Study on Integrated Circuit Field Based on Hot Topics

Ping Qin[1,2,*][a], Tingting Duan[3][b], Xiao Zhu[3][c], Chen Chen[2][d] and Xiaotao Li[1,2][e]

[1]*Evaluation Center of Industry and Informatization Think Tank of Nanjing University of Aeronautics and Astronautics, China*

[2]*Library of Nanjing University of Aeronautics and Astronautics, China*

[3]*College of Humanities, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China*

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Abstract: With the accelerated evolution of a new round of scientific and technological revolution and industrial transformation, integrated circuit disciplines have emerged. How to grasp global research hot topics is an urgent concern of governments, universities and enterprises. This paper adopts the combination of topic analysis and policy text analysis. Firstly, it analyzes the research topics of integrated circuit industry chain and components. According to the topic prominence and development trend, 30 hot topics in the rising trend are selected, and the national and regional distribution of their research is discussed. Through the tools Nvivo, the integrated circuit related policies and world-renowned think tank reports were further analyzed. The research results show that there are still shortcomings in the research of semiconductor materials, CMOS, block cipher, operational amplifier and other fields in China, and there is a big gap in EDA design software. In the future, China can develop the integrated circuit industry through policy making, encouraging innovative research, interdisciplinary talent training and international cooperation.

1 INTRODUCTION

Integrated circuit (IC) is one of the most important scientific and technological inventions of mankind in the 20th century. Its invention marks the entry of mankind into the information age. IC are the foundation of modern industry and national security. They are also an important part of emerging technologies such as artificial intelligence, 5G communication and quantum computing. IC and new generation of information technology will change the traditional manufacturing mode, additive manufacturing, intelligent manufacturing, intelligent networking will become a trend, intelligent manufacturing equipment, aviation equipment, satellite and application, rail transit equipment, marine engineering equipment and new materials and other industries will be a major change (Zou 2020).

In July 2022, the U.S. Congress passed the CHIPS and Science Act of 2022, to strengthen semiconductor manufacturing, design and research in the USA, as well as the the chip supply chain in the USA (SIA 2022). DARPA has invested in breakthrough key technology areas such as semiconductor materials, IC design softwares, microwave devices, microsystem technology, chip manufacturing, equipment. At present, many mainstream technologies come from DARPA projects (Trusted 2022). In June 2021, the Ministry of Economy, Trade and Industry of Japan announced the《Semiconductor Strategy》, believing that Japan should increase investment in advanced process manufacturing, research and development, and advanced packaging (Japanese 2021). The development of Korea semiconductor industry is based on memory as the starting point to layout the semiconductor industry. The Korean government

[a] https://orcid.org/0000-0003-3729-6012
[b] https://orcid.org/0000-0003-1598-8587
[c] https://orcid.org/0000-0002-6859-8614
[d] https://orcid.org/0000-0002-8429-3546
[e] https://orcid.org/0000-0002-6125-4536
[*] Corresponding author

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plans to build the world 's largest "K-semiconductor belt" in 2030, which will include semiconductor production, raw materials, parts, equipment and design (Interface 2021). Europe in promoting the development of IC more through the establishment of "sensors"', "power devices" and other areas of European semiconductor dvantage of large-scale chip research and development projects to continue to improve the competitiveness of European industrial technology (Zhou 2021). In 2006, the Chinese government issued and implemented the Outline of the National Medium and Long term Scientific and Technological Development Plan (2006-2020), which identified 16 major projects, including Core Electronic Devices, High-end General-purpose Chips and Basic Software Products and Very Large Scale IC Manufacturing Technology and Complete Processes (Outline 2022).

According to the Yidu report (Yidu 2022), the USA has a significant advantage in multiple subdivisions of IC support and IC manufacturing industry, especially in EDA/IP, logic chip design, manufacturing equipment and other fields, accounting for more than 40%. In Europe, the dominant fields are IP and photoresist. Japan's dominant areas are silicon wafers, photoresists and photomasks. Korea's dominant areas are memory. Taiwan 's dominant areas are wafer manufacturing and packaging manufacturing. The advantageous area in Chinese Mainland is packaging testing.

This paper analyzes, with three-dimension vision, academic achievements, national policy and reports of famous think tanks, using bibliometrics and text analysis methods. The development trend of IC and a number of hot topics and frontiers worthy of attention from a new perspective are presented. The results povide a decision-making support for domestic universities, research institutes and enterprises to Know the hot topics and development direction in the field of IC.

2 ANALYSIS OF HOT TOPICS IN IC FIELD

According to the IC related industry chain and originals, the main research countries and regions of 30 hot topics are analyzed in detail.

2.1 Concept of IC and Topics

IC is a kind of micro electronic devices or components, using a certain process, the required components in a circuit and wiring interconnection together, made in a small or a few small semiconductor wafers or dielectric substrate, and then packaged in a shell, become a micro structure with the required circuit function. In the IC industry chain, the upstream includes IC design automation tool EDA, core function module semiconductor IP, core production equipment and materials. The middle reaches are composed of chip design, manufacturing and sealing. The downstream is mainly applied fields, such as 5G, artificial intelligence, Internet of Things and so on (Yin 2021).

Select relevant keywords according to the IC related industry chain and the original, including: integrated circuit; IC; EDA; chip; semiconductor; CMOS; capacitor; inductor; resistor; transistor; diode; wafer; encapsulation; inverter; Router; microwave photonic; ciphers.

The Scival platform clusters about 50 million peer-reviewed journal articles and conference papers collected in the Scopus database from 1996 to the present to form a specific collection of documents, and uses direct citation analysis to gather these documents into nearly 96,000 specific research topics.

Prominence is an indicator to measure the visibility or development momentum of research topics, reflecting the global attention of the overall scientific research of small peers. The level of indicators reflects the significance, development momentum or activity of research topics. It is a momentum indicator, not a quality indicator. The saliency is composed of three parameters: total citations, total browsing times and CiteScore. The calculation formula is as follows:

$$\begin{aligned} \mathrm{P}_j = {} & 0.495[C_j - \mathrm{mean}(C_j)] / \mathrm{stdev}(C_j) \\ & + 0.391[V_j - \mathrm{mean}(V_j)] / \mathrm{stdev}(V_j) \\ & + 0.1149[S_j - \mathrm{mean}(S_j)] / \mathrm{stdev}(S_j) \end{aligned}$$

Among them, C_j is the total citation frequency of the literature published in the current year and the previous year in topic *j*; V_j was the frequency of the articles published in the current year and the previous year in Scopus viewed in the theme *j*; S_j is the impact factor of journals published in the current year and the previous year in topic *j*. The larger the value, the greater the display, which can be understood as the higher the research attention, up to 100%.

2.2 Analysis the High Frequency Keywords

More than 300,000 articles in Scival were retrieved by keywords of IC. According to the relevance and display of topics, 100 global hot topics from 2017 to 2022 were selected.

Extracting feature keywords from hot topic can show the research content of each hot topic in a more detailed and specific way. A total of 881 keywords were extracted from 100 hot topics, and 67 high-frequency keywords with word frequency > 3. These 67 high frequency words appear in more than 3 hot topics, which can better reflect the specific research hot topics in the field of IC.

The co-occurrence relationship of high-frequency words in the same research topic is counted, and the co-occurrence matrix of high-frequency words is calculated and imported into Netdraw to obtain the co-occurrence network of high-frequency keywords (Fig. 1). In Figure 1, each node represents one high-frequency keyword, and the node size is proportional to the keyword frequency. The larger the node, the higher the keyword frequency. The connection between nodes represents the co-occurrence relationship between two keywords. The higher the co-occurrence frequency, the thicker the connection, indicating that the knowledge association between the two words is closer.

High-frequency words such as CMOS, Converter, Inverters, Transistors, Nanowire, Millimeter Wave, Photonics, Gate, MOSFET, Microgrid, and III-V Semiconductors appear in a number of hot topics, and are at the core of the co-word network and are the focus of the IC hot topics.

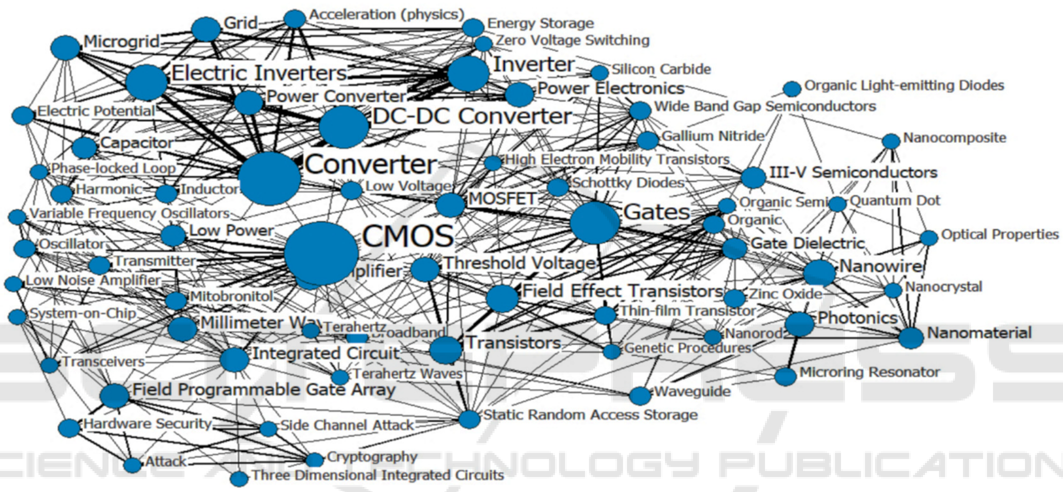

Figure 1: High Frequency Keywords Analysis of articles from top 100 topics of IC

2.3 30 Hot Topics in IC and Distribution

Among the 100 hot topics, 30 topics with a rising trends in recent five years were sele-cted, shown in Table 1. Include: Grid|Power Sharing|Inverters; Gallium Oxides|Schottk-y Di-odes|Energy Gap; Microgrid|DC-DC Converter|Electric Potential; Inverter|Space Vector Modul-ation|Electric Potential; Microresonators|Solitons|Comb and Wattles; etc.

Further analyzed the distribution of the countries/regions with 30 hot topics on the rise. According to the citation frequency under this topic, the first five countries/regions are determined. The first tier includes the USA and China, and the second includes India, Germany, UK, Japan, Denmark and Iran.

The USA leads in semiconductor materials, including CMOS, aluminum gallium nitride, III-V semiconductor, gallium oxide, hardware security, block ciphers, analog-to-digital converters, millimeter waves, and regulation. China leads in the Grid, insulated gate bipolar transistor, inverter, fuel cell, DC-DC converter, laser radar and monolithic microwave integrated circuit. In addition, Japan in the CMOS image sensor; Iran in single photon detector; turkey in the Schottky diodes; India in operational amplifiers, inverters.

Table 1: Country/region layout of IC hot topics (2017-2022).

No	Topic ID	Prominence	Topic	Top five countries / regions
1	304	99.854	Grid; Power Sharing; Inverters	China、USA、Denmark、Iran、Australia

No	Topic ID	Prominence	Topic	Top five countries / regions
2	8130	99.526	Gallium Oxides; Schottky Diodes; Energy Gap	USA、China、Japan、Korea、Germany
3	2967	99.502	Microgrid; DC-DC Converter; Electric Potential	China、USA、Denmark、India、Iran
4	103	99.414	Inverter; Space Vector Modulation; Electric Potential	India、Iran、China、Canada、Malasia
5	9544	99.094	Microresonators; Solitons; Comb and Wattles	USA、China、Switzerland、Russian、Germany
6	2844	98.593	Proton Exchange Membrane Fuel Cell (PEMFC); Fuel Cell; DC-DC Converter	China、Iran、Egypt、USA、India
7	36743	98.335	Synchronous Generators; Inertia; Inverter	China、USA、Denmark、Japan、Canada
8	4420	98.064	Insulated Gate Bipolar Transistor (IGBT); Power Electronics; Power Converters	China、Denmark、USA、Germany、UK
9	2445	97.988	Aluminum Gallium Nitride; Vapor Phase Epitaxy; III-V Semiconductors	USA、Japan、China、Germany、Korea
10	5888	97.758	Phase-Locked Loop; Inverters; Grid	China、Denmark、India、USA、UK
11	11828	97.577	Hardware Security; Internet of Things; RRAM	USA、China、Singapore、Germany、India
12	11540	97.533	Gallium Nitrides; High Electron Mobility Transistors; MOSFET	USA、China、Canada、Germany、UK
13	2329	97.473	Schottky Diodes; Thermionic Emission; Electrical Properties	Turkey、India、Saudi Arabia、Iran、Egypt
14	8455	97.206	Switch; Inverter; Fault Diagnosis	China、USA、Singapore、India、Iran
15	17323	96.898	Hardware Security; Malware; Obfuscation	USA、China、Arab Emirates、India、Germany
16	2792	96.517	Masking; Differential Power Analysis; Block Ciphers	USA、France、Belgium、Germany、China
17	53151	96.106	III-V Semiconductors; Light Emitting Diodes; High Brightness	USA、China、Taiwan、Korea、France
18	8513	96.075	Electric Potential; Converter; Resonant	China、USA、Korea、Canada、Denmark
19	14389	95.127	Single Photon Detector; Timing Jitter; Avalanche Photodiode	Iran、China、India、USA、Denmark
20	4989	94.938	Power Amplifiers; Millimeter Wave; Noise Figure	USA、China、Korea、Belgium、Germany
21	17541	94.653	DC-DC Converter; Microgrid; Acceleration (Physics)	India、Iran、China、USA、Australia
22	13515	93.979	Phase Shifters; Phased Arrays; Millimeter Wave	USA、Korea、China、Sweden、Israel
23	3703	91.812	Operational Amplifiers; Transconductance; Low Power	India、USA、Iran、Italy、Poland
24	1477	91.002	CMOS Image Sensor; Shutters; Integrated Circuit	Japan、USA、China、Korea、UK
25	25970	90.896	Antenna Arrays; Waveguides; Glide	Sweden、Spain、Canada、China、France
26	858	90.654	Voltage Controlled Oscillators; Analog-To-Digital Converter; Delta Sigma Modulation	USA、India、China、Spain、Korea
27	913	89.996	CMOS; Phase Noise; Frequency Offset	USA、Germany、Japan、Belgium、France
28	18039	89.619	Voltage Regulators; Drop Out; Regulator	USA、China、Korea、Mexico、HK
29	22101	89.288	Lidar; Photon Counting; Avalanche Photodiodes	China、UK、USA、France、Sweden
30	17428	88.594	Doherty Amplifiers; Broadband; Monolithic Microwave Integrated Circuits	China、UK、USA、Canada、Italy

3 ANALYSIS ON DEVELOPMENT OF IC FIELD

This section analyzes from three dimensions through policies and the reports of well-known think tanks and the qualitative research tool Nvivo, as shown in Figure 2. First, the interdisciplinary and talent training of IC disciplines; Second, the gap between China and the advanced level of IC short board and the reasons; Third, international cooperation is needed. A collection of think tank reports from thinktank. In addition, 22 IC-related policies were collected and six related web pages were obtained through the NCapture plug-in.

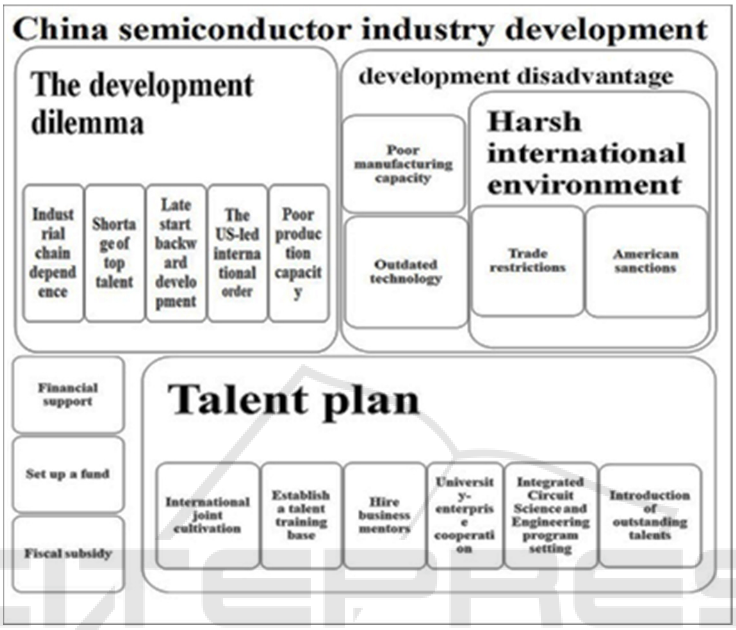

Figure 2: China semiconductor industry development.

3.1 Discipline Interdisciplinary of IC

In terms of interdisciplinary, a total of 16 documents were selected and 58 codes were completed. Among them, the interdisciplinary coding points of IC are mainly distributed in foreign think tank reports, and a total of 16 disciplines were mentioned. It can be seen that material science, applied mathematics, chemistry, biology, physics, computer science and electrical engineering are the main interdisciplinary disciplines of IC.

The think tank report and policy document mention the support measures of China and the USA for IC interdisciplinary. Therefore, the measures of China and the USA were coded. A total of 14 documents were coded and 31 coding points were generated. It can be seen that STEM in the USA is a plan to encourage students to major in science, technology, engineering and mathematics, which has played a huge role in the training of basic discipline talents in the country. In addition, the USA intends to develop a long-term plan to attract young students into the field of science and engineering, and the National Science Foundation, Defense, the National Institute of Standards and Technology, the Ministry of Energy and other institutions will provide the interdisciplinary cooperation between universities, research institutions ， industry and company cooperation will double the funding, especially in semiconductor related disciplines and research projects. The major difference between China and the United States is that China's IC disciplines and project research funding institutions are relatively single, mainly dominated by the government; In terms of interdisciplinary training, there is less interdisciplinary research on undergraduate and graduate programs in China, and more emphasis is placed on horizontal inter university, school enterprise and Sino foreign joint training.

3.2 Analysis IC Short Board of China

In terms of semiconductor materials, 37 of the 12 documents were coded. After subdividing, it was found that research mainly focused on the supply maintenance of semiconductor basic materials, the development of new materials, and the support for material research. At present, the USA, Japan and Germany are in the leading position in semiconductor materials. Although China has achieved the transformation in materials, there are still problems such as weak overall production capacity and insufficient research and development capacity. In terms of maintaining the supply of semiconductor basic materials, five companies, mainly Shinetsu and Sumco of Japan, hold 90% of the global supply.

In terms of R&D and support for new semiconductor materials, the USA, Europe and Japan have set up a series of plans to support technological breakthroughs in new semiconductor materials in the region, as shown in Table 2.

Countries usually set up special plans or funds to promote cooperation between research institutions, universities, industries and government for technological breakthroughs in semiconductor materials. China is relatively weak in the establishment of special plans for semiconductor materials, special funds allocation, and in the co-operation.

Analytical coding of think tank reports and national policy on CMOS, 53 coding points related to CMOS were distributed in four reports of think tanks, and 90% of the coding points were concentrated in the Semiconductor Research Opportunity Industry Vision and Guide (Semiconductor 2017). After classifying the coding points, it is found that the focus is on the application of CMOS in various fields, and finding a new material or technology to replace CMOS, so as to achieve continuous improvement of the performance of the semiconductor industry. To achieve this goal, the computerization of the national strategy announced by the United States in 2015 listed ' computing beyond Moore 's Law ' as one of its five strategic goals.

EDA, electronic design automation tool software, is a large-scale IC design software development platform. The world 's EDA software is dominated by the three giants in the USA. Cadence, Synopsys and Mentor Graphics. To recover the cost of development primarily by selling software copyright. The development of EDA industry in China is relatively late. After the first set of EDA panda system was introduced in 1993, the development of EDA in China is at a low ebb. Until 2019, the market share of EDA software in China was only 5% (Cai 2021). Although there is still a gap between China and developed semiconductor countries in terms of IC design, the gap is rapidly narrowing. The IC monopoly countries led by the USA feel threatened. In order to restrict the development of China's IC industry, the US Department of Commerce amended the Act to restrict the sale of EDA software tools and equipment to Huawei Technologies Co., Ltd. and its subsidiaries.

Table 2: Support Form of Semiconductor Material Projects/Institutions in Various Countries/Regions.

Countries /Regions	Plan or Institution	Content
USA	Nanoelectronics Research Initiative (NRI)	Industry-government partners supporting research in American universities to explore devices and materials beyond CMOS.
	STARnet	Supporting industry-government partnerships between U.S. universities and governments, the STARnet Functional Acceleration Nanomaterials Engineering and New Structural Center focuses on new materials including TMDs, functional oxides and magnetic materials.
European Union	CEA-leti	France Research and Technology Organization, specializing in the application of nanotechnology in various fields of the country.
	European Graphene Flagship Program	The budget of EUR 1 billion is dedicated to exploring graphene materials, devices and applications, and to bringing graphene into society from academic laboratories within 10 years.
Japan	National Institute of Industrial Technology (AIST)	AIST is one of Japan 's largest public research institutions dedicated to materials and chemistry departments studying the computational design of nanomaterials, carbon nanotube applications, and advanced functional materials.

Countries /Regions	Plan or Institution	Content
	Center for I-nnovative Integrated Electronic Systems (CIES)	CIES is established for the research cooperation of international universities and industrial sessions, focusing on exploring spin transfer torque magnetic RAM materials, devices and architectures.
China	14th Five-Year raw material industry development plan	It is proposed to focus on the major needs of national defense construction, people's livelihood short board and manufacturing power construction, and carry out coordinated research on bandgap semiconductors and display materials, key materials for ICs, carbon based materials, biomedical materials, etc.
	Key Laboratory of Semiconductor Materials Science, Chinese Academy of Sciences	Focusing on the frontier of international semiconductor material science and the key scientific and technical problems to be solved, we carried out basic research on semiconductor materials and device applications, focusing on semiconductor functional materials and integration.

3.3 International Cooperation in IC

In terms of international cooperation and competition in IC, as the USA holds the core technology of IC and relies, only on Asian suppliers in chip manufacturing, international cooperation is needed. In recent years, Korea has also clearly demonstrated its willingness to lead the world in the cutting-edge field of IC and build itself into a manufacturing power, thus its technical strengthened cooperation with Germany, the USA and Israel. China relies heavily on other countries and regions in the IC industry, especially the USA, Korea, the European Union and Japan. Therefore, China strongly encourages domestic companies, universities and research institutions to actively participate in international cooperation, carry out transnational cooperation and exchanges, and facilitate attracting foreign investment to set up factories in China or companies to set up overseas research centers. At present, the University of Electronic Science and Technology of China has set up a joint Chinese and foreign degree program of electronic information. Together with the University of Grassla, it has trained a group of outstanding talents with international vision, international competitiveness and a high sense of responsibility.

4 CONCLUSION

In recent years, China has made progress of IC, such as grid, Insulated Gate Bipolar Transistor, inverters, fuel cells, DC - DC converters, Lidar and Microwave IC. There is still a gap with the advanced countries in the fields of semiconductor materials, CMOS, block ciphers, operational amplifiers, etc. In the future, we can provide support for the development of IC in China from four aspects: interdisciplinary talent training, policy formulation, encouragement of innovative scientific research and international cooperation.

First, in terms of policy, learn from the experience of developed countries and improve the promotion policy in this field. For example, the government has provided tax incentives, low-interest loans, and free land use rights for these companies, as well as through various initiatives such as expanding capital investment, reforming the immigration system, and protecting intellectual property rights.

Second, in terms of interdisciplinary talent training, the integrated circuit interdisciplinary system should be improved. Integrated Circuit Discipline Should Get More Resources to Provide Support for the Introduction and Training of High-level, Interdisciplinary and Compound Talents.

Third, in terms of encouraging innovative scientific research, according to the hot research topics of global IC, combined with the weak and short links in the field of IC in China, we will break through China 's shortcomings in the field of IC and maintain and develop leading technologies by expanding investment, targeted training and introduction of sophisticated talents.

Fourth, in terms of international cooperation, based on the country / region layout of hot research topics, we will carry out multi-field and in-depth exchanges and cooperation with countries in a dominant position in the field of IC shortcomings in China.

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