The eGrain system - using fine electronic particles

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With microelectronics as the technology and the Internet as its applications platform, the changes to all areas of our professional and private lives will be ever-more rapid and far-reaching. Today, visions of the future are all founded on a common theme: Seamless communication based on the Internet and mobile multifunctional terminal devices. As is apparent with mobile phones, the trend is moving towards smaller, more complex, autonomous systems, in which the telephony element is of diminishing, almost insignificant importance. The mobile phone is emerging as a universal information and communication terminal, characterized by extreme miniaturization and the integration of a wide range of services. This trend will inevitability be carried forward into the future.

In the process, present-day systems integration requires production of ever-more complex systems, comprising an increasing number of active and passive components while reducing production costs. The International Technology Roadmap of Semiconductors (ITRS), for example, predicts a further reduction in the size of semiconductor-chip structures and greater chip complexity. Depending on the application, this will result in chips with a greater number of I/O ports and higher loss, as well as larger dimensions than those currently available on the market. Consequently, the performance of integrated systems is growing, but with a corresponding increase in physical dimensions, which conflicts with the miniaturization objectives of systems integration.

In order to reduce the physical space requirements of a system, researchers are firstly looking to develop new integration technologies which also use the third dimension for systems integration; secondly, they need an alternative to replace the conventional method of systems integration through rigid connections.

This represents the framework for a new concept of systems integration, based on so-called "electronic grains". eGrains are tiny, autonomous, functional units, and are distinctive, not only through their ability to communicate with each other, but also because they are freely programmable and to a certain degree modular. At the same time, these units are universal and partly specialized, for example, through the integration of selective sensor properties.

In terms of technology and software design, systems integration based on the innovative eGrain system represents an entirely new challenge and requires a synergy of individual technologies at an exceptionally early stage. And naturally, through the differing nature of the approaches used to find a systems solution, it also holds a particular techno-scientific appeal, at the same time yielding extremely high innovative potential.

This technology poses particular challenges with regard to the desirable sizes (a few cubic millimeters), the need to achieve continuous operation through an integrated or external wireless power supply (for example, solar power), and the necessity of allowing multiple eGrains to communicate. The system is characterized by a large number of individual interconnected eGrains. The "eGrain" vision therefore represents a new approach to systems integration that will help to develop complex, flexible and cost-efficient integrated systems with black-start capability, based on ultra-small subcomponents.

Due to the high density required for integration, the production of "eGrains" necessarily involves stacking thin functional films which are then electrically bonded together. To do this, a new three-dimensional bonding technique based on conductive polymer films is under

consideration. The development of highly integrated three-dimensional wiring calls for a vertical-integration technology that allows interconnections to be fabricated and precisely aligned on ultra-thin substrates. The production of ultra-thin functional films as well as their integration to form a complete wafer-level system is therefore a key technology. In addition to reducing the size of active chip surfaces, the miniaturization of passive components is also fundamentally important for the complete system. New solutions also need to be found for these areas, which, in part, will lead to the elimination of passive components. To achieve this, the development of components and technology requires new polymer materials featuring complementary and partly opposing properties. For example, structured materials with an adjustable dielectric constant, which at the same time demonstrate high thermal stability.

The "eGrain" system requires that the tiny electronic units are capable of meeting their own energy requirements autonomously, over a certain period of time or during the entire operating life. This necessitates energy storage devices with high power density compatible with the system in terms of dimensions and production technology. Using current battery technology, the manufacture of micro-batteries requires wafer-compatible systems which allow cost-effective production.

Another important issue of the "eGrain" system is wireless linking of individual "eGrain" cells. Microwave frontend technology will therefore assume a key position as a connecting link between data-processing electronics and the transmission channel. In view of the low range of 1-10 m and the already oversubscribed utilization of frequencies in the range below 10 GHz, which restricts the flexibility required by the "eGrain" system, transmission will lie in the mm wavelength range (24.5 GHz or 60 GHz).

Communication between the large number of tiny, highly integrated "eGrains" presents a particular challenge in the design and implementation of this communications system. One of the important parameters for communication between a number of "eGrains" is the available energy capacity which is greatly limited by the low volume. Special attention is also given to the way in which two individual "eGrains" communicate, address assignment within an self-organized network, a flexible semantics-based grouping of messages within an "eGrain" network as well as interfaces to applications and management.

To create a self-organized ad-hoc network that can comprise a large arbitrary number of "eGrains" requires a suitable operating-system environment that provides the necessary administration services. In its entirety, this form of ad-hoc network can be seen as the configurable system, whereby the networked components represent the configurable resources. The actual operating system provides the necessary administration services with which to monitor and control this type of system. For example, this also includes the programming of individual "eGrains". In addition, the operating system offers a µNet interface though which the applications themselves can access the network components ("eGrains"). For the integration of the "eGrains" in other networks (LAN, Internet), the operating system provides gateways with the corresponding address and protocol conversion functions.

Consequently, the "eGrain" concept endeavors to link all types of system without using hardware-related packaging technology. The objective supports the future creation of complex, hyper-miniaturized systems. Moreover, they will be autonomous, small, efficient, mobile, interactive and will feature wireless and bi-directional communication. The "eGrain" system will not only make it possible to produce cost-effective microsystems based on standardized miniature modules. Furthermore, it will allow the systems to be integrated in existing local and global networks.

Perhaps in just a few years' time, an individual application-specific systems solution will no longer be developed in the currently known form. Instead, it will use 100 g of universal "system grain" ("eGrain") that can be integrated in any human environment, for example, in the home, and will meet a specific information and communication need through application-related, software-based networking.