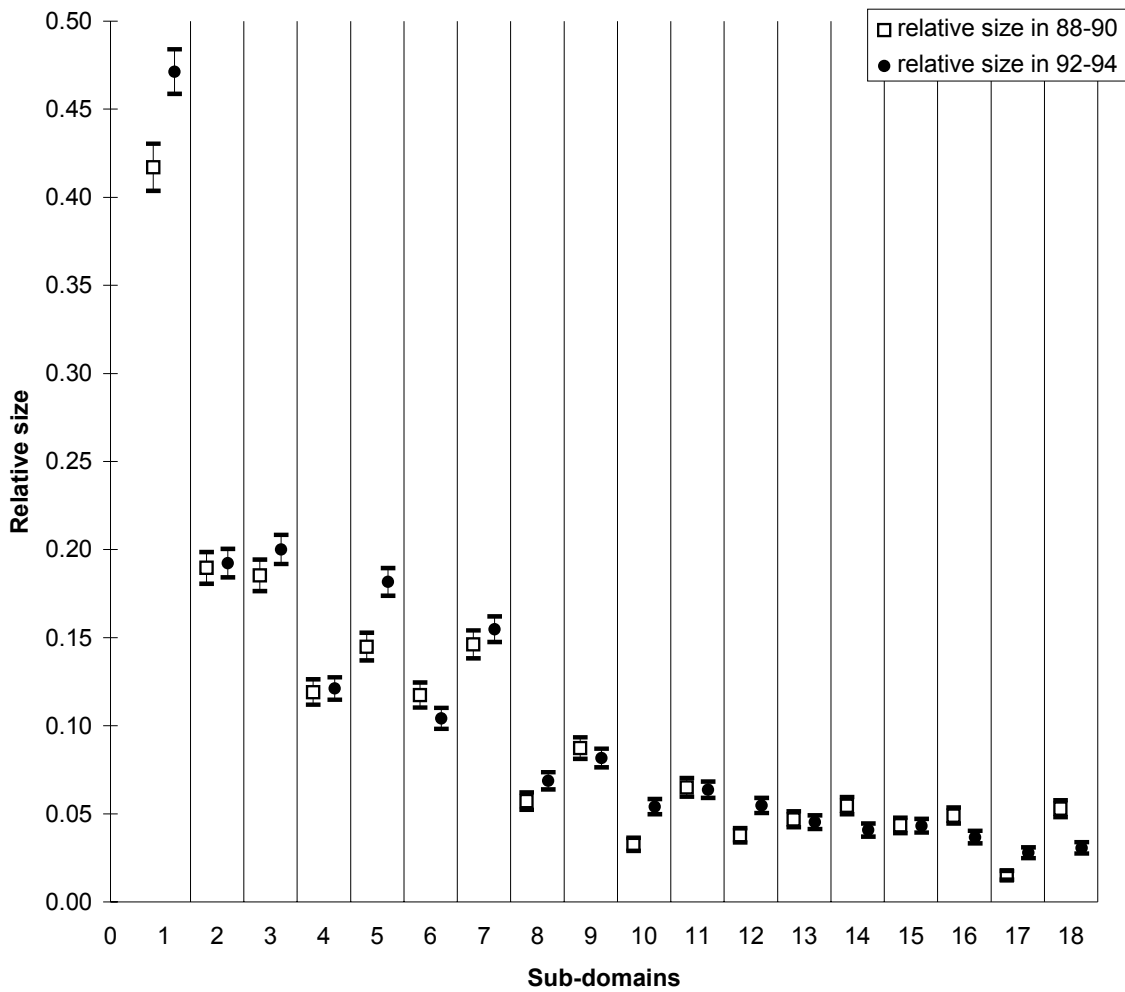
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[19] In a later stage of the project, we also enhanced the database with information about the similarity of the scientific output of the benchmark institutes to that of IMEC. By selecting only those benchmark papers which had the same classification codes as IMEC's publications, a subset of publications considered to be closely related to IMEC's research was selected. In fact, we limited the output of the benchmark institutes to 2 levels of relatedness. Most related were those papers which had at least one of the 16 most important classification codes of IMEC in common (level 1). Second most related were those papers which had at least one classification code in common with the 69 most important codes from IMEC's papers (level 2). By making those selections, IMEC's output was also reduced to the core activities. The former (level 1), and most stringent, selection criterion reduced the overall output of the benchmark institutes by 60%, and IMEC's output by 30%. The latter, less stringent, selection criterion reduced the output of the benchmark institutes by 37% and IMEC's output by 8%.

data itself, rather than being derived from an existing (hierarchical) classification scheme. The research represented by the publications is dynamic. A structure based on an existing scheme does not leave room for identification of new developments, unexpected merging or splitting-up of areas and so on. Particularly, these aspects are of great importance to assess an actor's activity. Actors with a preference for areas that have an unexpectedly split-up or merger show a profile which differs from that of actors with a preference for more 'stable' areas. The map shows the structure of the most important sub-domains in a field. Each sub-domain seeks its own position on the map, taking into account its relations with *all* other on the map. The sub-domains are defined by sets of classification codes. The assignment of codes to sub-domains is established by the application of specific clustering techniques. The core classification codes (i.e. the most frequently used codes) of the field are clustered on the basis of their co-occurrences. The more two classification codes appear in the same publications, the more likely it is that they are clustered. The emerging clusters represent the mentioned sub-domains of the field.

The structure is derived from the 1992 to 1994 data (i.e., the most recent period, see Noyons and Van Raan, 1998). The definition of the sub-domains is given in Table 9–1. Per sub-domain, a set of classification codes is given. In the third column a characteristic name is given, referring to the most frequent classification codes in a cluster (sub-domain).

Table 9–1   INSPEC classification codes by cluster (sub-domain)

Sub-domain	Classification Codes	Name
1	B01, B22, B25	General Micro-Electronics
2	B12, C51, C52	Circuits & Design
3	A68, A81, B05	Materials
4	B11, C74	Circuit Theory
5	B02, B61, C11, C12, C41	Maths Techniques
6	A61, A64, A66	Liquids/Solids Structures
7	A71, A72, A73, A78	Electron. Struct/Propert Surfaces
8	A42, B43	Optics; Lasers & Masers
9	C42, C61	Computer Theory; Software Eng
10	B62, C56	Tele/Data Communication
11	A07, B72, B73	Measuring & Equipment
12	B41, B42	Optical/Optoelec Mat & Dev
13	C13, C33	Control Theory/Appl
14	A79, A82	Physical Chemistry
15	B13, B52	Micro/Electromagn Waves
16	B64, C53	Radio/TV/Audio; Computer Storage
17	A77, B28	Dielectric Propert/Mat/Dev
18	A74, A75	Supercond; Magn Propert/Struct

Subdomains:

1	General Micro-Electronics	10	Tele/Data Communication
2	Circuits & Design	11	Measuring & Equipment
3	Materials	12	Optical/Optoelec Mat & Dev
4	Circuit Theory	13	Control Theory/Appl
5	Maths Techniques	14	Physical Chemistry
6	Liquids/Solids Structures	15	Micro/Electromagn Waves
7	Electron. Struct/Propert Surfaces	16	Radio/TV/Audio; Computer Storage
8	Optics; Lasers & Masers	17	Dielectric Propert/Mat/Dev
9	Computer Theory; Software Eng	18	Supercond; Magn Propert/Struct

Figure 9-1   Evolution of sub-domains (1988-1994)

In Table 9–2, the numbers of publications per sub-domain are given in the three successive two-year blocks investigated in this study. In Figure 9-1, we present an

overview of the evolution of the sub-domains in terms of numbers of publications included in the most recent and 'oldest' year block of the studied period. Per sub-domain, the proportion of publications included relative to the total number in a period was calculated. Moreover, we calculated the error for both data points, under the assumption of a Poisson distribution. In this figure, we detect a significant increase in sub-domain 1 (*General Micro-Electronics*), 5 (*Maths Techniques*), 10 (*Tele/Data Communication*), 12 (*Optical/Optoelectronic Materials & Devices*), and 17 (*Dielectric Properties/Materials/Devices*) and an activity decrease in sub-domain 18 (*Supercond; Magnetic Properties/Structures*). In 14 (*Physical Chemistry*) and 16 (*Radio/TV/Audio; Computer Storage*) the relative decrease is beyond the error bars, but the absolute number of publications remain at the same level.

Table 9–2   Numbers of publications per sub-domain

Sub-domain	Name	88/90	90/92	92/94
1	General Micro-Electronics	970	1337	1385
2	Circuits & Design	441	537	565
3	Materials	431	529	588
4	Circuit Theory	277	340	356
5	Maths Techniques	337	480	534
6	Liquids/Solids Structures	273	299	306
7	Electron. Struct/Propert Surfaces	340	458	455
8	Optics; Lasers & Masers	133	182	202
9	Computer Theory; Software Eng	203	236	240
10	Tele/Data Communication	76	113	159
11	Measuring & Equipment	151	176	187
12	Optical/Optoelec Mat & Dev	88	128	161
13	Control Theory/Appl	109	128	133
14	Physical Chemistry	127	127	120
15	Micro/Electromagn Waves	101	124	127
16	Radio/TV/Audio; Computer Storage	114	122	108
17	Dielectric Propert/Mat/Dev	35	67	82
18	Supercond; Magn Propert/Struct	123	112	90

Figure 9-2 presents the cognitive structure of micro-electronics, as defined by the publications of the seven institutes covered by INSPEC. The relatedness of the sub-domains, based on the number of overlapping publications, is depicted by multidimensional scaling. The structure remains stable throughout the entire period of 1988 to 1994[20]. All sub-domains have approximately the same position every year. The most general or basic sub-domain (*General Micro-Electronics*) in the center of the map has sub-domain 11 (*Measuring & Equipment*) in its vicinity, with an agglomeration of sub-domains in the field of materials science (3: *Materials; 6: Liquids/Solids Structures*; 7: *Electronic Structures/Properties Surfaces*; 14: *Physical*

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[20] A film of the interaction of sub-domains during the period can be viewed at http://sahara.fsw.leidenuniv.nl/ed/projects.html.
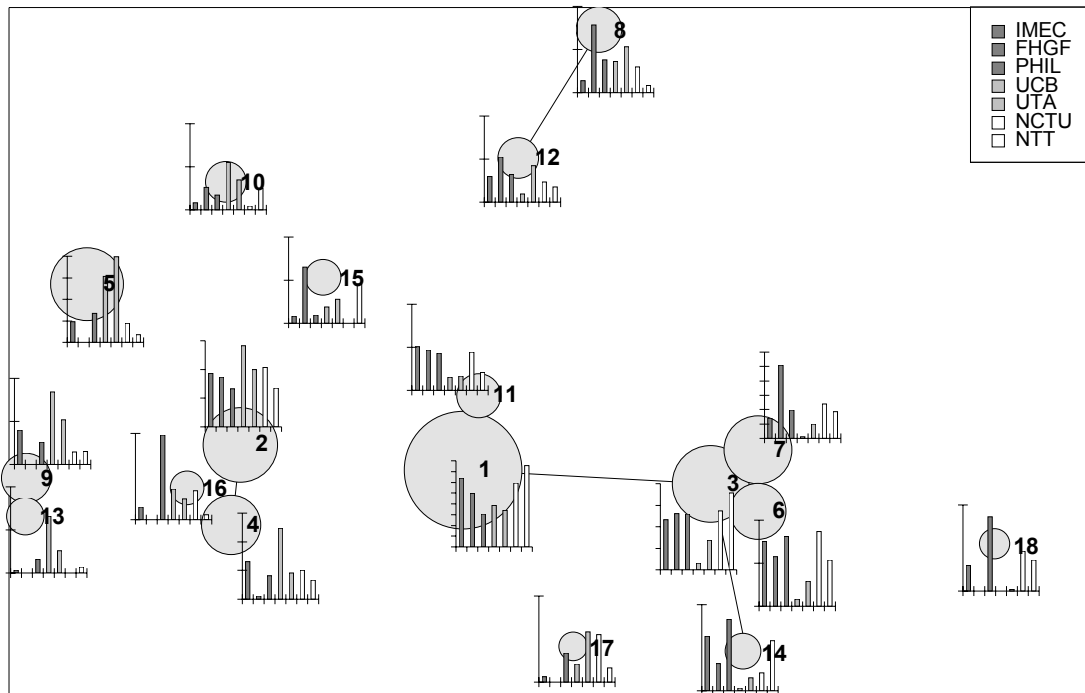
Chemistry; 17: *Dielectric Properties/Materials/Devices*; and 18: *Supercond; Magnetic Properties/Structures*) on the right-hand side. On the left-hand side, research topics on circuits (2: *Circuits & Design*; 4: *Circuit Theory*) can be found, and in their vicinity are sub-domain 16 (*Radio/TV/Audio; Computer Storage*) and related topics. In the upper part of the map, are sub-domains 8 (*Optics; Lasers & Masers*) and 12 (*Optical/Optoelectronic Materials & Devices*).
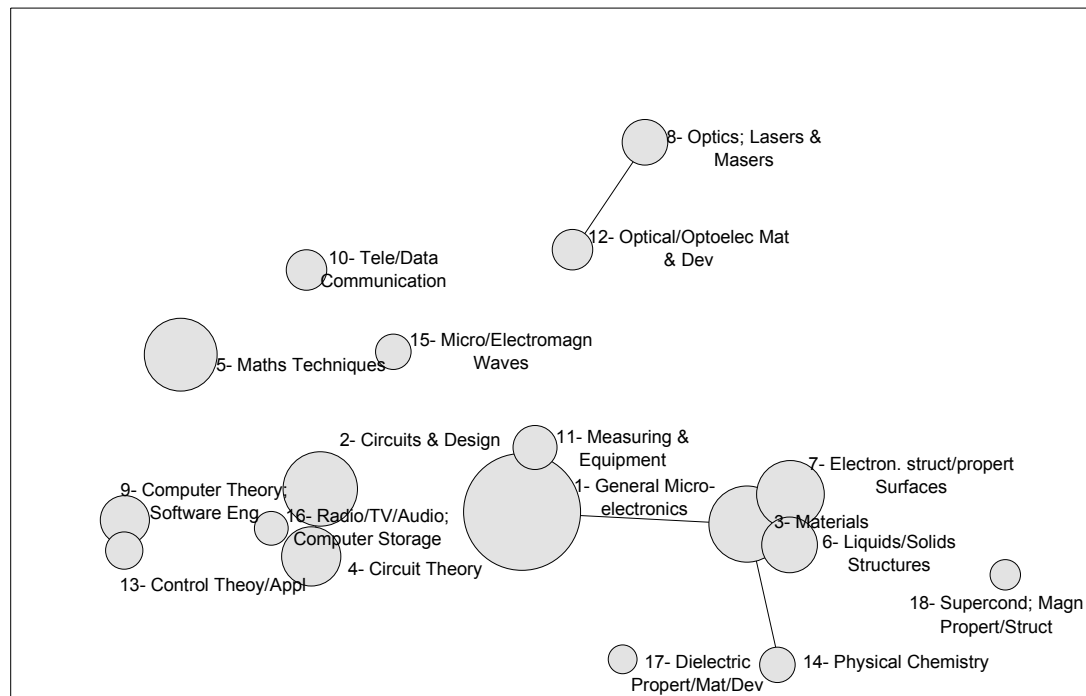
The circles in the map represent sub-domains in micro-electronics (1992/1994). The field is defined by the publications of the seven investigated institutes, covered by Inspec. The size of the circles represents the number of publications in a sub-domain. The distance between sub-domains is determined by the share of overlapping publications. Lines between indicate a relatively strong one on one relation.

Figure 9-2   general overview map of micro-electronics in 1992/1994 (Inspec)

In order to generate a general overview of the activities of the IMEC and of the benchmark institutes, we labeled the relative activity in 1992/1994 of the investigated institutes to the sub-domains in the map. The relative activity is defined the proportion of publications of an institute in a particular sub-domain relative to the whole number of publications by that institute. The results are plotted in Figure 9-3.

Subdomains: see legend Figure 9-1

Figure 9-3   Actors in micro-electronics map (1992/1994)

The figure shows that each sub-domain has its own specific profile. On the lower right-hand side of the map (3 ,6 ,7 ,14 and 18), the activity of the two institutes in the United States is less prominent than in other areas. Their activity is mainly focussed on the left-hand side of the map (2: *Circuits & Design*, 4: *Circuit Theory*, 5: *Maths Techniques*, 9: *Computer Theory; Software Engineering*, and 13: *Control Theory/Applications*). The IMEC's activity focuses on the central area of the map.

9.2.4.2 Fine-structure analysis

To obtain a more detailed overview of developments in the field and how IMEC's work fits in, we zoom in on the 18 sub-domains by creating co-word maps. These co-word maps are created for the year block 1992-1994 only, and are based on the co-occurrences of Controlled Terms (terms provided by the INSPEC database producer, and attached to the publications) within each sub-domain. The fine structure maps show related words close to each other, and words that are less related at a distance from each other. As an example, we present the fine-structure map of one of the 18 sub-domains. We added 'map-external' information to improve their applicability for evaluative purposes:

- a connecting line indicates a stronger than average link between two individual words, used to simplify, somewhat, the complex structure of the map;

- if a word is prominent for the sub-domain (more than 10 of the papers included), it is in bold print and capitals;

- if a word has an increasing interest within the same sub-domain during the period 1988-1994, it is preceded by a (+), if the interest is decreasing the word is preceded by a (-);

- words with *no* IMEC activity are underlined.

As an example we present the fine-structure map of sub-domain 11 (*Measuring & Equipment*). In this area, "Semiconductor Quantum Wells" is one of the topics for which there is a significantly growing interest. And although IMEC is very well represented in this area, it lacks activity on this particular topic. Furthermore, it is not very active on the subjects represented on the left-hand side of the map ("Automatic Testing" and related topics).

We emphasize that the maps describe the situation of IMEC's activity within this sub-domain. They do not prescribe what it should be. It may well be a strategy of IMEC not to publish about 'Automatic Testing' and 'Semiconductor Quantum Wells'.
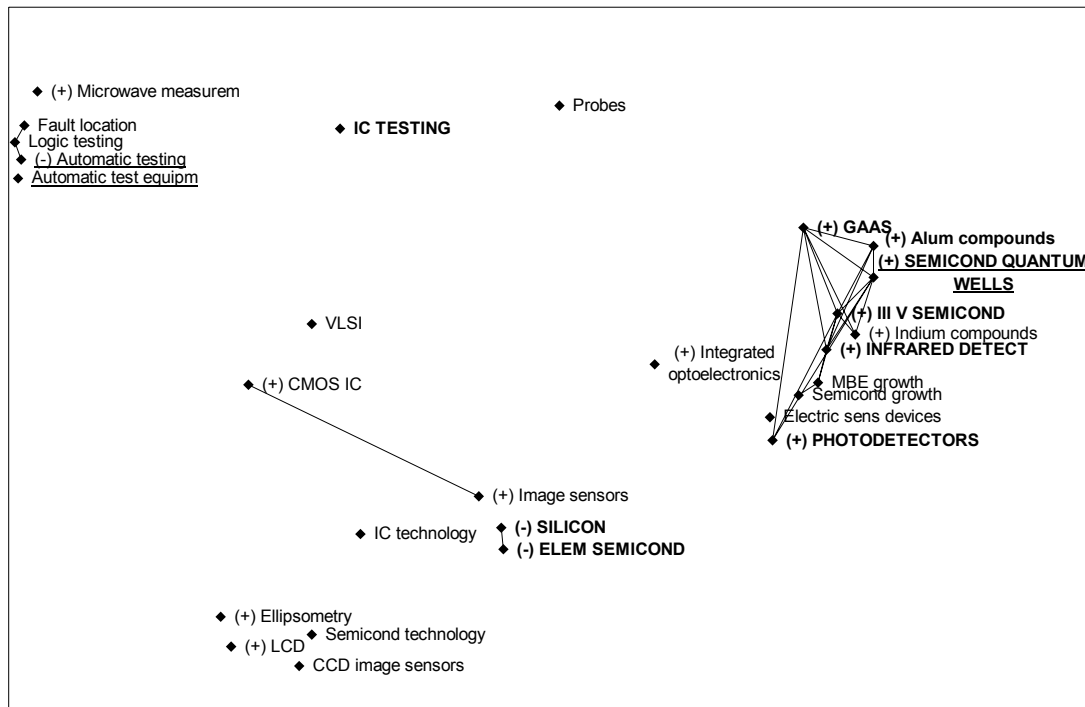
Co-word map of a sub-domain, as defined by the publications of the seven institutes with the classification codes used to delimit it. Lines between words indicate strong linkages between two individual words. Words with a coverage of more than 10% of the publications are printed in bold face and capitals. Words with an increasing interest are preceded by a (+), and words with a decreasing interest by a (-). Words with no IMEC activity are underlined.

Figure 9-4   Fine-structure map of sub-domain 11, Measuring & Equipment

9.2.4.3 Performance analysis of the IMEC as compared to benchmark institutes

In the citation analyses, we calculated a range of bibliometric indicators. The first set is comprised of:

- An indicator of the number of publications published in a particular year or range of years. This indicator is symbolized by means of the symbol P. It is calculated for each institute and for each year during the time period 1989 to 1994.

- Moreover, for each institute we determined the percentage of publications, relative to the total number of publications published by all selected institutes aggregated (symbol: $\%P$). We emphasize that the publication data analyzed in this section is extracted from the INSPEC database.

The next set of indicators relates to the impact of the publications.

- We calculated per institute the number of citations received by all publications during a time period starting with the publication year and ending with September 1995. Self-citations are not included (symbol: *Cex*).

- Moreover, for each institute we determined the percentage of citations received, relative to the total number of citations of all institutes (*%Cex*).

- The next indicator is the average number of citations per publication. Self-citations are not included (*CPPex*).

- We calculated the average number of citations for publications from all institutes. This statistic is indicated as *Overall Mean*. Using this statistic, we determined the ratio *CPPex/Overall Mean* for each institute. If this ratio exceeds 1.2 for a particular institute, the impact of the institute is qualified as high compared to the overall mean. If the ratio is below 0.8, the impact is considered to be low. The qualification "average impact" is given to institutes for which the ratio *CPPex/Overall Mean* is between 0.8 and 1.2.

The final set of citation-based indicators does not relate to the mean of the distribution of citations amongst publications, but to other parameters of that distribution.

- For each institute we calculated the number and percentage of publications not cited during the time period considered (symbols : Pnc and *%Pnc*, respectively).

- In addition, we identified the 10%most frequently cited publications in the collection of publications from all institutes in a particular year, by calculating the 90th percentile (*P90*) of the citation distribution. This parameter enabled us to determine the number and percentage of publications for each institute which were among the 10% most frequently cited publications from all institutes aggregated (*P|cit>P90* and *P|cit>P90*).

- Finally, for each institute we counted the number and percentage of publications which received more than 10 citations (*P|cit>10* and *P|cit>10*).

The basic question addressed in this section is: how does the scientific production and impact of IMEC compare to the output of the benchmark institutes listed in section 9.2.3? Scientific production is measured through the number of scientific publications published by researchers from an institute. Indications of the impact are derived from the number of times these publications are cited in international scientific literature.

The analyses presented in this section relate to data on scientific publications included in the INSPEC database. As outlined in section 9.2.1, from INSPEC we extracted all publications containing the names of IMEC or one of the benchmark institutes in the address field. Since INSPEC processes only the address of the *first* author of a publication, for each institute involved we selected only those publications of which the *first* author is located at that institute. Consequently, co-publications between the

IMEC and other institutes are included only if the first author is working at the IMEC. The same holds true for co publications of the benchmark institutes.
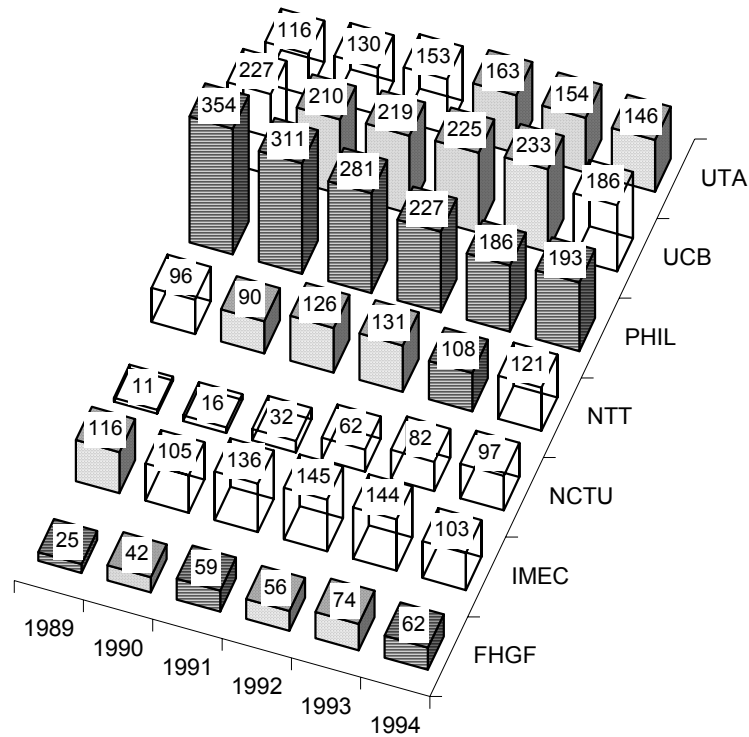
The publication data relate to the time period 1989 to 1994. However, it should be noted that the publication data of the year 1994 is incomplete. This is due to the fact that INSPEC processes publications with a certain delay. Publications published in 1994 but processed for the INSPEC database after April 1995 (i.e., the time the evaluation study was started) are not included. We estimated that we are missing about 10% of the publications with publication year 1994.

The results are presented in Table 9–3 and Figure 9-5. Table 9–3 shows the results for each institute with respect to publications published during the time period 1989-1993, as well as citations received until September 1995. As publications published in 1994 receive very few citations during the period before September 1995, these publications were not included in the results presented in Table 9–3. Figure 9-5 presents bibliometric scores per publication year. Since the figure shows the publications arranged by publication year, we decided to include the publications of 1994 as well.

Table 9–3   Bibliometric indicators for IMEC and benchmark institutes, based on INSPEC publication data

Indicator	FHGF	IMEC	NCTU	NTT	PHIL	UCB	UTA
P	256	646	203	551	1359	1114	716
% P	5.3	13.3	4.2	11.4	28.0	23.0	14.8
Cex	968	1345	135	1742	7403	3206	1518
% Cex	5.9	8.2	0.8	10.7	45.4	19.6	9.3
CPPex	3.8	2.1	0.7	3.2	5.4	2.9	2.1
CPPex/ Overall mean	1.1	0.6	0.2	0.9	1.6	0.9	0.6
Pnc	100	350	134	208	490	496	389
Pnc	39.1	54.2	66.0	37.7	36.1	44.5	54.3
P|cit>P90	29	36	0	56	231	101	47
% P|cit>P90	11.3	5.6	0.0	10.2	17.0	9.1	6.6
P|cit>10	26	32	0	49	206	89	39
% P|cit>10	10.2	5.0	0.0	8.9	15.2	8.0	5.4

P	:	The number of publications included in INSPEC and published during the time period 1989-1993
% P	:	The percentage of publications relative to the total number of publications published by all institutes
Cex	:	The number of citations received during a time period starting with the publication year and ending with September 1995. Self-citations are not included
% Cex	:	The percentage of citations received relative to the total number of citations of all institutes
CPPex	:	The average impact (number of citations) per publication. Self-citations are not included
CPPex/ Overall mean	:	The impact per publication relative to the average impact of the publications from all institutes
Pnc	:	The number of publications not cited during the time period considered
% Pnc	:	The percentage of publications not cited during the time period considered
P|cit>P90	:	The number of publications among the 10 percent most frequently cited publications from all institutes
% P|cit>P90	:	The percentage of publications among the 10 percent most frequently cited publications from all institutes
P|cit>10	:	The number of publications which receiving more than 10 citations
% P|cit>10	:	The percentage of publications more than 10 citations
FHGF	:	Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany
IMEC	:	The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium.
NCTU	:	The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan.
NTT	:	NTT-LSI Labs at Kanagawa, Japan.
PHIL	:	Philips Research Labs at Eindhoven, the Netherlands.
UCB	:	The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA.
UTA	:	The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Publications from INSPEC and citations from SCI (time period 1989 - Sept. 1995). Numbers in the squares indicate the numbers of publications in INSPEC. Shading of the bars indicates the impact compared to the overall mean for all institutes aggregated. FHGF: Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany; IMEC: The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium; NCTU: The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan; NTT: NTT-LSI Labs at Kanagawa, Japan; PHIL: Philips Research Labs at Eindhoven, the Netherlands; UCB: The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA; UTA: The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Figure 9-5   The Number of publications in INSPEC and their average impact per institute and per year
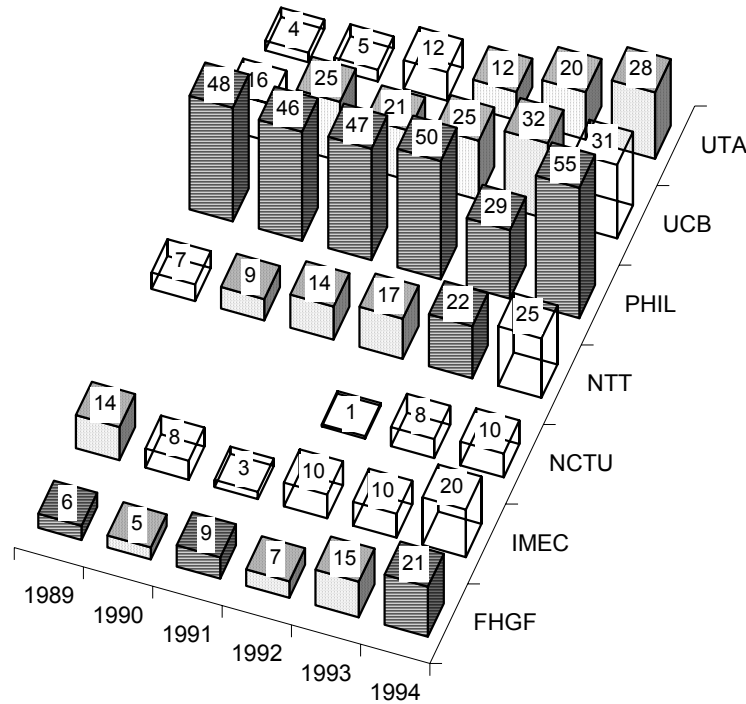
Publications from INSPEC and citations from SCI (time period 1989- Sept. 1995). Numbers in the squares indicate the numbers of publications in INSPEC among the 10 percent most frequently cited publications published in a particular year by all institutes aggregated. Shading of the bars indicates the impact compared to the overall mean for all institutes aggregated. FHGF: Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany; IMEC: The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium; NCTU: The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan; NTT: NTT-LSI Labs at Kanagawa, Japan; PHIL: Philips Research Labs at Eindhoven, the Netherlands; UCB: The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA; UTA: The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Figure 9-6   The number of frequently cited publications in INSPEC per institute and per year

Table 9–3 shows that during the time period 1989 to 1993, the IMEC published 646 publications included in INSPEC and registered under IMEC's address. IMEC's output constitutes 13.3% of the total number of publications published by the IMEC and all benchmark institutes. The share of IMEC publications per year remains rather stable and only varies between 11% and 14%. Considering the total period 1989-

1993, the *Philips Research Laboratories at Eindhoven* appears to be the most productive institute in terms of INSPEC publications, followed by the *Department of Electrical Engineering and Computer Science at the University of California at Berkeley*. The share of *Philips* in the total publication output amounts to 28%. However, in Figure 9-5, it is shown that the absolute number decreased from 354 in 1989 to 186 in 1993. The contribution of the *University of California at Berkeley* decreased slightly, while *NTT-LSI* and the *Fraunhofer Institut für Andewandte Festkorperphysik at Freiburg* showed an increasing trend.

Considering the impact of the INSPEC publications from the various institutes involved, Table 9–3 and Figure 9-5 show that *Philips'* publications have the highest impact on the average. In fact, according to Table 9–3, the ratio of the impact of *Philips'* publications and the average impact of the publications from all institutes aggregated (*CPPex/Overall Mean*) amounts to 1.6. Figure 9-5 shows that this ratio is above 1.2 for each publication year separately. The ratio for IMEC is 0.6, which is equal to the value obtained by the *Department of Electrical and Computer Engineering at University of Texas at Austin*, and slightly lower than the *Department of Electronic Engineering at the National Chiao Tung University in Taiwan*.

The other impact indicators given in Table 9–3 and displayed in Figure 9-5, show that the IMEC and the *University of Texas at Austin* have similar results. With respect to publications published in 1989, the IMEC has published 14 publications among the t10% most frequently cited publications with publication year 1989 by all institutes aggregated (*P|cit>P90*=14). These 14 publications constitute approximately 12% of the IMEC publication output that year. In terms of impact of papers published during 1989-1993, 1989 is the IMEC's most successful year. In fact, in this particular year, IMEC occupies third position in the ranking of institutes, both with respect to the absolute number as well as to the relative percentage of publications among the 10% most frequently cited INSPEC publications.

As indicated in Section 2.3, the benchmark institutes were partly active in research topics in which the IMEC has hardly published anything. We analyzed whether the impact position of the IMEC compared to the benchmarks changed if only publications are considered about topics in which the IMEC was active. From the collection of INSPEC publications from the benchmarks we selected only those documents whose indexing terms closely matched the profile of the IMEC publications, applying several levels of correspondence. The outcome of the impact analyses based on these selected sets of publications was very similar to the one presented above.

9.2.4.4 Performance analysis of IMEC compared to world average

The analyses presented above relate to publications included in the INSPEC database and compare the IMEC's production and impact to a number of benchmark institutes.

In this section we address the following question: what is the IMEC's impact compared to the world citation average in the sub-fields in which the IMEC is active? The methodology applied in this section is identical to the one developed in several studies on the research performance of universities in Flanders (e.g., De Bruin et al., 1993). It is based on all of the IMEC's articles published in journals processed for the CD-ROM version of the SCI. For further details with respect to the methodology, we refer to the publications cited above. It should be noted that all co-publications between the IMEC and other institutes - and published in SCI journals - are included in this analysis. The results are presented in Table 9–4. The table shows that the total number of articles published by the IMEC during the time period 1984 to 1993 in SCI journals amounts to 599. These articles are cited 1381 times from 1984 to 1993. The Institute for Scientific Information (ISI) has classified journals into sub-fields or journal categories. For the IMEC, the most important sub-fields are: *Applied physics* (198 articles); *electrical engineering* (117 articles); *condensed matter physics* (60 articles); *general physics* (39 articles) and *chemical physics* (27 articles).

Table 9–4   Impact of IMEC articles published in SCI journals

Indicator	*Score*
Nr. SCI publications in 1984-1993	599
Citations during 1984-1993 to SCI publ., self-citations not included	1381
Citations per SCI article, self-citations included	3.5
Citations per SCI article, self-citations not included	2.3
World citation average	2.6
Average impact journal packet	2.9
Impact compared to world citation average	1.3
Impact compared to average impact journal packet	1.2
Impact journal packet compared to world citation average	1.1

Taking into account the distribution of the IMEC's articles among sub-fields, we calculated the average impact of papers in all sub-fields in which the IMEC is active. Comparing the IMEC's impact to this world citation average, we obtained a ratio of 1.3. This means that the IMEC's articles have an impact which is a factor of 1.3 higher than the average impact of all articles in the sub-fields in which the IMEC is active. If we compare the impact of the IMEC articles to the average impact of all papers in the journals in which the IMEC has published, we found a ratio of 1.2. Finally, the impact of the journals in which the IMEC has published is 1.1 times higher than the world citation average in the sub-fields covered by these journals.

9.2.4.5 Research performance of IMEC's divisions

In this section, we present the results of the analyses based upon IMEC's total publication output. We give results regarding the production, productivity and impact

of IMEC during the time period 1985 to 1994. In addition, we present the outcomes per division. The production and impact indicators applied in this section are similar to those presented in section 9.2.4.3. For a more detailed methodological discussion on these indicators, we refer to that section.

The main results per IMEC division are summarized in Table 9–5 and Figure 9-7. Table 9–5 gives the results for each IMEC division regarding publications published during the time period 1989 to 1993, and citations received until September 1995. Figure 9-7 presents the bibliometric scores per publication year.

Table 9–5   Bibliometric indicators for IMEC by division

Indicator	ASP	INTEC	MAP	VSDM	Rest
P	578	59	547	187	25
% P	41.4	4.2	39.2	13.4	1.8
Cex	1033	120	1128	124	49
% Cex	42.1	4.9	46.0	5.1	2.0
CPPex	1.8	2.0	2.1	0.7	2.0
CPPex/	1.0	1.2	1.2	0.4	1.1
Overall mean					
Pnc	312	25	309	42	14
Pnc	54.0	42.4	56.5	75.9	56.0
P|cit>P90	6	9	6	7	3
% P|cit>P90	11.2	15.3	12.1	3.7	12.0
P|cit>10	26	2	26	2	1
% P|cit>10	4.5	3.4	4.8	1.1	4.0

P: The number of publications published during the time period 1989-1993 (all types of publications included); %P: The percentage of publications relative to the total number of publications published by all IMEC divisions; Cex: The number of citations received during a time period starting with the publication year and ending with September 1995. Self-citations are not included; %Cex: The percentage of citations received relative to the total number of citations to all IMEC divisions aggregated; CPPex: The average impact (number of citations) per publication. Self-citations are not included; CPPex/Overall mean: The impact per publication relative to the average impact of the publications from all IMEC divisions aggregated; Pnc: The number of publications not cited during the time period considered; %Pnc: The percentage of publications not cited during the time period considered; P|cit>P90: The number of publications among the 10 percent most frequently cited publications from all IMEC divisions aggregated; %P|cit>P90: The percentage of publications among the 10 percent most frequently cited publications from all IMEC divisions aggregated; P|cit>10: The number of publications which received more than 10 citations; %P|cit>10: The percentage of publications which received more than 10 citations.
ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems; Rest: All other divisions
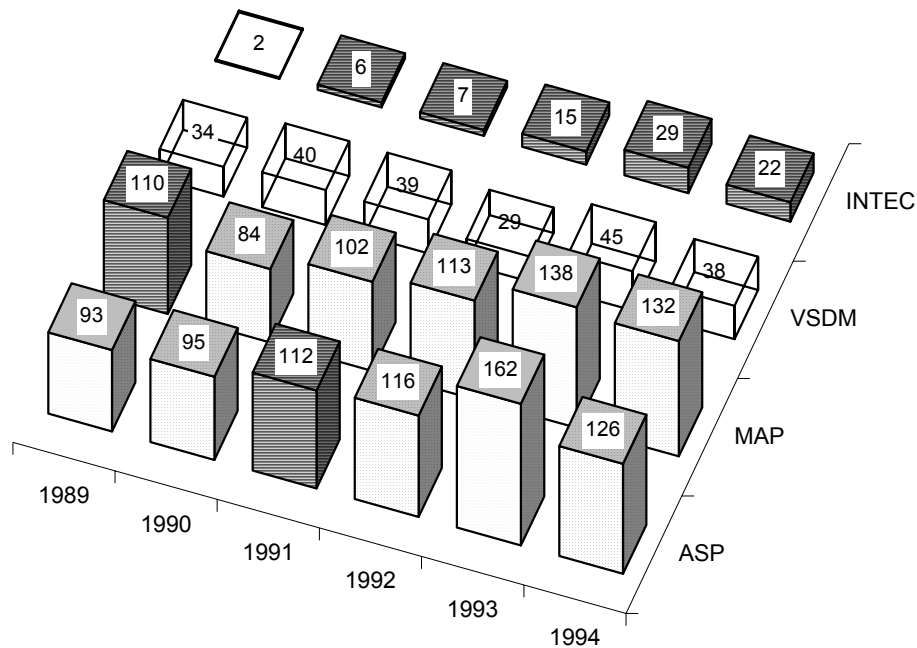
All types of publications included. Citations from SCI (time period 1989- Sept. 1995). Numbers in the squares indicate the number of publications. Shading of the bars indicates the impact compared to the overall mean for all IMEC divisions.

ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems.

Figure 9-7   The number of publications and their average impact per IMEC division and per year

The divisions ASP and MAP have published 547 and 578 publications, respectively. These two divisions account for approximately 81% of all the IMEC publications. The share of publications from VSDM researchers amounts to 13%. About 25 researchers are on the IMEC's payroll but actually work in the INTEC Laboratory at the University of Ghent. They have published 59 documents, which constitute 4% of the IMEC's total publication output.

Considering the impact indicators, Table 9–5 and Figure 9-7 show that ASP and MAP publications have generated rather similar impacts on the average. The impact of the

VSDM documents is lower than that of these two divisions. According to Table 9–5, the impact of scientists on the IMEC payroll and working at INTEC is higher than that of the other IMEC divisions.

9.3   Comments of experts and additional analysis

9.3.1 Introduction

In this section, we discuss the comments of researchers in the field given at the end of the evaluative bibliometric study. We collected these comments in discussions with the staff of the IMEC, and researchers in the field from the IMEC and other institutes in Europe and the United States. The comments were collected to evaluate the potentials of evaluative bibliometric studies and to improve their quality. Moreover, we present results of additional analyses, aiming at validating the results of the conducted studies.

9.3.2 Comments of experts

In general, two main issues were raised. Firstly, the experts found the maps a useful tool but had difficulties with locating their own research (relocatability). It was suggested that this might be due to the limitations of the classification scheme of INSPEC, on which the coarse structure of the field was based. They found it difficult to link their own work to classification codes. They questioned the usefulness of the classification scheme to structure the field.

Secondly, the experts emphasized the role of the researchers' publication strategy. On the one hand, the IMEC and other strongly industry-related institutes tend more and more to present their research results at conferences and in proceeding papers. On the other hand, institutes with a formal academic link still attribute great value to publishing their results in scientific journals. A study based on publications from both kinds of institutes seems to disclose results from two different 'worlds'. In the first place, because the publication delay of scientific (refereed) journals is much longer than the delay of proceeding papers. The time periods in our studies are based on the publication date of the articles, so that the research results represented in period t originate from different periods before t. In the second place, the performance analyses are based on citations to publications. It is a well-known fact that the impact of journal articles is on average much higher than the impact of proceeding papers. By comparing the performance of institutes with different publication strategies, we seem not to be comparing like with like.

9.3.3 Relocatability

We implemented several adjustments to the 'older' maps aiming at improvement of the relocatability of topics and publications. One of the adjustments concerns the digitalization of the maps. The maps have been made clickable' so that a user (e.g., researcher) can easily zoom into sub-domains and to the publications represented by topics in the sub-domain maps (cf. Figure 9-4). Moreover, we developed a graphical interface to "click" from authors' addresses to sub-domains and thereon to topics[21]. It should be noted that such "tools" are not easily applicable to a map on paper.

Moreover, we compared the map structure of micro-electronics to the internal structure of the IMEC in order to investigate the relocation potentials of the map. In Figure9-8, an overview is given of the proportional presence of each of the four publishing IMEC divisions in the map, based on co-classification (cf. Figure 9-2). The map shows that the research of the four divisions can be relocated in different areas. VSDM can be found mainly on the left-hand side (2: *Circuits & Design*, 4: *Circuit Theory*, 5: *Maths Techniques*, and 9: *Computer Theory*; *Software Engineering*). The specialties of INTEC's activity within IMEC is at the top of the map (8: *Optics; Lasers & Masers*, and 12: *Optical/Optoelectronic Materials & Devices*). And the research of ASP and MAP, and some of the work of INTEC is found just outside the center of the map on the right-hand side (3: *Control Theory/Applications*, 6: *Liquids/Solids Structures*, 7: *Electronic Structures/Properties Surfaces*, and 14: *Physical Chemistry*). Not surprisingly, the activity of all divisions is high in the center of the map (1: *General Micro-Electronics*). Besides their usefulness for relocatability, these results show that the structure of the field represented by co-occurrences of classification codes corresponds rather well to the internal structure of the IMEC. Hence, it seems that the structure is appropriate to structure the research output of the IMEC, although the description of the classification codes is not sufficiently specific for researchers to recognize their own work.

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[21] Examples of such digital maps are demonstrated at the WWW-page of CWTS (http://sahara.fsw.leidenuniv.nl).
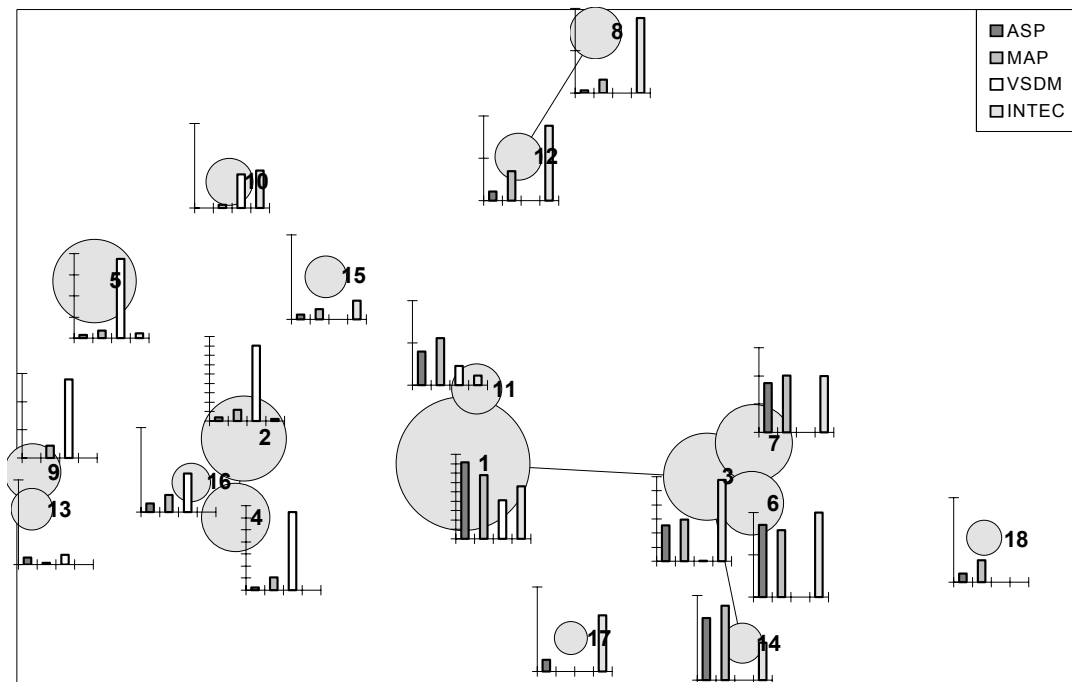
Circles in the map represent sub-domains in micro-electronics. Their size represents the proportional number of publications included. The column charts per sub-domain represent the publication profile of the three main divisions of IMEC. The value is determined by the ratio of publications of a division in a sub-domain and the overall production of that division.

Subdomains:

|			
1	General Micro-Electronics	10	Tele/Data Communication
2	Circuits & Design	11	Measuring & Equipment
3	Materials	12	Optical/Optoelec Mat & Dev
4	Circuit Theory	13	Control Theory/Appl
5	Maths Techniques	14	Physical Chemistry
6	Liquids/Solids Structures	15	Micro/Electromagn Waves
7	Electron. Struct/Propert Surfaces	16	Radio/TV/Audio; Computer Storage
8	Optics; Lasers & Masers	17	Dielectric Propert/Mat/Dev
9	Computer Theory; Software Eng	18	Supercond; Magn Propert/Struct

ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems.

Figure 9-8   Position of IMEC divisions in map (1992/1994)

9.3.4 Publication strategy

In the discussion with the experts in micro-electronics, the issue was raised of the strategy of institutes and of the IMEC's divisions to publish their papers, and the

effect on impact of their work. Industrial-related institutes tend to present their work at conferences, whereas institutes with a more academic-related character, attribute great value to publishing their work in learned journals. As conference proceedings on average receive fewer citations than journal articles, this will have its effect on the impact figures of each individual institute, and even of each individual division.
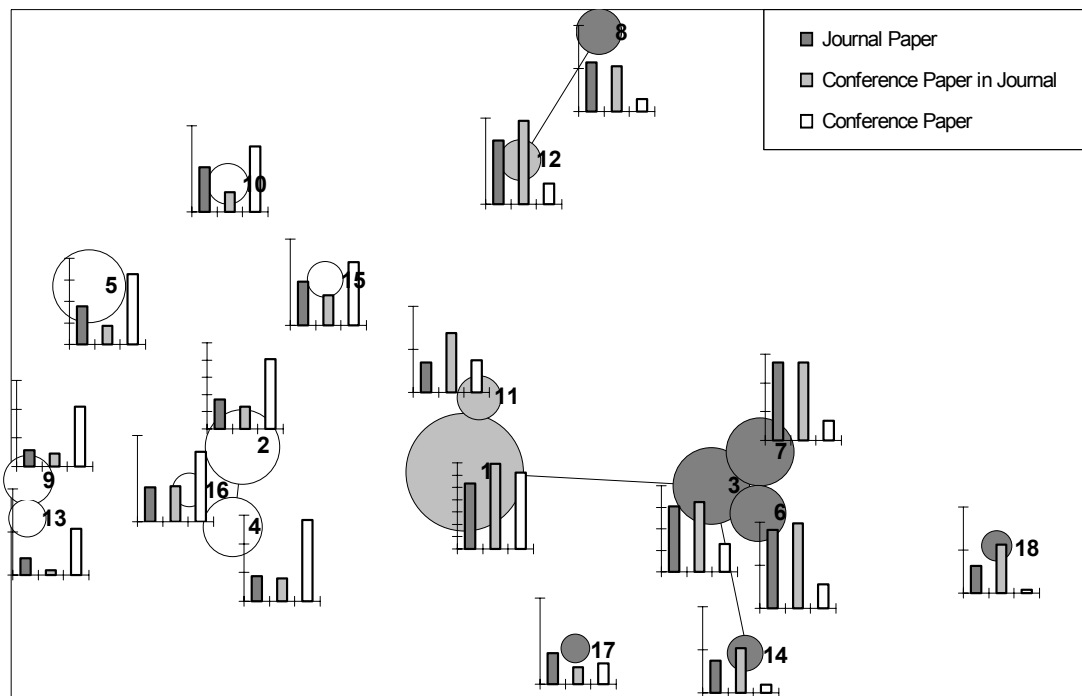
Subdomains: see Figure 9-8. Circles in the map represent sub-domains in micro-electronics. Their size represents the proportional number of publications included. The column charts per sub-domain represent the relative number of publications per document type. The value is determined by the ratio of publications per document type in a sub-domain and the overall number of publications of that type in the field. The shading of the circles indicates the average impact in a sub-domain (white if CPP < 2.1, dark Grey if CPP > 3.2).

Figure 9-9   Proportional distribution of document types in micro-electronics map, and average impact per sub-domain

The situation in micro-electronics is illustrated by Figure 9-9. The structure of the map reveals both to the distribution of document types and to the impact of micro-electronics publications. On the left-hand side, eight sub-domains are located with a relatively high number of proceedings papers with an impact below average, whereas on the right-hand side of the map we find the sub-domains with a relatively high number of journal papers with an impact above average. Again, we found an objective support for the obtained co-classification structure. The structure corresponds to the distribution of document types in the map and therefore, according to the experts'

comments concerning publication strategy, it is strongly related to the character of the research: industry-related on the left, academic-related on the right hand side of the map. As a result, the structure appears meaningful, particularly in combination with the results of Figure 9-8. Moreover, the results support the observation of the experts that the impact figures should be treated with great care because of the differences among document type of the cited item and among the areas in which the paper is published. The structures represented by the maps reveal large differences between sub-domains with regard to average impact and usage of document types.

The fine-tuning of impact data using the field structure on the one hand and the break-down of documents over IMEC's divisions, enable us to assess more accurately the impact per division. Within each sub-domain, the overall results will then become more valuable.

In Figure 9-10, we plotted the impact per division relative to the average impact in a sub-domain. The figure shows that in general the impact IMEC is somewhat below the average of all investigated institutes. This consists with the findings in Figure 9-5. In some cases, however, the impact of IMEC divisions is above the average. In sub-domains 2 (*Circuits & Design*), 8 (*Optics; Lasers & Masers*) and 12 (*Optical/Optoelectronic Materials & Devices*), the impact of INTEC is above average and in sub-domain 3 (*Materials*) the impact of VSDM is above average. This observation is remarkable, taking the interest of VSDM in consideration. In Figure 9-8, we saw that VSDM mainly focuses on the area on the left hand side of the map. In this particular area, the impact of VSDM is in most cases higher than the impact of the other IMEC divisions, although still below the average. The impact of ASP and MAP is always just below the average. In their area of interest (right-hand side of the map), the overall average impact is relatively high (dark Grey circles).
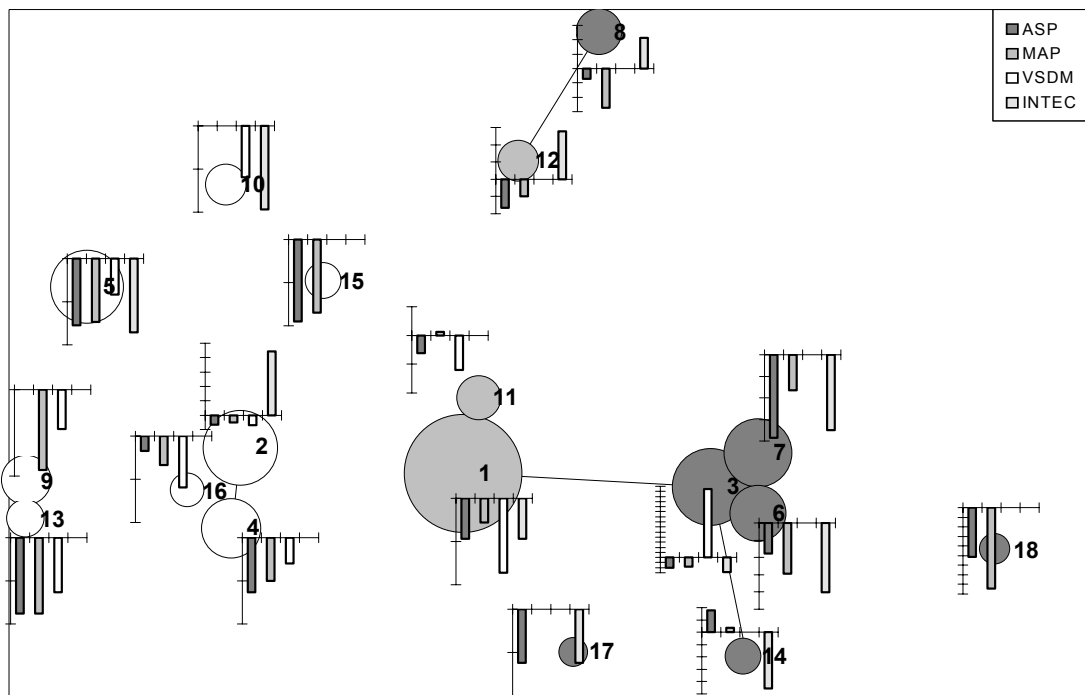
Legend, subdomains and divisions: see Figure 9-8.

Figure 9-10   Impact of papers per IMEC divisions related to sub-domain average

9.4   Concluding remarks

At the end of most bibliometric studies for evaluative purposes, experts in the evaluated field and/or users of the results have the opportunity to give their comments and recommendations. Through these comments, experts make important contributions to the development of bibliometric tools. In this study, we used the comments and recommendations to improve the quality of some of the existing indicators by combining two bibliometric applications. We found that the mapping procedure can enhance the impact analyses in order to investigate the performance in a research field in more detail. On the other hand, the impact figures contribute to validation of the structures obtained by bibliometric mapping. The structure in the field of micro-electronics generated by co-classification mapping of publications, corresponds to a large extent to a (hidden) structure based on citations received by these publications. The combined procedure provides a monitoring tool for research performance on a detailed level, taking into account recent developments in the field.

Thus, a bibliometric picture can be obtained of an actor (e.g., country, university, department) compared to its peers and from a dynamic perspective at once.

Several comments gathered from experts and users of the study still have to be investigated. The most important one is the claim that the research topics covered by proceeding papers differ from those covered by journal articles. Although we found that the distribution of document types highly correlates with the structure based on classification codes, this is still an issue to be studied in more detail. At the least, the publication delay of the latter type of documents seems problematic. By comparing the dynamics of a subset of proceeding papers on the one hand and journal articles on the other, we intend to study this matter in the near future. An additional requirement will be that the structure is obtained by analyzing words in abstracts, rather than using classification codes and controlled terms (of INSPEC). The structure of a field will then stay even closer to the most recent (and "actual") developments.

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