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Editorial:
Implantable Microsystems for High-Resolution Interfacing to the Brain

Almost a decade after the invention of the first semiconductor transistor in 1948, it took the revolutionary technology almost a decade to evolve from producing single devices to integrating only a few transistors as the first integrated circuit (IC) in 1958. Since then, integrated circuits have been in continuous progress for more than half a century as predicted by the well-known Moore's law. While integrated circuits still continue their progress with the same exponential pace, it is almost a decade that a new branch of science and technology has emerged, known as integrated microsystems. This can be taken as the natural technological evolution from individual circuit chips and non-circuit modules to complete systems with small physical dimensions and light weight. Integrated microsystems have opened windows of hope to providing efficient solutions to some of the problems that have not been resolvable by any other means whatsoever.

Among many kinds of microsystems being developed for a wide variety of applications, such as automotive industry, aerospace engineering, environmental monitoring, and defense systems, implantable biomedical microsystems are of increasing interest to both medical and engineering communities. This is mainly because of the capabilities such devices are expected to provide on the medical side, and also the technical challenges available on the engineering side. Examples of biomedical implants are pacemakers, cochlear implants, neural recording microsystems, and deep brain stimulators.

Electrically interfacing with the nervous system goes back to Benjamin Franklin's works no more than 250 years. Intra-cortical interfacing with the brain with high density and at the same time with high spatial resolution is, however, a rather new concept, being made possible by using unique capabilities advanced microtechnology has to offer. This technology is capable of implementing complex circuits with up to millions of transistors on silicon chips as small as a few millimeters on a side, realizing non-electronic structures such as probes and electrodes with sub-micron fabrication resolution, and finally integrating and packaging of all the electronic and non-electronic parts required to make a tiny implantable microsystem.

Implantable neural interfacing microsystems are known as powerful tools to enable neuroscientists perform high-density intra-cortical studies in the order of tens to hundreds and even thousands of parallel channels, and with high spatial resolution in the order of hundreds to tens of micrometers and even finer. It is also believed that such devices can successfully treat neural disorders such as epilepsy, paralysis, and Parkinson's disease, and even help effectively overcome deafness and blindness. On the non-medical side, researchers in cognitive sciences are among the other groups that anxiously await fully functional neural interfacing implants, using which they can talk to the brain and learn about how the signals sensed from the outside world are recognized.

Implantable microsystems designed and developed for intra-cortically interfacing with the central nervous system can be considered among the most sophisticated types of biomedical implants, possessing perhaps the most interesting applications. The extent of interest attracted to research in this area is clearly reflected in the daily increasing number of publications on the design and application of such devices. As evidence, Fig. 1 shows the exponential-like growth of papers and other relevant scientific and technical documents being published. This plot is the result of a search over Elsevier Scopus database for documents of any type with the words 'microsystem' and 'neural' in their titles, abstracts, or keywords.

An implantable neural interfacing microsystem, in general, comprises a microelectrode array (MEA), an analog front-end interfacing with the target tissue for recording and stimulation, and a radio frequency (RF) front-end for wireless interfacing to the external world. In order to be fully implantable, a neural interfacing microsystem needs to fulfill the following requirements:

Small physical size–No matter how powerful it is, it is evident that a microsystem needs to be small enough in size in order to be implanted in the brain without considerable damage to neighboring organisms and living tissues.

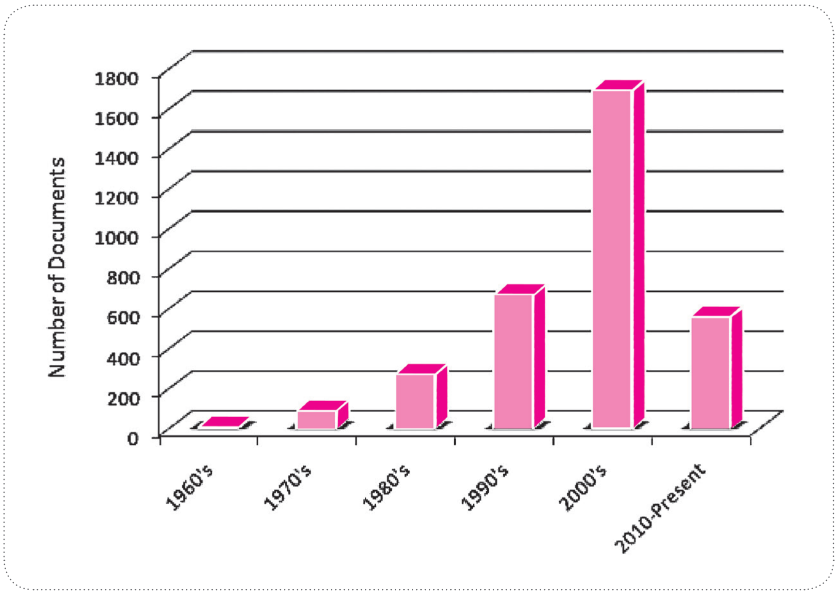

Figure 1. Number of scientific and technical documents published with the words 'microsystem' and 'neural' in their titles, abstracts, or keywords

Wireless operation–An implantable microsystem needs to bidirectionally communicate to an external setup through wireless connection. Programming a neural interfacing implant to operate in the proper mode, setting parameters such as amplification gain and bandwidth for recording and the details stimulation pulses for stimulation necessitate the flow of data from the external side to the implant. In the reverse direction, one needs to transfer recorded neural data from the implant to the external setup, too.

Packaging– Electronic circuitry in an implant, need to be properly packaged and sealed in order to be protected from undesired chemical and electrochemical interactions with their surroundings. Moreover, packaging of an implant is sometimes necessary in order to protect the living body from the toxic materials used in the implant.

Biocompatibility–It is also of crucial importance to avoid bringing materials in touch with the body that might cause irritation, inflammation, or any other undesired reactions by the body. Even if the materials used for the development of an implant are not toxic, it is important to avoid unwanted reactions the body might show to the implant as a foreign object. For these reasons, implantable microsystems are either made out of biocompatible materials such as silicon, titanium, platinum, or gold, or encapsulated with materials such as silicone and parylene.

Over the past few decades, depth and breadth of research on the design, development, and employments of implantable neural interfacing microsystems has been expanding with an admirably rapid pace. These devices are expected to revolutionalize research in the near future not only in basic and clinical neuroscience, but also in so many other application areas.

References

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