The challenges of implementing a Field Emission Gun into a desktop Scanning Electron Microscope – a product development story

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SUMMARY

Desktop scanning electron microscopes (SEMs) are a relatively new product category. They are smaller, easier to use and faster than conventional SEM systems. However, their resolution is generally not as good. In order to reach ultra-high resolutions of three nanometers and below, the use of a high-voltage field emission gun (FEG) as the electron source is required. In 2018, *Thermo Fisher Scientific*™ succeeded, for the first time, in implementing an FEG into a commercial desktop SEM. Several challenges had to be overcome – such as reaching ultra-high vacuum levels within such a small system. The *Thermo Scientific*^{TM} *Phenom Pharos Desktop SEM* now provides a resolution smaller than three nanometers, roughly three to five times better than most other desktop SEM models.

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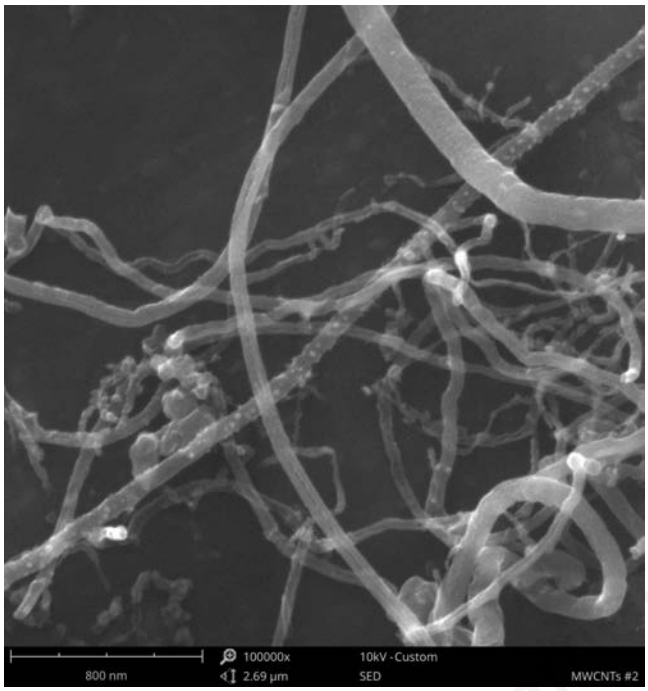
Scanning electron microscopes (SEMs) are widespread and a valuable tool, both for scientific research and industry. However, traditional SEM systems are relatively large and in general more difficult to operate. Desktop SEMs, on the contrary, are smaller, easier to use and their imaging process is significantly faster. Only their resolution is not as good: desktop SEMs can usually display feature-sizes down to, or below, roughly ten nanometers, while ultra-high resolution SEMs reach one nanometer or even less. The reason for this lies primarily in the electron source: desktop SEMs generally use compact electron sources like tungsten or cerium hexaboride (CeB_6), while ultra-high resolution is only possible with field emission guns (FEGs). Addo Hammen, R&D System Architect for the *Thermo Scientific™ Phenom Desktop SEM*, remembers that, at some time, his team started asking: Why should not it be possible to develop a desktop SEM using an FEG?

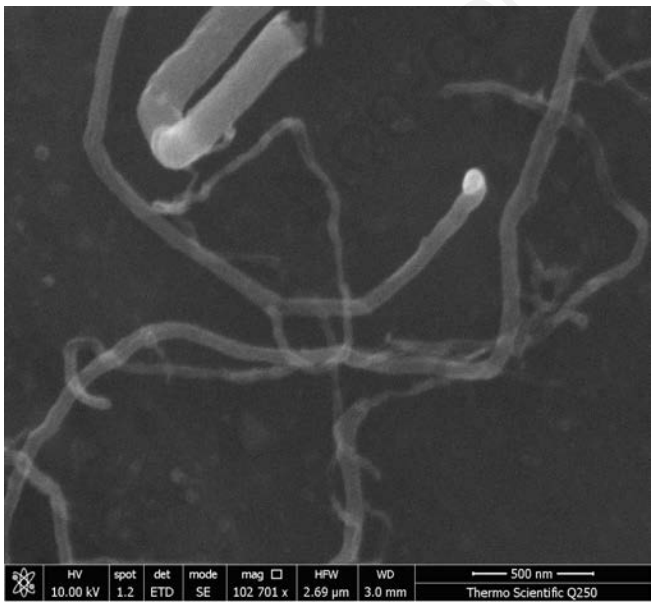
"The important difference between the two types of sources is brightness", Hammen explains. "An FEG source is much brighter than a tungsten or CeB_6 source, and resolution is directly correlated to brightness: the brighter the source the smaller the spot you can focus while still having enough signal to reach the detectors." In this context, Hammen mentions that a brighter source not only improves the resolution, it also makes the SEM much easier to work with.

So, what makes it so difficult to use an FEG in a desktop SEM? The answer primarily lies in the vacuum system. In order to use an FEG, you need to reach very low-pressure levels of 10^{-10} millibar. For their desktop SEM models, this meant an improvement of the vacuum level of at least 100 times compared to the CeB_6-system. Such ultra-high vacuum chambers require sophisticated technology, occupying quite some space. For instance, simply a stronger pump is not enough to establish such a high vacuum since water molecules tend to stick to the sidewalls of the column. The solution for this is heating the column, or "baking out the system"– that's how specialists like Hammen refer to it. For this reason, the microscope expert and his team had to incorporate heating components into the instrument. They needed to

Thermo Scientific™ Phenom Pharos Desktop SEM. Image courtesy of Thermo Fisher Scientific.

make sure that the most sensitive parts become the hottest since the water always drifts from warmer to colder areas. On the other hand, they had to be careful not to overheat lenses or detectors. Especially in compact desktop SEMs, all these conditions are difficult to meet due to the small column size and because the components are tightly packed together. Moreover, the developers of the *Phenom Pharos* microscope wanted to stick to their well-proven turbopump system, as it ensures a short sample loading time. In the *Phenom* desktop SEMs, the evacuation or venting process, respectively, can be done within 30 seconds. This is several times faster than any other SEM system available to date. In the *Phenom* desktop SEMs the sample chamber, the optics and the electron source region are all evacuated by one pump. Therefore, the engineers of the *Phenom Pharos* had to make a considerable amount of changes to their pump and chamber design. After having succeeded in generating vacuum levels, which were sufficient for running an FEG, minimizing vibrations became a critical issue. Such disturbances negatively influence the image quality. For example, the turbopump is a rotating component. That is why the developers had to put a lot of effort into dampening the vibrations generated by this device. Apart from mechanical movements, electromagnetic fields from both the inside and the outside must also be shielded. For instance, the condenser system required for operating an FEG needs to be designed such that it is insensitive to electromagnetic influences. And protection against all these disruptive factors becomes more difficult the smaller the SEM system is. In addition, the high-voltage board of the new source, had to be significantly adapted. That in itself was doable, Hammen says, but the stability of the high-voltage had to be improved as well, which turned out to be very challenging.





Phenom Pharos *vs* floor model Tungsten. Image courtesy of Thermo Fisher Scientific.

Hammen concludes that many different changes were necessary to eventually make the new set-up robust and stable enough, while keeping it small, easy to use and affordable to make. In the end, he and his team successfully preserved all the advantages of a desktop SEM and were able to improve the resolution to below three nanometers. He remembers how he and his colleagues were very happy when their company started shipping the first machines. Plus, there was something else: "The customers were very happy too," he adds. "Most of them are amazed by the quality of images delivered by such a small instrument."

Would you like more information about Phenom Pharos Desktop SEMs?

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