A scanning electron micrograph shows Breguet's silicon spring attached to a 4-armed balance with recessed timing screws. Note that the inner end of the spring is attached to the balance arbor by an integral triangular collet. Although the spring is said to 'breathe' concentrically (expanding and contracting with even spacing between the spirals) it does not have the bulge in the outer coil said to be necessary in Patek Philippe's new silicon 'Spiromax' spring.

Heart of Lightness

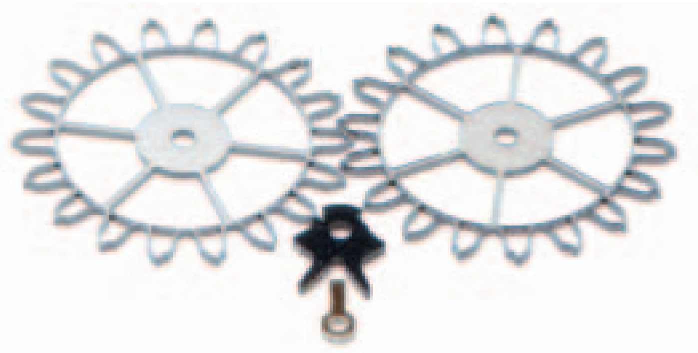
Physicists, not watchmakers, are re-engineering the wristwatch

Timothy Treffry

The mechanical watch has been a mature technology since the 1930s. With its rebirth as a luxury product in the last decade or so, modern technology has largely been applied to better ways of making 1930s watches, albeit in a modern form. Only rarely have attempts been made to make a better watch – mostly tentative attempts that have failed to find broader applications. This year however, the industry is suddenly awash with traditionally constructed watches spiked with truly cutting-edge technology. Where cutting the edges is almost as hard as the materials themselves, *QP* explores the horological revolution being waged with silicon and nickel-phosphorous.

When Omega embraced George Daniels' Co-Axial Escapement in 1999 it was the first fundamental change for generations. And this initiative seems to have released a growing flood of innovation. In 2001, with the Freak, Ulysse Nardin pioneered a completely new approach to the watch escapement using a technology that was yet to fully emerge from university laboratories and a material completely new to watchmaking; mono-crystalline silicon, otherwise used as a substrate for transistors and computer chips.

Before we go any further, some clarification is probably required, as 'silicon', 'silica' and 'silicones' are sometimes confused. Silicon is an element; a pure metal. Combined



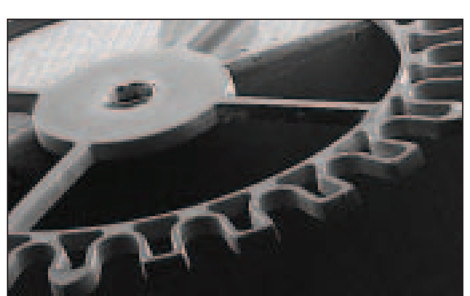
with oxygen, it forms silica, which is quartz – an entirely different material. When silicon is combined with hydrocarbons, we have silicones; slippery molecules used in polishes and rubber. Silicon is very strong, light, and non-magnetic – the properties that appeal to watchmakers. Additionally, crystalline silicon has the same structure as diamond.

The great escape

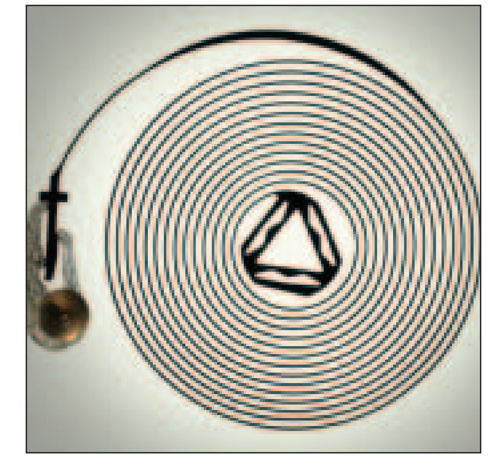
It was perhaps a pity that Ulysse Nardin put its pioneering 'Dual Ulysse' escapement in the Freak. The watch itself was so unusual that the merits of the new escapement, and the material from which it was made, tended to be overlooked – except perhaps in research departments of other watch companies. For this escapement the escape wheels needed to be very light, to keep the inertia down. The designer of the Freak, Dr Ludwig Oeschlin, had been experimenting with silicon – less than a third of the weight of steel – to make a balance spring for a pocket watch. He thought it might also be suitable for the new escapement components. Making things out of mono-crystalline silicon wafers is not trivial, though. It requires high-energy plasma etching in a machine usually found only in the more sophisticated physics laboratories.

Although the layman may think of watch parts as tiny, these traditional metal parts are much heavier than they need to be, because they have to withstand the rigours of the manufacturing process. Cutting-tools in lathes and milling machines, however sharp, tear at the metal, hacking it off bit by bit, albeit on a microscopic scale. In contrast, plasma etching a silicon wafer (deep reactive ion etching – DRIE) simply vaporises the atoms, placing no stress on the material being shaped, so very thin, light, components can be made.

(Above and top right) The Ulysse Nardin-160 Anniversary watch and its nickel phosphorus escape wheels. Only flat objects can be made by the electro-deposition method , so the components of the alternator (the form of lever used in this escapement), which are also shown, are made separately. £14,750 in a rose-gold case.



(Left) As first seen in Issue 6, the escape wheels and balance spring in an experimental version of the Ulysse Nardin Freak were etched from a sheet of poly-crystalline diamond. One of its two transparent wheels can be seen in an electronmicrograph, left. The diamond balance spring is shown, right. At present, the cost of making these components is too high for series use but the physical properties of diamond make it an ideal material.

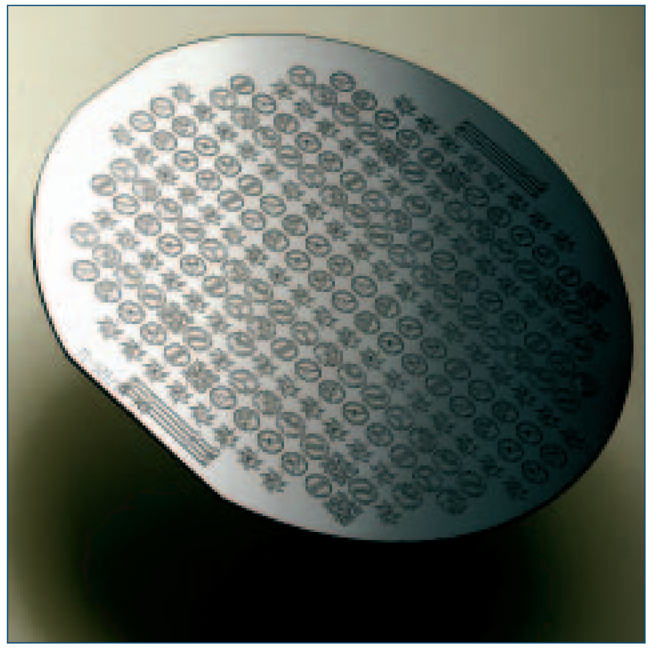


Patek Philippe's silicon escape wheel (far left) and 'Spiromax' silicon balance spring (left) are used in a special limited edition of the ref. 5350R annual calendar (below). At £17,210, it is only a small premium on the conventional version; probably a good investment. The components show some of the special properties of this technology. They can be made very precisely in any desired shape. The central, springy triangle in both wheel and spring allow them to be a close 'press-fit' on the arbors that carry them. Note also that the spring is integral with its central mounting section and that its outer end fits a purpose-built clamp. There can be no attachment errors. The thickened portion near the outer end of the spring acts like an overcoil and ensures that the spring moves concentrically as the balance swings.

Abraham-Louis Breguet said: "Give me a perfect oil and I will give you a perfect watch." A much better approach is to eliminate the oil altogether.

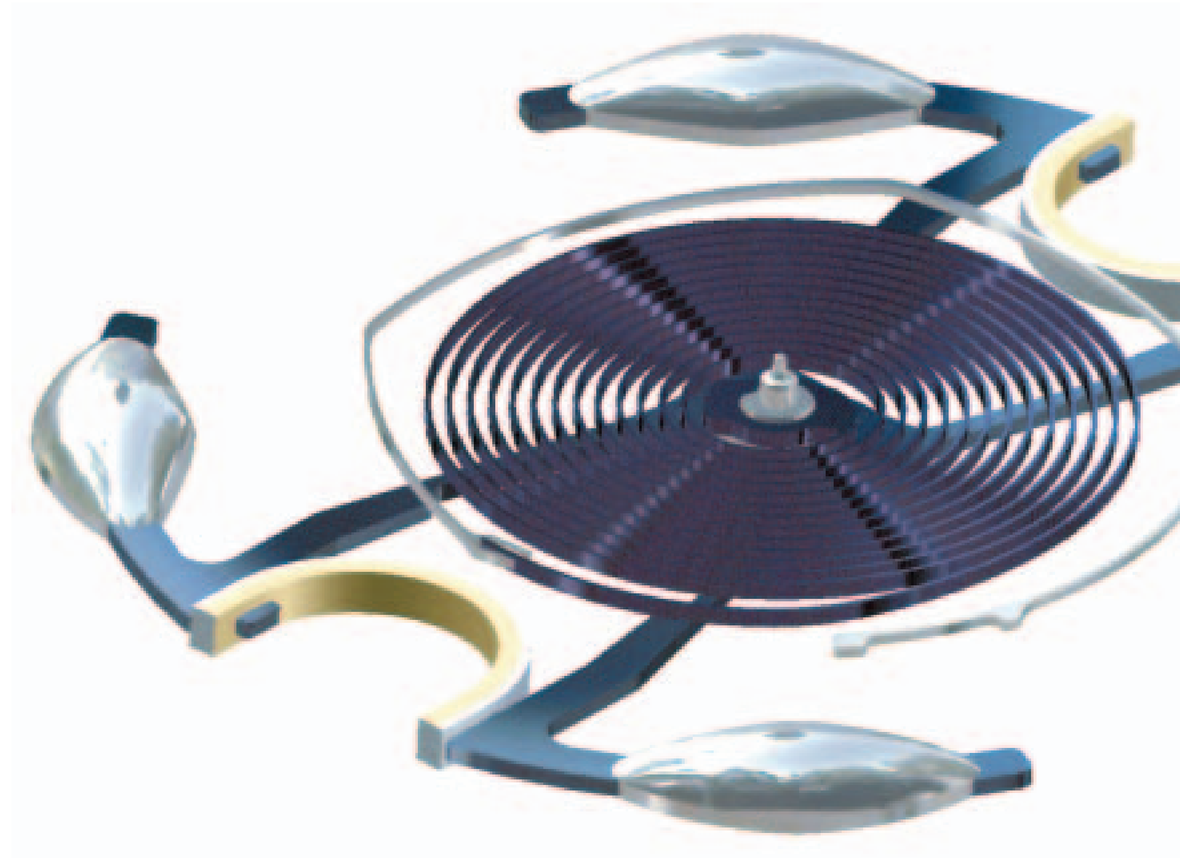
There is no way that wheels like those in the Ulysse Nardin escapement could be machined, but in plasma etching you can make any shape you can draw. The same principle applies to a different technique, micro moulding and electro deposition (MMED), which is now used to make a range of parts for modern watches from another new material, nickel-phosphorous. To make a component in both conventional machining and DRIE, you start with a larger piece of material and remove what you don't want. In MMED you build up the component atom by atom rather than take anything away. It is a two-stage process. The same masking system as DRIE is used to create chambers in the shape of the component where it is then formed by electro-deposition of nickel-phosphorous. Ulysse Nardin used this method to create the extraordinarily light, almost diaphanous, escape wheels used in this year's new Anniversary 160. This watch celebrates UN's 160th birthday with the brand's first in-house self-winding base calibre, the Calibre 160. Its Dual Ulysse escapement permits a dramatic increase in the freedom with which the balance swings, as its contact with the escapement is reduced from the usual 50°-52° to approximately 30° and therefore a lower disturbance in the natural oscillation of the balance. Having two escape wheels instead of one (as in the Swiss lever escapement), meant the mass of these wheels had to be radically reduced, so that the impulse to the escapement did not have to increase – hence the use of nickel-phosphorous.

In the 19th century Abraham-Louis Breguet said: "Give me a perfect oil and I will give you a perfect watch." A much better approach is to eliminate the oil altogether – at least from the escapement, as the deterioration of even modern oils means that a watch needs servicing every few years. In both UN's Anniversary 160 watch and the earlier Freak, the well-designed low-friction escapement does not require lubrication.



(Above left) A Patek Philippe silicon wafer, etched precisely by deep reactive ion etching (DRIE) to form hundreds of components.

(Above right) Part of Breguet's silicon balance spring and balance wheel. Historically Breguet placed a tiny, scarcely visible 'secret signature' on the dial of his watches. Here the signature has been added to the rim of the new escape wheel.



(Left) This unusual balance by De Bethune has an X-shaped silicon frame and a silicon balance spring. A brass and steel bimetal strip between the arms of the balance will move the platinum weights inwards at higher temperatures. This reduces the inertia of the balance as the elasticity of the spring drops, keeping the amplitude constant. The additional section at the outer end of the spring is designed to have the same effect as a Breguet overcoil – nearly a full turn of beryllium copper modulating the spring's breathing.

(Above) The beautifully finished hand-made movement by Kari Voutilainen is fitted with a balance by Gideon Levingston. This has a 'Carbontime' balance spring oscillating a silica disc with gold U-shaped weights inserted in gold collars around the periphery for poising and timing the balance. The system is thermally neutral as well as being unaffected by magnetic fields.

Levingston's may be a splendid system – Voutilainen has certainly put it into a splendid watch – but it is not always the best system that wins. There is still a lot of money riding on silicon.

Ulysse Nardin's exploration of new materials has extended, almost unbelievably, to diamond. An experimental watch produced two years ago had not only diamond escape wheels, but also a diamond balance spring produced by DRIE. The starting material was a wafer of polycrystalline diamond – normally used to make scalpel blades for eye surgery.

Patek Philippe also launched a watch with a silicon escape wheel at Baselworld 2005, using it with a conventional lever escapement in the ref. 5250 annual calendar. Again, they found that the smooth surface of the silicon made lubrication unnecessary.

In the balance

Meanwhile, many other companies have been using the laboratories of the Swiss Centre for Electronics and Microtechnology (CSEM). When Patek Philippe announced its 'Spiromax' silicon balance spring in January this year (used with the silicon escape wheel in the ref. 5350 annual calendar), it was revealed that the company was part of a consortium, including the Swatch Group and Rolex, investigating the use of silicon for watch components. News began to emerge that these components were also to be used by Breguet and Omega and that the Swatch Group's escapement manufacturer, Nivarox, was building a facility to produce them, set to open in September. At Baselworld this year Breguet revealed one new movement (calibre 777) with a silicon escape wheel and lever, and another (calibre 591A) that has a silicon balance spring as well. The 777, using a conventional Breguet spring, will become the basic movement in future watches with complications. Neither Omega nor Rolex will make any comment about their interest in silicon at the moment.

One of the fundamental problems facing watchmakers has always been the balance spring. If watches are subjected to a change of temperature, the elasticity of the spring will change, leading to errors in timekeeping. This problem was solved a hundred years ago with the discovery of nickel-iron alloys leading to development of Elinvar, used in modern balance springs. Its elasticity does not vary with temperature over the range that watches are likely to meet. Elinvar springs do, however, change their elasticity when exposed to magnetic fields. They are also relatively heavy and can distort permanently if a watch is dropped; hence the interest in silicon. But with silicon the elasticity/temperature problem is even greater. Patek Philippe solved it in the Spiromax by an oxidation treatment that coats the surface of the silicon with silicon dioxide. Breguet is said to have discovered a different solution, but won't say what it is.

Another company, De Bethune, has also produced a watch with a silicon balance spring and exhibited it during Baselworld in a boat on the Rhine. Interestingly, De Bethune has solved the temperature problem by learning to live with it. The watch has an unusual X-shaped balance with platinum weights on its arms that move towards the centre as temperature rises. This means that, as the silicon spring loses its elasticity, it has less work to do. The skill in producing such a watch is to match these effects as perfectly as possible.

Ideas bubble

As well as silicon, diamond, and nickel-phosphorous, another pair of new materials is being tried in the watch balance: carbon and quartz. This approach is being developed by Gideon Levingston, an Englishman living in France, and was exhibited at Baselworld in a new watch by Kari Voutilainen (see interview, Issue 18), a Finnish watchmaker living in Switzerland. Levingston will not reveal exactly how his 'Carbontime' balance springs are made, except that they are a type of carbon fibre. But he does say he can 'tune' them during manufacture to be a perfect match for thermal response of any type of balance. He has also designed a completely novel balance wheel. This is a disc of quartz (thermally inert) with horseshoe-shaped weights set at the periphery to allow poising and regulating. This may be a splendid system – Voutilainen has certainly put it into a splendid watch – but it is not always the best system that wins. There is still a lot of money riding on the silicon systems.

It is an exciting time for those interested in mechanical watches. After a long period of quiescence, watchmakers seem to be bubbling with ideas and the industry is giving a lot of thought, and investing considerable resources, on re-engineering the heart of the watch. In doing so, they are liasing with laboratory-based researchers and bringing the leading edge of materials science to the mechanical watch. At the same time, the search continues for more efficient escapements using conventional materials. Audemars Piguet showed one at SIHH in the new Tradition d'Excellence No. 5, and Jaeger-LeCoultre promised that it would reveal details of another in May. European watchmakers realise that there is no fundamental reason why the Chinese cannot produce top quality watches, as well as buy them. To maintain an edge, the European industry needs a continuing supply of patentable new technologies.