SOFT MAGNETICS READY FOR THE FUTURE!

Evatec's Senior Product Marketing Manager, **Maurus Tschirky** tells us how taking a proven concept, leveraging other existing know-how and a bit of simple thinking is the risk free way to develop a high performance new module for production of integrated voltage regulators on 300mm in quick time.

Ongoing miniaturization in the semiconductor industry has made it essential to address the critical power density issue by developing cost effective manufacturing of high-frequency (> 100 MHz) fully integrated voltage regulators (FIVR) assembled directly on the microprocessor package, or in the die itself. These regulators convert the input voltage down to the output voltage and enable its dynamic distribution across the microprocessor die. Until now, FIVR applications have been held back by the unavailability of appropriate power inductor based on integrated thin film soft magnetic cores.

Soft magnetic cores for Integrated Voltage Regulators on 8 and 12 inches

We recognized that manufacturing solutions had to be found overcoming both technological and economic hurdles. Starting with the production proven soft magnetic process capabilities of our LLS EVO batch processing approach, we began to develop and sputter the desired layer stacks on 200mm, working together with our partners in industry and academia. In bench marking against latest state of the art, results achieved by our French partners at CEA Leti (see figure 2) using our LLS EVO, showed that the LLS drum concept remained an ideal approach providing we could develop a tool capable for 300mm wafer to satisfy the expectations of the industry. This was then the starting signal for the development of a new platform.

"THE RESULT IS REALLY CONVINCING AND SUPERIOR IN TERMS OF THROUGHPUT AT LOWER COST OF OWNERSHIP ON 300MM WAFERS"

Maurus Tschirky,
Senior Product Marketing Manager

CLUSTERLINE® 300 equipped with the BMD process module

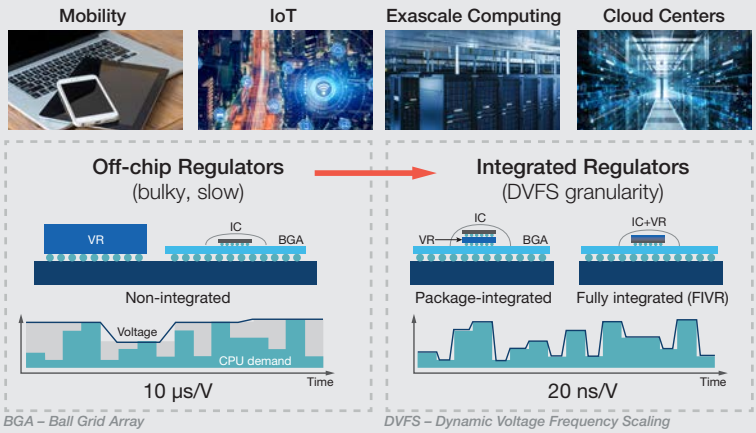


Figure 1. Evolution of Voltage Regulators onto the chip

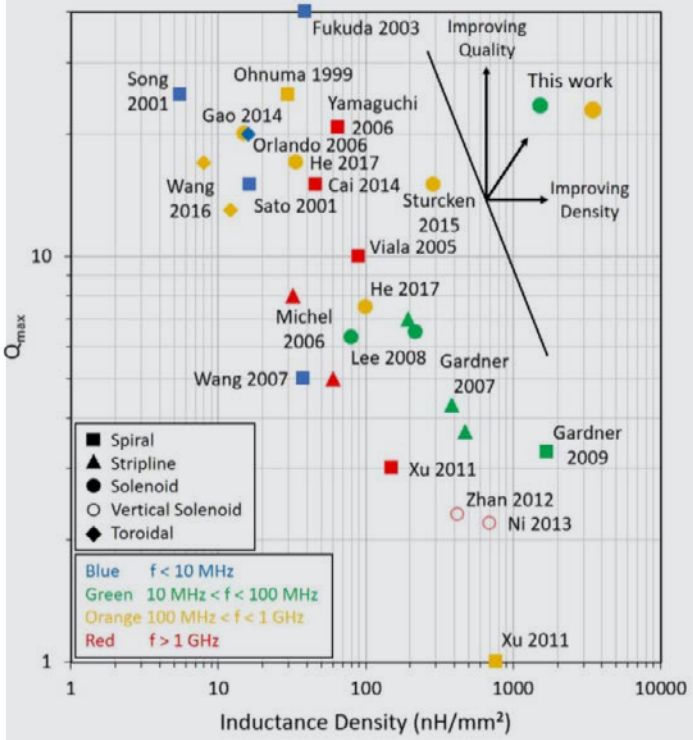


Figure 2. Peak quality factor versus inductance density of on-chip inductors from published measurements. The colours represent the frequency of the peak quality factor. – J.P. Michel et al., *IEEE Trans. Magn.* **55**, 8401207 (2019)

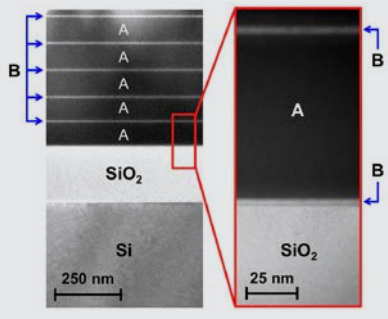


Figure 3: Cross-sectional Transmission Electron Microscopy (TEM) image of a soft magnetic multilayer sputtered on a Si/SiO_2 wafer in an Evatec batch tool. The dark contrast thick layers labelled with "A" represent the soft magnetic layers (e.g. CoTaZr, FeCoB, NiFe, etc.), whereas the light contrast thin interlayers labelled with "B" represent the dielectric interlayers (Al_2O_3, AlN, Ta_2O_5, SiO_2, $Si3N_4$, etc.).

Conceptual work and machine building

Despite approaching the challenge as openly as possible, we ultimately wanted to stick to the batch concept and thus to dynamic sputtering. It is the optimal way of depositing laminated stacks and thus our USP compared to any competition following a single wafer concept. In fact, the advantage is even two-fold: as the handling for a batch of 9 wafers with dynamic sputtering is significantly quicker per se, an additional advantage arises process wise from the possibility of running 6 cathodes at the same time. Free choice of both composition of materials and individual layer thicknesses contribute to superior flexibility for process design and development. We are therefore able to improve on materials and productivity!

"WE MADE A SIMPLE DECISION TO TILT THE DRUM ROTATION AXIS FROM VERTICAL TO HORIZONTAL"

In terms of architecture for the system we quickly identified the non-availability of vacuum robots for placing a horizontally picked wafer on a vertical axis drum as a problem. Solving this ourselves using concepts like an intermediate wafer tilt transfer module would have been detrimental to both footprint and throughput, so we made a simple decision to tilt the drum rotation axis from vertical to horizontal. The drum became a wheel, which was hooked up to our standard vacuum transfer module (VTM) of the CLUSTERLINE® 300. The system development thus changed into a module development, ready for attachment to an existing and proven platform.

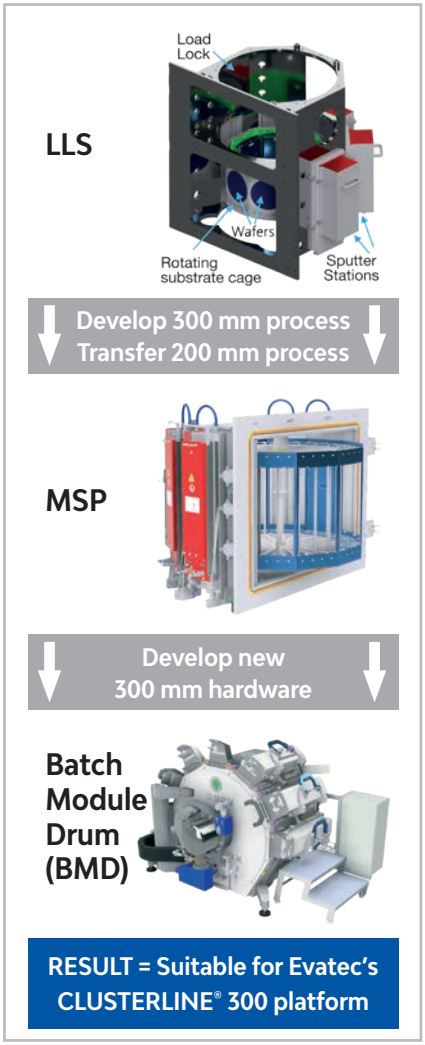


Figure 4. Development process of a new module

Process development

Evatec's broad product range brings great advantages and this was a perfect example where we could not only profit from the previous results achieved on the LLS EVO, but also leverage capability of the MSP, the second drum type batch system within our portfolio. Due to its larger size and geometries we were able to emulate the new source, magnet system and aligning field on our MSP lab tool, copying the exact conditions we expected for any new purpose built 300mm module (See figure 4).

The development of process relevant features such as the cathode, its magnet system and the aligning field could take place in parallel to the development of the new BMD module. Based on tests in our lab system we could be fully confident in the performance of the new BMD even before the first one was fully assembled. Figure 5 shows typical results that can be expected on 300mm.

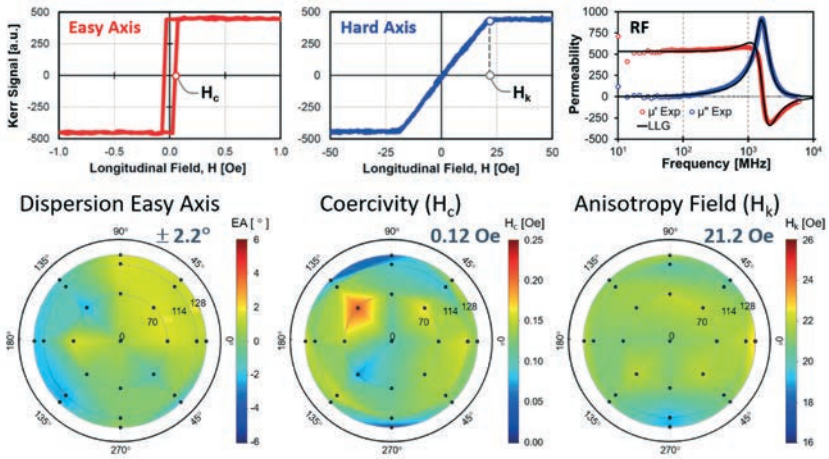


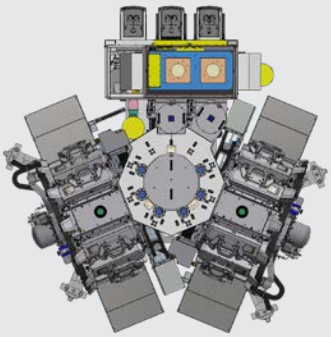
Figure 5. Results on 300mm depicting the static and dynamic magnetic properties of a several micrometers thick CoTaZr/Ta_2O_5 multilayer.

A tool that satisfies the market

The result is a BMD process module that can be seamlessly attached to an existing CLUSTERLINE® 300. The advantages of batch processing compared to single wafer processing will now enable the application of this technology for fully integrated voltage regulators in terms of design and commercial viability.

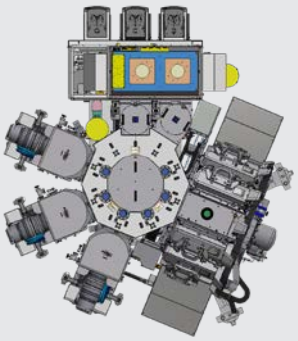
Modularity and flexibility are maintained and allow for a range of different configurations.

Figure 6 shows 2 example layouts for fully automated cassette-to-cassette tools. The first integrates two batch modules for typical throughputs of more than twenty (20) 300mm wafers per hour based on a 3 µm design of the soft-magnetic core. Needless to say, the thicker the design, the more advantageous is our concept. The second shows a configuration with just a single batch module but which then allows for tool flexibility by the addition of other single process modules.



OPTION 1

- Up to 2 x BMD
- Throughput >20 wph : 3um CTZ/Ta_2O_5 (80nmCTZ/4nm TaO)



OPTION 2

- 1 x BMD
- Up to 3 x SPM CLUSTERLINE® 300
- Throughput >10 wph : 3um CTZ/Ta_2O_5 (80nmCTZ/4nm TaO)

Figure 6. Typical CLUSTERLINE® 300 layouts