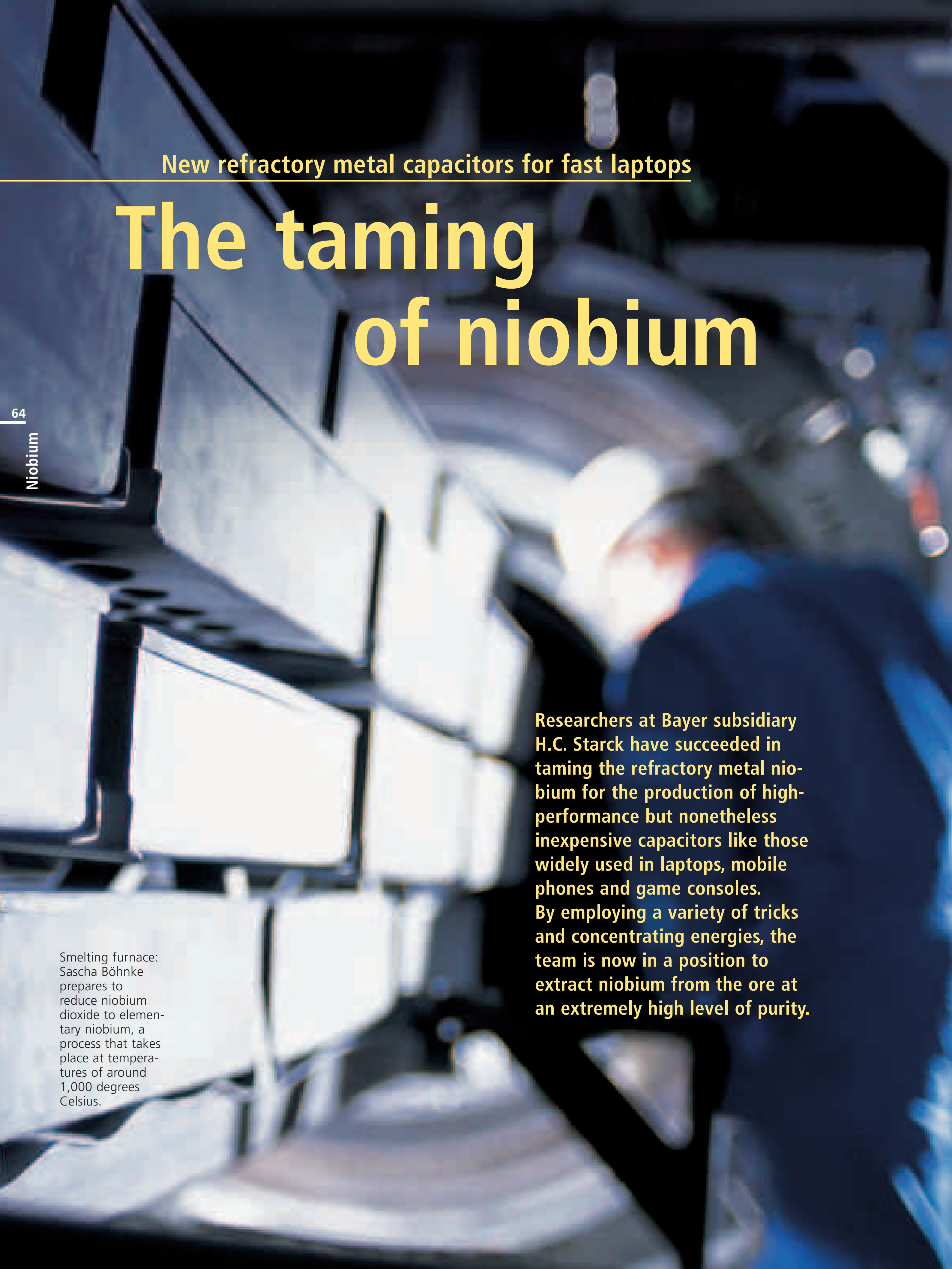
New refractory metal capacitors for fast laptops

The taming of niobium



Researchers at Bayer subsidiary H.C. Starck have succeeded in taming the refractory metal niobium for the production of high-performance but nonetheless inexpensive capacitors like those widely used in laptops, mobile phones and game consoles. By employing a variety of tricks and concentrating energies, the team is now in a position to extract niobium from the ore at an extremely high level of purity.

Smelting furnace: Sascha Böhnke prepares to reduce niobium dioxide to elementary niobium, a process that takes place at temperatures of around 1,000 degrees Celsius.

Dr. Christoph Schnitter has developed a process to produce niobium with a purity of 99.95 percent.

Most of the people who travel to the Harz mountains near Hanover go there with the aim of filling their lungs up with oxygen as they hike around the hilly countryside. Yet in Goslar, a town situated in the foothills, there are some people who have a genuine fear of oxygen. They perform chemical reactions with two powders behind thick steel walls at temperatures of over 1,000 degrees Celsius. If oxygen were to become involved, too, the consequences would be devastating.

One person at H.C. Starck who has full command of this reaction is Dr. Christoph Schnitter. Together with his colleagues from Goslar and Newton, Massachusetts, he has succeeded in developing a process that enables niobium metal to be produced with a purity of 99.95 percent. Because the melt temperature of niobium is so high, it cannot be simply smelted from the ores like other metals. Instead, the scientists at H.C. Starck have to subject it to a costly and complex process. But the effort is worthwhile, because niobium is the key to the production of new, small, high-performance yet inexpensive capacitors. Without capacitors, no laptop can calculate, no mobile phone can ring and no game console can function.

Tons of ultra-pure niobium powder for capacitor production

At present, many high-performance capacitors contain tantalum, an element related to niobium. H.C. Starck, which specializes in what are known as refractory metals such as tantalum, niobium, tungsten, molybdenum and rhenium, is one of the world's leading players in the production of tantalum. However, the metal is rare and therefore expensive. For some time now, the experts from Goslar had been toying with the idea of using the more common, and therefore cheaper, element niobium, which is often found in natural ores together with tantalum. Before now, niobium could not be used for the production of capacitors because it did not have the necessary combination of high purity and large specific surface area – and nobody had been able to completely tame the bulky niobium. Until Schnitter and his colleagues came along, that is. They are now producing high-purity niobium in a pilot plant in Goslar – tons of it every month in fact – and supplying it to capacitor manufacturers so that they can carry out extensive field tests. Extracting the niobium from the ore is a very complex process. Some of the raw materials, which H.C. Starck buys from Southeast Asia, are first processed in Laufenburg on the river Rhine. "That's what I imagine hell to look like", says Schnitter, who once visited the facility. Electrical currents of thousands of amperes are used to melt the raw material. Undesirable constituents can then be poured off from this melt as slag. The crushed residue, which looks like cold lava and now contains higher concentrations of tantalum and niobium, is then treated with hydrofluoric acid, one of the most difficult-to-handle chemicals in existence. The acid dissolves the two metals. In the hydrofluoric solution, tantalum and niobium are separated by a special technique and then subjected to further processing. From the hydrofluoric salt of the niobium, for example, high-purity niobium pentoxide (Nb_2O_5) is produced with the aid of ammonia.

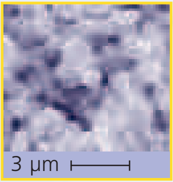
1,300 degrees, magnesium vapor and furnaces like bank vaults

The white, flour-like powder is the starting substance for H.C. Starck's patented two-step process developed in Goslar and Newton. The first step is a reduction stage in which oxygen is split off with the addition of hydrogen at temperatures of more than

Capacitors are needed everywhere

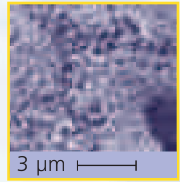
Whether in mobile phones, game consoles, computers, digital cameras or cars, capacitors are the second most common passive components in electronic circuits after resistors.

Device	Number of capacitors
Mobile phone	260
Digital camera	310
Game console	315
Computer	700
Car	1,700

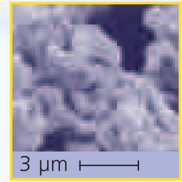


Step 1:
Reduction with hydrogen

Step 2:
Reduction with magnesium vapor



Step 3:
Reaction with niobium pentoxide and hydrogen



Starting material: Niobium pentoxide (Nb_2O_5)

Intermediate compound: Niobium dioxide (NbO_2)

Capacitor material: Niobium (Nb)

Capacitor material: Niobium monoxide (NbO)

Steps towards success
Using a patented multi-step process, H.C. Starck produces niobium powder in capacitor quality. The various products are shown in electron micrographs. Some of the high-purity niobium is processed into niobium oxide.

High safety: Earthing the shovels for the niobium powder ensures that every electric charge is dissipated.

1,000 degrees Celsius to produce niobium dioxide, NbO_2. In metal boxes, the white powder then passes on a conveyor belt through an oven. But any baker would soon get fired if he produced anything similar to what comes out at the other end of the oven: a black briquette with the consistency of charcoal. But for H.C. Starck, it is just what they wanted.

The next step involves grinding the black blocks and sifting the product before the next reaction step – further reduction of the niobium dioxide with magnesium.

This process is likewise quite a technical feat. The metal barrel containing the magnesium, for example, has to be well protected from electric discharges for safety reasons. For this reason, the barrel and all the metal shovels for the magnesium are earthed via clips and wires to dissipate any electrostatic charge. The shiny silver magnesium powder and the black niobium dioxide powder are carefully filled into two boxes and placed one on top of the other in another box. In a barrel-shaped steel furnace with thick walls and a door that would do credit to any bank vault, a mixture of elementary niobium and magnesium oxide is produced under the magnesium vapor at a temperature of around 1,000 degrees Celsius. To prevent oxygen from fanning the reaction, it is displaced by an inert gas at the beginning of the heating-up phase. Superpressure is then applied to prevent any oxygen from subsequently seeping in.

The magnesium oxide is then flushed out with acid and water one floor lower in large reactors. Another floor down, the niobium powder is finally dried on trays in drying cabinets. Here, too, the safety precautions are very strict. If a probe detects any impermissible temperature increase in the niobium powder, the unit switches itself off automatically and floods the chambers with inert gas to displace the oxygen. After all, the niobium would ignite if it got too hot and oxygen were present.

Microscopic heavy-metal sponges store energy

In the last production stage, some of the niobium is mixed with approximately equal parts of the starting substance – niobium pentoxide – to perform a reaction to create niobium monoxide, NbO. Compared with elementary niobium, this compound is somewhat less expensive and is also suitable as a starting substance for capacitors. Niobium monoxide can withstand higher temperatures, while niobium is more pliable and can be processed much more easily.

For the production team at H.C. Starck, that is basically the end of the process. But for the members of the research team, the work goes on, as they carry out experiments on the subsequent processing of the niobium.

The know-how they accumulate in this way benefits their customers, the capacitor manufacturers. Like batteries, capacitors store an electrical charge between two electrodes, the anode and the cathode. However, whereas batteries take up the charge by chemical processes over a period of several hours and then release it again, capacitors work by other physical laws, and can absorb the maximum charge within fractions of a second and discharge it again. The rule is that the greater the surface area of the anode and cathode and the closer they are to each other, the higher the charge that can be stored, in other words the higher the capacity.

Present-day capacitors nowadays have little in common with the simple multilayer structures that many of us learned about in physics lessons at school. Tantalum and niobium capacitors are more like microscopic sponges. To obtain this structure, the grains of powder, which are only a few thousandths of a millimeter in size, are

Niobium mill: Axel Krämer controls the crushing-grinding-sifting step for the niobium dioxide.

compressed around a tantalum wire to form beads measuring about a millimeter. They are then fused together to produce an anode with an all-conductive structure and a large specific surface area. This is given a wafer-thin, non-conductive oxide layer in an acid bath under electrical voltage. This layer insulates the anode. The cavities left in the sponge-like structure are filled with manganese dioxide or increasingly with conductive polymers such as the H.C. Starck material Baytron® as the subsequent cathode.

Niobium capacitors work in game consoles and laptops

Niobium capacitors have about the same performance properties as tantalum capacitors. Whereas tantalum capacitors are suitable for operating voltages up to 60 V and are exceptionally stable and reliable, the cheaper niobium capacitors are only able to handle voltages up to 10 V. Tantalum is therefore predestined for the really tough, precision work in aircraft, cars and medical products, while niobium tends to do duty in mass products like game consoles and laptops. Both of them, says Schnitter, have to compete with aluminum and ceramic capacitors. Although aluminum capacitors are cheap, they have very high resistances because of their liquid cathode. Up to ten conventional aluminum capacitors, adds Schnitter, can therefore be replaced by one niobium capacitor for certain applications. The price advantage of aluminum then disappears. Although high-performance aluminum capacitors with a conductive polymer cathode also exist, they are much more expensive. The situation is similar with ceramic capacitors. If only small capacitors are needed, they are unbeatable in terms of price. Such capacitors are used in the conventional multi-layer structure. The greater the capacity needed, the thinner the layers must be so that as many as possible can be stacked on top of one another and higher capacities can be reached. That pushes up the cost.

With computers' clock rates getting faster and faster, the operating voltages are falling, and that's good news for niobium capacitors. H.C. Starck's niobium powder is therefore paving the way for the future of electronics. Some of the latest generation laptops can already boast they have 'Niobium inside!' The pilot plant in Goslar is no longer big enough to tackle some of the future market developments, so another larger plant is now on the drawing board.

www.deutsches-museum.de/e_index.htm

Via the "Exhibitions" and "Metallurgy" links, you can access information and graphics about the permanent exhibition on the world of metals.

Co-reactant: Excess hydrogen is burned off.