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Evolution of the content and the approach of Microelectronics training to regain skills and competences

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Abstract— The international development of digital technology is creating numerous problems for the use of associated equipment based on electronics and microelectronics. Increasing the performance of equipment, minimizing the use of natural resources and reducing energy consumption call for a very high-level industry and many new skills. The only way to meet these challenges is to train microelectronics specialists at all levels, in order to counter the phenomenon of shortage jobs and meet the priority of improving microelectronics. In line with promising research results, all specialties are concerned, and all skill levels too. An inventory of technical priorities has enabled us to establish a strategy for training technicians, engineers and PhDs, who need to acquire the skills and know-how to be integrated into both companies and training structures. The attractiveness of the field is also part of the drive to attract more future graduate people with female representativity. The paper concludes with details of the strategy pursued by the French microelectronics training network to meet these objectives. (Abstract)

Keywords—microelectronics training, jobs in shortage, global challenges, new skills, advanced practical activities

I. INTRODUCTION

On a global scale, we are in the midst of a digital revolution, with changes in societal behavior and the implementation of numerous new approaches. The development of the Internet and the use of digitized data have invaded our daily lives, whether for administrative procedures, financial management, citizen security, control of industrial production, media activities, controlled entertainment, advertising, commercial activities or education. Figure 1 shows this growth, which varies exponentially and should lead to storage capacities in excess of one zettabyte (10^{24}) in the next few years [1]. The second consequence is the need for reliable, increasingly high-performance objects and equipment, in line with the needs expressed by industry and the market for societal applications. The application domains involving connected objects [2] are more and more devoted to security, finance and environment monitoring for which the reliability is the priority [3]. To this end, the design of the integrated circuits must be optimized, tested and verified at all the steps from the concept to the layout and the technological processes must be reproducible without any defects and with a very high yield of fabrication. The third consequence concerns energy consumption, which is increasingly high [4-5].

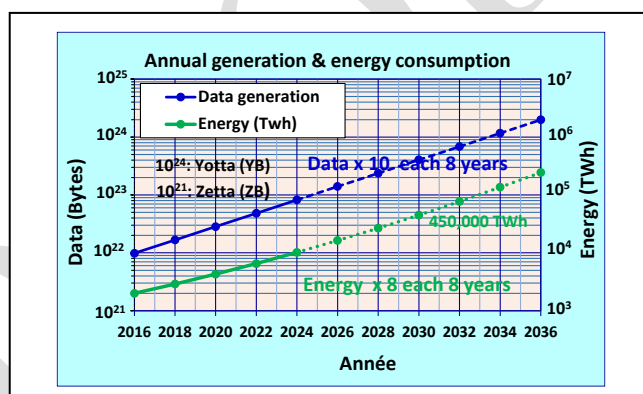


Fig. 1. Exponential growth of data and energy consumption. In less than one decade, the energy needed for digital equipment should pass over the global electrical production.

Serious forecasts show that consumption is growing exponentially, rising 8 times at every 8 years every 3 years (figure 1), and will lead the world to an energy impasse within a decade if drastic action is not taken. In this case, all electricity production would become insufficient to support digital activities. Since digital development is unlikely to slow down over the next few years, the most realistic solution is a significant improvement in the electronics associated with equipment dedicated to data generation, transmission and processing, whether for users, servers or data centers. A strategy is therefore needed to meet this demand, which can only be satisfied if the necessary human resources are available with the necessary skills. Firstly, this document presents the workforce requirements for improvements in electronics and microelectronics, followed by human resources needs, highlighting jobs in shortage. Next, it looks at the actions taken in France by the national microelectronics and nanotechnology training network (CNFM) [6-7] to meet technical and technological needs in line with the results of available research, and to meet human resources needs by making the field more attractive. It then looks at the actions taken by the national microelectronics and nanotechnology training network in France to meet both technical and technological needs, in line with recent research results, and human resources needs, by focusing on the attractiveness of the field. The implementation of a 5-year innovation strategy project should boost this development. The name of this project is INFORISM for Strategic and Innovative Training Engineering in Microelectronics [8], included in the France 2030 plan [9].

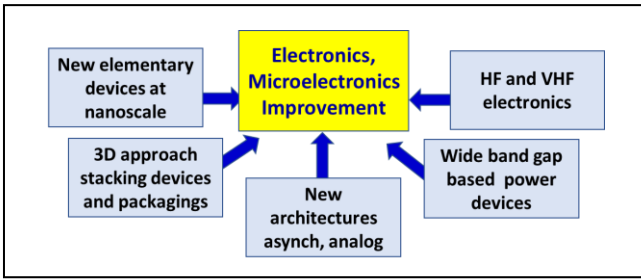


Fig. 2. Different approaches for improving the performance of microelectronics circuit and systems.

II. MICROELECTRONICS IMPROVEMENT REQUIRED

To reduce energy consumption, several approaches have been proposed. On the one hand, it is necessary to reduce the power consumption of elementary microelectronic components, while improving data throughput and reducing dimensions. On the other hand, circuit design and architecture need to be reviewed in order to optimize the size and number of components per circuit, control active zones and minimize interconnection distances between the various electronic functions of the circuits. This applies to analog and digital circuits, as well as to power and frequency [10]. Figure 2 summarizes these points. At the level of nanoscale components, the primary objective is to reduce leakage currents, mainly due to tunneling in ultra-thin layers. Indeed, for circuits such as memories with several billion transistors, the sum of leakage currents becomes much greater than the processing current more especially for the technologies developed in new nodes lower than 7nm [11]. These technologies are expected to increase the flow of data, and the integration as well. To decrease the leakage current, the proposed solutions involve using materials with higher permittivity and wider bandgaps, but also introducing insulating zones, as in the case of SOI (Silicon on Insulator) technologies such as FDSOI. The development of wide-bandgap components such as SiC or GaN minimizes off-state currents and on-state resistance. This is particularly important for power supplies, which are very useful for all transmission and processing stages in data centers. Promising new results have been obtained with semiconducting oxides such as GIZO (Gallium Indium Zinc Oxide) [12], but also with organic semiconductors. The use of chiplets not only minimizes Joule effect losses, but also improves response times. Circuit packaging using chiplets also improves frequency and energy performance. For example, stacked MOSFET circuits may improve the memories integration and decrease the losses. The introduction of new functions, such as neuromorphic circuit modules, allows minimizing the size of integrated circuits, which is a step in the right direction in terms of power consumption and computing speed. The analog design is becoming much more useful for many electronics functions. The proportion of analog parts even in high integrated digital circuits is permanently increasing. In the future 7nm and smaller nodes, the importance of analog modules should represent more than 50% of the total circuit as predicted by W. Haensch [13]. This approach allows minimizing the leakage currents generated by the synchronous electronic functions that induces a permanent electrical energy consumption. In circuit architecture, one way of reducing power consumption is to introduce new standby modes that enable low-power operation by cutting power to the inactive chip, even when other chips in the same package are active. [14].

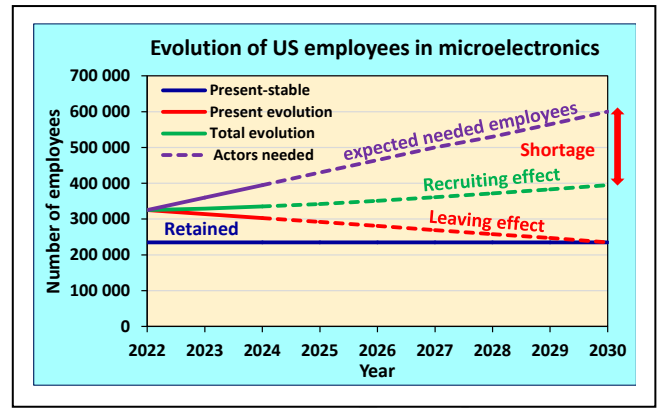


Fig. 3. Shortage in microelectronics employers in US expected by Intel. A deficit of two hundred thousands recruitment should not be satisfied.

This technique allows dropping power consumption significantly in standby mode. Looking ahead, several improvements should be achieved in the next few years if quantum electronics involving qubits is sufficiently integrated to cover the consumer market. These approaches mentioned above are among many others that can be consulted in the review article by J.R. Léquepeys *et al.* [15]. Clearly, the tasks are enormous, and new skills and competencies are needed to face these challenges.

III. SKILLED HUMAN RESOURCES SHORTAGE

In fact, if the need for skills is growing, it's important to remember that in the field of information and communication technologies, the skills shortage is nothing new. Worldwide, and particularly in the USA, this deficit has been predicted for almost a decade [16]. Figure 3, which shows the evolution of jobs in this scientific field in the USA, highlights the gradual increase in the employee deficit up to 2030, considering departures (leaving people) and recruitment. These departures include the retirement of older employees, as well as people leaving for other, potentially more lucrative, sectors of the economy. Recruitment will not be able to compensate for these departures and to satisfy the projected needs. This shortfall could represent 200,000 employees [16] in this country. This trend is unfortunately similar for the Western countries, at least. The reasons for the departure of some skilled employees may be linked to the level of salaries in this field, which is highly competitive on a global scale. The competition with the huge number of companies in the Far East forces Western companies induces a limitation of the remuneration of even their most highly skilled and indispensable employees. The competition with the huge number of companies in the Far East forces Western companies induces a limitation of the remuneration of even their most highly skilled and indispensable employees. Figure 4 deduced from the analysis made by Khonexio company in 2022 on French salaries [17], shows this parameter. Analog electronics, device process manufacturing and power electronic devices and circuits pay less and are therefore more in shortage. The shortage of specialists in "embedded electronics" is due to the considerable increase in connected object applications, which call for more specialists, even with higher remuneration [2]. Figure 5 shows the impact of this parameter, among others, on the recruitment shortage derived from the French government website [18]. In 2022, an average of 40% of vacancies at all diploma levels failed to find a candidate.

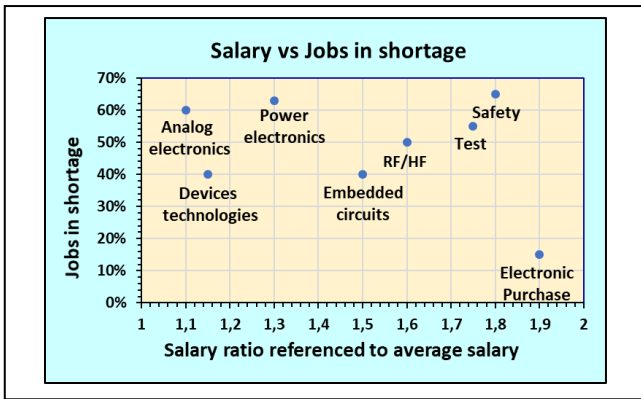


Fig. 4. Salary ratio by area of specialization. The current priority skills correspond to the lowest salaries. This is one explanation for the shortage in these specific fields. [From Khonexio analysis, 2022].

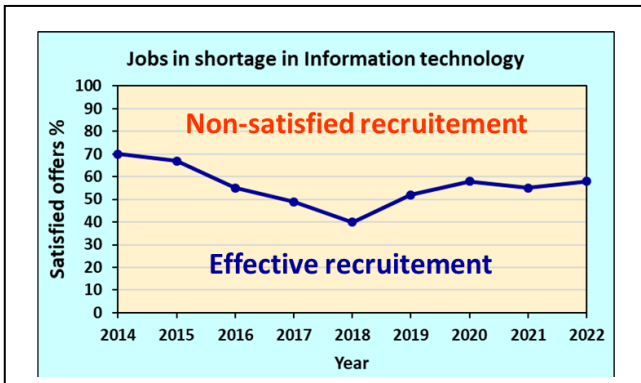


Fig. 5. Difficulty of recruitment in the information technology whatever the level, from technicians to engineers and doctors.

As a result, academic institutions need to increase the number of students in this field via attractiveness actions, whatever their level of graduation, and adapt the content of their teaching, particularly know-how, to meet the technical and energy challenges.

IV. ACTIVITY OF THE FRENCH NETWORK TO PRODUCE SKILLS AND KNOW-HOW

The French microelectronics training network, GIP-CNFM [6], was set up over 40 years ago [7]. Its main mission is to develop and maintain technical and technological platforms on which students at all levels, from technician to engineer and doctor, can acquire the know-how essential to the technical professions in this engineering field. This network is made up of 12 academic establishments, which operate technical platforms that are locally inter-university, and the “ACSIEL Alliance électronique”, an industry union with over 120 industrial members involved in the design and manufacture of microelectronic components, circuits and boards. This organization enables us to maintain a close link between the needs of industry and research, and the training strategy and development of technology platforms. In view of the skills shortages mentioned above and revealed in a “Comité Stratégique de Filière”, set up in 2019 and steered by the industry union and representatives of the training network, the government has launched an action plan and opened calls for projects. It is in this context that the network’s activities are being developed within the INFORISM project [8]. Every year, the platforms are used by around 20,000 students on platforms distributed throughout the 12 inter-university clusters.

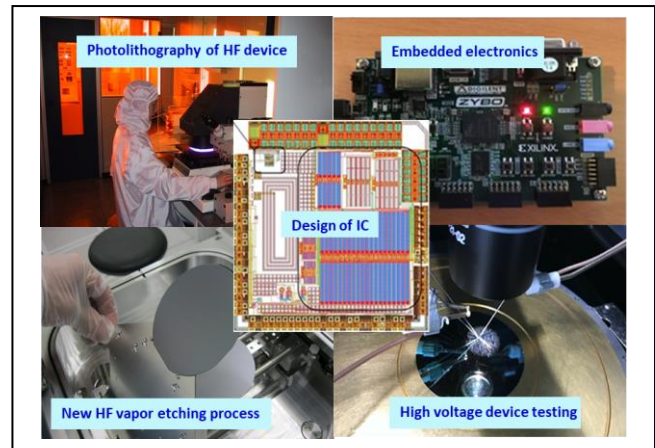


Fig. 6. Examples of realization by the students on several platforms of the main priority domains.

Figure 6 shows the achievements of students on different workstations, bearing in mind that to cover the whole discipline at network level, more than 100 platforms are offered to university training courses, but also to companies as part of vocational or lifelong training. 7 platforms are clean rooms in which students can build elementary components and circuits. Given that students may use several technical platforms in the course of their studies, these 20,000 students on platforms may in fact be coming from a physical community of around 16,000 people. The number of users graduating in bachelor's, master's, engineer's and doctorate degrees is around 5,000 annually, with degree courses lasting several years. The topics are directly connected to the priorities, knowing that more than a half of the students have practice in order to acquire the background that can be provided in all the interuniversity centers. At post-graduate level, the centers specialize in nanotechnologies at Paris-Saclay, Toulouse and Grenoble, CAD for advanced integrated circuits at Montpellier, Marseille and Paris, prototyping at Grenoble, HF electronics at the Lille and Limoges centers, electromagnetic compatibility (EMC) at Strasbourg, power electronics at Lyon and organic electronics at Bordeaux and Rennes. Figure 7 shows the distribution of activities for the majority of students in initial training. The five priorities appear in this survey. Maximum job offers from companies are in the specialties of integrated circuit design, testing and characterization, and embedded electronics. Computer-aided design activities are well managed by the network, thanks to the national software services of the GIP-CNFM network under the responsibility of the Montpellier center. All CAD software licenses are negotiated by colleagues at this center. Another joint activity is managed by the Grenoble center, enabling circuit prototyping for multi-chip projects. A part of the mission of the network consists to convince the higher education institutions (engineers, masters, PhD), to maintain a significant part of electronics in the menu of their students that can take benefit of these platforms to be better adapted to industry and research activities. This number of graduates is insufficient to meet needs, but they now have skills in priority areas [10]. To increase the pool of trainees, the network is carrying out awareness-raising and attractiveness campaigns. It should be noted that efforts have been made for several years to attract young women, as presented at SBMicro 2019 and published in 2020 [19]. In fact, in companies and

universities alike, women account for less than 20% of technical employees at all levels from technician to doctorate.

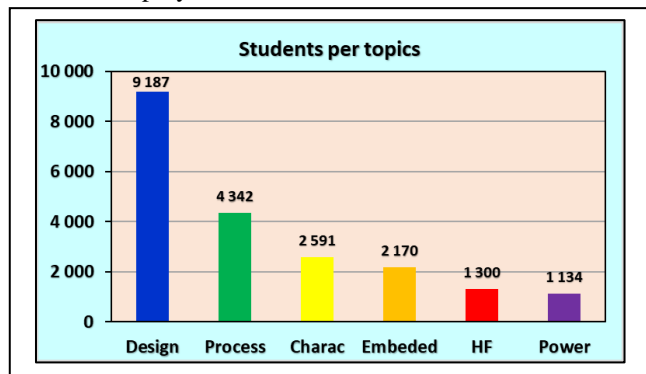


Fig. 7. Number of students per main training topic on the platforms of the French network. The data are issued of the last academic year, corresponding to the beginning of the 5-years project.

This missing community presents a problem, as it leads to a 40% reduction in the skills pool compared to other industrial fields. Another way to increase the number of students consists to attract foreign students. Unfortunately, the worldwide political situation during the recent years has increased the difficulty to receive students coming from abroad, mainly at the level of master and PhD. However, the possibility to receive in the academic institution the foreign remain a priority for doctoral schools, at least in France. To meet these needs, we would also need to increase the number of teachers in the field. As already mentioned, the number of graduates, engineers and PhDs is below requirements, as is the case in higher education. The trend over the last ten years has been not to renew retirements. This has led to a reduction in the community of electronics and microelectronics educators to around 30%, with the recruitment decision moving from a national to a local organization by the academic institution. Because they are increasingly financially independent, the strategy of universities and engineering schools is based on a clientelist approach to students, for whom the cost of studies is minimized. As a result, future engineers are less and less offered studies of a highly technological nature, leading to a sharp decline in the number of professors at these establishments. This trend naturally runs counter to the national strategy, and several joint working groups of professors and industrialists have been set up to convince government bodies to adapt the organization of higher education specifically to microelectronics.

V. CONCLUSION

The meteoric evolution of societal needs has led to a galloping demand for digital tools for all kinds of applications, resulting in an exponential growth in the number of these objects, coupled with an exponential growth in energy consumption. It is urgent to counter this deleterious trend by significantly improving all equipment based on electronic components and circuits. This strategy is now spreading over the world with new national programs such as Chips Acts that are established all over the major countries involved in the microelectronics industry [20]. For this aim, new and more abundant skills are needed. Actions are being taken in this direction at French level, namely to provide new trainees with the skills for innovation and to increase the pool of trainees. Behind this, there is a problem linked to the media that are not interested to promote sciences and technologies, and to the higher education institutions that are preferring to attract

students in other fields that are more lucrative with lower and cheaper practice. This approach is not adapted to a long-term policy. However, it is clear that the strategy developed by the French network should be applied worldwide. This means a higher cooperation between international academic institutions to gather the efforts of all the global skills in order to avoid a tragic freeze in energy consumption.

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