A world of colors: the Max Planck researchers heat the synthetic material in order to mimic the beige hue of natural ivory. They have also identified numerous dyes that they can add to the starting materials, opening up a range of potential applications in addition to the design of keyboards.

PHOTO: WOLFRAM SCHEIBLE

IVORY FROM A TEST TUBE

TEXT: PETER HERGERSBERG

For a long time, pianists have had to live without the sensation of playing on ivory keys. One remedy for this is synthetic ivory, a substitute developed by Dieter Fischer, Sarah Parks, and Jochen Mannhart, who usually spend their time researching quantum electronic phenomena at the Max Planck Institute for Solid State Research in Stuttgart. Now, a start-up is planning to produce the material on a large scale – and not only for use in piano keys.

Jochen Mannhart had not expected his Christmas trip to have such a lasting effect on him. In 2014, he and his team opted to visit a piano maker for their annual end-of-year excursion – a rather unusual destination for a group that studies effects relating to quantum electronics at the Max Planck Institute for Solid State Research in Stuttgart. Whereas in previous years' visits – to suppliers of lasers and machine tools or automotive manufacturers and suppliers – seemed like fairly obvious choices, there was not exactly an urgent need for technical contacts in the piano-making industry.

In any case, the 2014 excursion brought the group to the Black Forest town of Spaichingen to visit Sauter – by its own account, the oldest pianoforte workshop in Germany. "I was really amazed at how much time they spent with us – even the Managing Director," says Jochen Mannhart. "It's not as if we had much to offer Sauter, either as a customer or for recruiting new staff members." At the end of the visit, Mannhart asked whether there was anything Sauter wished scientific researchers would invent. The answer he received from Otto Hott, Managing Director and joint owner of the company, was not only succinct but also surprising: "Synthetic ivory."

When it comes to the veneer applied to piano keys, ivory remains the material of choice for pianists. But the international trade in ivory from elephant tusks was banned in 1989 to protect the animals from extinction – and piano makers have yet to find a substance that offers pianists the same feel as the natural material. Although the properties of ivory depend to a certain extent on its origin and the animals' diet, it is always warm to the touch, absorbs moisture effectively, and is preferred by pianists when it comes to slip resistance.

With this in mind, the team of Stuttgart researchers took Otto Hott's wish back to their laboratories and set about making it come true. This task fell to Dieter Fischer and Sarah Parks, who normally spend their time producing inorganic materials such as unusual metal structures or complex metal oxides, in which exotic quantum effects take place. In order to produce such substances in the greatest possible purity, they have always needed expensive apparatus and an ultra high vacuum. "But

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it was immediately clear to me that we could rule out all production methods in a vacuum from the word go," says Dieter Fischer. Even if this approach could create a substance resembling natural ivory, large-scale production would be impractical and too expensive.

A simple idea that no one had tried yet

With a view to developing a workable formula for ivory, he first embarked on an in-depth study of the material and of the approaches that scientists had previously pursued (in vain) in order to produce it by chemical methods: ivory is partly made up of hydroxylapatite crystals, which also provide hardness in bones. These mineral particles are embedded in a framework made up of a protein called collagen, which gives the material its robustness. The first patent for the synthetic replication of ivory was awarded at the end of the 19^{th} century to the chemists A. and S. De Pont, who had even attempted to replicate the formation of the natural material by growing hydroxylapatite crystals within a collagen framework. Although this approach failed to produce a viable substitute for ivory, it seems that many scientists who also tried to make ivory assumed they would have to follow a similar path.

Dieter Fischer wanted to conduct a much simpler experiment first. Why not simply mix a suspension of hydroxylapatite particles with dissolved gelatin (which is derived from collagen)? This was a radical idea by virtue of its sheer simplicity, but he was not about to leave its implementation to chance. "We first gave some thought to which parameters might be important for direct synthesis," says Dieter Fischer. "And luckily, the ones we chose worked quite well from the outset." For instance, the temperature and the concentration of the components turned out to be crucial factors in production.

The joy of playing: Dieter Fischer led the development of the synthetic ivory and is seen here trying out the piano at the Max Planck Institute for Solid State Research. The instrument, whose keys are covered with the material his team developed, was a gift to the researchers from the piano maker Sauter.

PHOTO: WOLFRAM SCHEIBLE

The right conditions also produced the right result when the researchers mixed the two components. They first obtained a milky liquid, from which they then evaporated most of the solvents. The viscous mass that remained was poured into flat molds and left to dry on a lab bench. Dieter Fischer describes the resulting white substance as "jellybabies with hydroxylapatite" – and it was a very good approximation of natural ivory.

However, it still took the researchers in Stuttgart a few more attempts to turn this substance into a material that was barely distinguishable from its natural counterpart – both visually and to the touch. For this, they enlisted the help of the staff at Sauter, whom they provided with several batches of samples. The piano makers machined the plates using exactly the same methods as had traditionally been used for natural ivory and tested them in their keyboards.

They then reported back to the research team in Stuttgart to tell them which properties still needed to be optimized.

In the meantime, the scientists Sarah Parks and Dieter Fischer set about analyzing different variations of the synthetic ivory in their laboratory, where they performed a range of experiments to measure the material's moisture absorption, thermal conductivity, and hardness, as well as the amount of grip it provided. In order to analyze slip resistance, they built a special artificial finger – a spring-loaded rod with a leather-covered tip. "Although leather is not identical to human skin, it is quite similar," says Sarah Parks. "Besides, we were more interested in comparing different samples." To do so, the scientist would apply the test finger to one of the materials and measure the horizontal force required to move the plate.

Both in the laboratory and at the pianoforte workshop, the synthetic ivory passed the tests with flying colors: it feels as warm as its natural counterpart, is able to absorb moisture from the pianist's fingers just as well, and provides similar slip resistance. The material's grip can even be optimized according to players' individual requirements. However, given that what really matters is how the keys feel to play, the synthetic ivory met its litmus test not in the laboratory but rather under the fingers of an actual pianist – and of course, the team of Stuttgart researchers traveled to Spaichingen for the occasion. Sauter had manufactured a piano with white key veneers made of the material from the Max Planck Institute for Solid State Research and had arranged for the instrument to be played by a trained musician. Surrounded by piano makers and basic researchers, Eugene Mursky took to the ivory keys to perform pieces by Chopin, Schubert, and Liszt, but his audience was more delighted with his ensuing praise for the material than with the concert itself: "It's fantastic – it feels warm like real ivory," said Mursky, who has had the opportunity to play on historical pianos with real ivory keys in the past.

Ivortec will market the synthetic ivory

The fingers of many people have since played on this keyboard made with the synthetic ivory. "The first pianists to play our instruments so far have all had positive things to say about the playing characteristics of the synthetic ivory," says Sauter's Managing Director, Otto Hott. The unanimous verdict was that the material is less slippery than substitute materials used in the past. After these successful tests, Sauter is obviously keen to fit its pianos and grand pianos with the synthetic ivory as standard in the future. However, producing the necessary quantities of the material is no longer a job for the Max Planck Institute. It was with this in mind that Jochen Mannhart founded the company Ivortec with the Max Planck Society in July 2019, bringing in David Butcher as the external Managing Director. The company will be responsible for marketing the synthetic ivory – and not only as a veneer for piano keys.

Numerous potential applications: a member of the Max Planck team used a lathe to make chess pieces from the synthetic ivory. However, the material could also be used in the furniture or yacht building industries.

The Max Planck researchers also made contact with a jewelry designer, who has fashioned a pendant from the elegant-looking material. Likewise, an artist has carved a replica of a Stone Age bird figure out of the ivory, and Manfred Schmid, a member of Mannhart's group, has used it to produce a set of chess pieces on a lathe in one of the Institute's workshops. The sheer versatility of the test-tube ivory is partly thanks to a slightly modified process by which Sarah Parks and Dieter Fischer have managed to give it a cylindrical shape. It's no surprise, then, that David Butcher has a long list of potential applications in mind. As Managing Director of Ivortec, he is therefore working not only to raise start-up capital and forge collaborations with production companies, but also to reach out to firms that may be interested in synthetic ivory as a material. In many situations, it could act as a substitute for plastics or even wood. "The ivory has attracted considerable interest from furniture manufacturers and yacht builders, not only for its elegant looks but also because it doesn't burn until it reaches 1,000 degrees Celsius – so it's like decorative fireproofing," says Butcher. The material also scores highly in terms of sustainability, especially in comparison with plastics. For one thing, it is not made from petroleum and is biodegradable at the end of its life cycle. The synthetic ivory therefore not only offers pianists a playing experience that would otherwise be off limits for the sake of wildlife conservation, but – unlike plastic – it also leaves behind no waste.

PHOTO: WOLFRAM SCHEIBLE

SUMMARY

A Max Planck team has succeeded in producing synthetic ivory that closely resembles the natural material.

During synthesis, the researchers mix hydroxylapatite particles into dissolved gelatin, which is formed from collagen, the organic component of ivory. Chemists had previously assumed that the hydroxylapatite crystals had to grow within collagen, just like in the natural formation process.

Among other applications, the synthetic ivory will be used as the veneer for piano keys, as it offers pianists the same feel as its natural counterpart. However, it could also be used as a flame-resistant and biodegradable alternative to wood and plastics.