Center for Open Access in Science ▪ https://www.centerprode.com/ojsh.html
Open Journal for Studies in History, 2021, *4*(2), 55-66.
ISSN (Online) 2620-066X ▪ https://doi.org/10.32591/coas.ojsh.0402.02055s

Manufacture of Gilded Threads in the 15-17th Centuries

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Received: 28 July 2021 ▪ Accepted: 25 September 2021 ▪ Published Online: 4 October 2021

Abstract

Since ancient times, gilded threads have been used to decorate textiles in different cultures around the world. In the article, the author examines the threads manufacturing in the 16-17th centuries in Europe and Western Asia, trying to answer two, as it seems to him, the main questions: what was the method of gilding and what was the method of cutting if width error was less than 10 μm. It is assumed that the main gilding method was the diffusion one, and the main cutting method used rollers and a sharp blade at a small angle. The first one has not been proven but the second has been proved. The article lists all marks, diffusion and adhesion coefficients, human angular resolution, and much more.

Keywords: gilded threads, diffusion gilding, cutting into strips.

1. Introduction

Gilded threads (golden, fil d'or, goldfaden) are strips of metal used either in the form of a separate thread, or twisted in a spiral (spin) around a silk core (Figure 1). Since ancient times, metallic threads have been used to decorate textiles. There are metal threads in every museum where textiles are exhibited. Typical thread widths were 130-420 μm with thickness 3-15 μm in the 15-17th centuries. Substrate metals are copper, copper alloys and silver. The edges of the threads are straight and almost without traces of the instrument (a trace remains, of course, but a few micrometers). Some of the threads are gilded on two or one side. For some reason, gold threads were more popular in French, in German, etc., but not in English.

The author studied the characteristics of the threads from both literary sources mainly (see references) and samples provided by Ms. Vasilyeva. The last ones were cut from the 15-17th centuries textiles from Iran, Turkey, Crimea and Russia, but it is impossible to answer which threads were imported or made in the country of origin.

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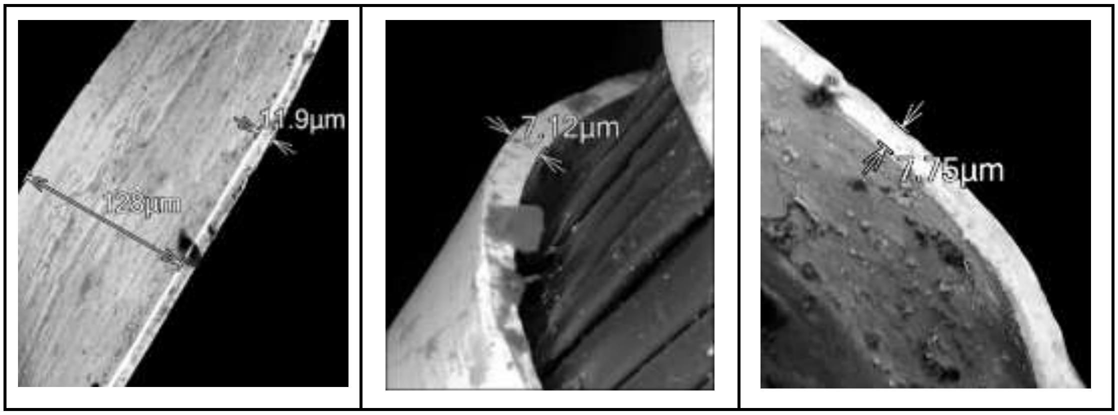

Figure 1. Samples (5-10 µm) of thread

As it seems to the author, the study of manufacturing techniques should answer two questions first of all: the method of gilding the threads and the method of cutting along. Unfortunately, there are not too many ancient texts. This is first of all “De la Pirotechnia”' by V. Biringuccio (1540) (Biringuccio, 1990), “Essay des Merveilles de Nature et des plus Nobles Artifices” by E. Binet (1632) and much later “Die Entwicklung des Maschinenwesen und die Frauenarbeit” by A. Schwarz (Schwarz, 1928) and “Nordisk guld spinding og guldbroderi i den tidlige middelalder” by S. Larsen (1939) (Larsen, 1939).

V. Biringuccio in his very cognitive book “De La Pirotecnia” drew how two goldsmiths forge a gilded sheet of silver (Figure 2). The sheet will then be cut into strips and used to produce gold, spin as it was called, i.e., will be twisted in a spiral around the core. Biringuccio writes that it was “women who are much more patient than men” who knew how to cut into narrow strips with long, flexible and sharp scissors, as long as the length of a strip of gilded silver. Note that the word “scissors” (forbici) is found only on this page (p. 141) and it is not a fact that Biringuccio was allowed everywhere he wanted.

Figure 2. Goldsmiths forge double sheet (Biringuccio, 1990)

Schwartz’s book is devoted primarily to the history of thread spinning and others like it, but a couple of drawings are interesting, for example. There are two funny paragraphs in Larsen’s book in its translation of K. Finch (Finch, 2005):

> “*Sofus Larsen ends this chapter by describing how the Greeks learned about gold-worked textiles from the prizes of war brought back by the army of Alexander after the fall of Persia. Persian and Babylonian weavers had long before begun to fill the vast stores of Eastern courts with costly excesses of precious garments made from silks woven with figured designs or embroidered with gold and silver and precious stones”.*

Another passage:

> "*Flat Cyprian gold wire may have been exported already by about 1200 but the method by which it was flattened to achieve comparison with or battu or Insegold remained a secret for a very long time. For more than 500 years after its invention, there was no literature that concerned itself with how it was done. It is not mentioned in Biringuccio's Pirotechnia of 1540, although this was compiled at about the time Cyprian textile workers began to settle in Venice, nor in any other place until the middle of the eighteenth century, when the art of flattening thread had become a relatively common occupation, not only in Italy, but in France and Germany as well*".

Of course, that translation is only Fitch's responsibility and is not proof of anything, just a hint. The hint is: the Greeks adopted the manufacture of gold threads during the time of Alexander the Great (4th centuries BC) and for 500 years the manufacture of flat threads remained a Cypriot secret (1200-1700) almost 2000 years after its adoption.

There are modern papers (Soviet authors too (Laman, 1989)) where a metal thread is made from a wire. Many researchers (Jaro & Toth, 1991; Ward, 2008; Hackea et al., 2005; Katarzani, 2014) write about (a) cutting off threads from a long wire, and about (b) the gilding method (without specifying the method itself). Many of them have noted that textile threads have become both longer and better with the invention of wires. For example, Anna Katarzani (Karatzani, 2014) when she writes about cutting simply refers to V. Biringuccio, and when gilding method whites the following: "*goldsmiths produced alloys of gold with silver and copper and invented methods of gilding less precious metals*" (p. 10).

During review of literature, we found almost nothing with the terms "diffusion" and "gilding" except for the articles by Balta et al. (2015), which use PIXE (Particle-Induced X-ray Emission), necessary software and therefore speak directly about diffusion welding: "*The gilding layer is separated from the silver bulk by an interface layer resulting through atomic diffusion of silver into the gold, which lead to the conclusion that the methods used for gilding were probably either the diffusion bonding or the fire gilding*" (Abstract).

In this article research methods are natural science ones, spectrography, etc. As an additional example, a gilded disc from the British Museum is used. To determine the parameters of diffusion gilding and why it was used for gilding threads, a comparison was made with gold leaf gilding and mercury amalgam. If something is proved it is a theorem and lemma, proof of the theorem is given, the lemma is considered obvious.

There are only two workshops that produce gold threads in England today (Carpenter, 2020).

2. Inventions that could change thread making

Several inventions may have influenced the manufacture of threads. Many modern researchers believe that metal threads were made from wire therefore the first one is the drawing of non-ferrous wire and, later, the invention of the draw plate itself (Figure 3). Wire drawing is believed to have originated around the 20th century BC, when wire was drawn to make jewelry. The small number of wires draws that have survived to this day, when (it would seem), irrefutable evidence of the drawing process exists, is due to the processing of the metal of the dies. Using a die with a cone-shaped hole, the wire could be pulled up to half a square millimeter in area (0.8 mm diameter). However, the wear of the wire dies was significant, most of the dies "lived" only a few wire pulls depending on the length of the wire. Since the dies were made of precious metal and were used for only a few drawing pulls, they were most likely subsequently recycled (reused). In any case, the wire before and after the invention of the dies was different.

Rollers and roller mills are another invention. It is believed that it was Leonardo da Vinci (1452-1519) who first drew rollers, but in the literature, there are descriptions of the use of rollers by jewelers a hundred years before Vinci. Metallurgists only adapted not their invention for cutting hot iron, but it was the jewelers who were the real inventors of rolling and cutting machines. “During the fourteenth century, small, hand-driven rolls about half an inch in diameter were used to flatten gold, silver, and possibly lead” (Roberts, 1978). Rolls were used not only to make a wire or plate flat and thin, but also to move parallel to avoid possible misalignment. Leonardo da Vinci, for example, drew so-called perspectives, which required parallel movement. Various musical instruments were in use – organs, harps, lutes – created using such a movement. In 1575, the Sienna printer Francesco Rampasetto invented the *scrittura tattile*, a machine for printing letters on paper; maybe the paper was fed in it with rollers.

Figure 3. Drawing wire through a die fixed on a table, Nuremberg, 1625 (Hausbuch 1625)

An invention that could be used to make threads was an obsidian blade. Obsidian (rock glass) was well known, and in particular the Sicilian one. True, by now the use of obsidian blades in the manufacture of threads has almost been forgotten: either such blades were not used at all, or the use of obsidian was especially conspiratorial. The main minerals forming the obsidian mineral are quartz and feldspar. Obsidian is chemically and morphologically extremely variable, being a mixture of different minerals. Obsidian is far from the hardest mineral (5.0-5.5 out of 10), but it is the sharpest. If a steel knife can be sharpened to a minimum blade thickness of 0.05 µm then an obsidian blade, correctly split, can be only 3 nm thick. In any case, there was a blade that cut metal strips without any marks and with a rectangular side. Of obsidian or steel but some kind of sharp blade was used to cut.

The geometry of the cutting edge of knives and other blades has also been improved. Three main characteristics of the edge can be distinguished: (a) the angle of inclination, (b) the radius of the tip, and (c) the thickness of the blade if it is 1 mm back from the edge in the form of a cone (in the manufacture of cutlery, this bevel is called a “channel”). Typical angles are 15° for blades, 20-30° for microtome knives (see below) and 30-40° for kitchen knives. The radius is 5 µm for a scalpel and 17 µm for a new safety razor (34 µm for a worn one).

A little later, the Microtome, a special device for cutting very thin slices of material, known in biology as a cross-section, was invented. At the dawn of light microscopy (before the 17th century), sections of animals and plants were obtained using blades only. It was important that the thickness of any specimen was less than 100 µm in order to view the specimen in transmitted light. The first mechanical device was proposed by George Adams Jr. in 1770 and later improved by Alexander Cumming. The device was moved manually, the specimen was placed in a cylinder, and its sections were obtained from above using a handle. The microtome uses steel, glass or diamond blades, depending on the sample to be cut and the desired thickness of the cut parts. The microtome is listed here only to get an impression of how engineering thinking developed during this time.

3. Gilding methods

In ancient times, only seven metals were known: gold, silver, copper, tin, lead, iron and mercury. Zinc, cadmium, etc. were found as chemical compounds in the composition of minerals only. The eighth metal was discovered only in the 13th century (arsenic). Silver (in part) and gold (especially) do not allow corrosion and therefore were actively used as a measure of value, for making coins and in jewelry. The first gold coins were minted in Lydia (Asia Minor) around the 6th century BC.

Let's arrange the gilding methods before the invention of electroplating by appearance of the main component or main property. From about the 30-40th century BC gilding meant gilding with gold leaf (gold leaves are glued to the surface with organic glues). In the 30th century BC soldering on soft (tin and lead) soldiers was invented (MM # 22.1.61). From the 12th century BC diffuse bonding was used. From the 6th century BC mercury amalgam has been applied for gilding. From the 1st to the 10th century AD in the New World and from the 12th century AD in the Old World, nitric acid was invented, which can be used for gilding by depletion, like hydrochloric acid and pieces of chlorine gold. Mr. Oddi lists gold foil also, but forgets about soldering, probably because he writes about statues first of all (Oddy, 2000). Can we accurately identify the gilding method by its composition (see Table 1)?

Table 1. Gilding methods and composition

	Gilding methods	**Composition adds**
1	Foil gilding	organic glue
2	Leaf gilding	organic glue
3	Solder gilding (Humpston, Jacobson, 2004)	tin and lead
4	Diffusion gilding (Aufderhaar, 2009)	—
5	Mercury gilding (Anheuser, 1997)	mercury
6	Depletion gilding (Sáenz-Samper, Martinón-Torres, 2017)	—
7	Pieces of gold from gold chloride	—

Gold leaf, sometimes called gold foil, is gold that has been beaten into a very thin sheet. When depletion gilding is used, a special surface layer appears that can be detected.

According to the EDS, there is absolutely nothing between a gold leaf and a thread: no organic matter, no tin with lead, no mercury. There is no surface layer and gold does not appear in pieces also. It may feel like we've proven something, but we do not know the error. EDS (Energo-Dispersion Spectrometer) is XRF an electron microscope that uses photons generated by the deceleration of the beam electrons, as well as vacuum. Regular custom EDS is installed together with its own software and it is difficult to calculate the error, only by calibration. Lemma 1: If we know the result of measurements V by any device but we do not know the error σ of measurements and even the origin of the error, then the interval of true values V ± σ can be any. We cannot use an EDS because we do not know the error (Towett et al., 2013).

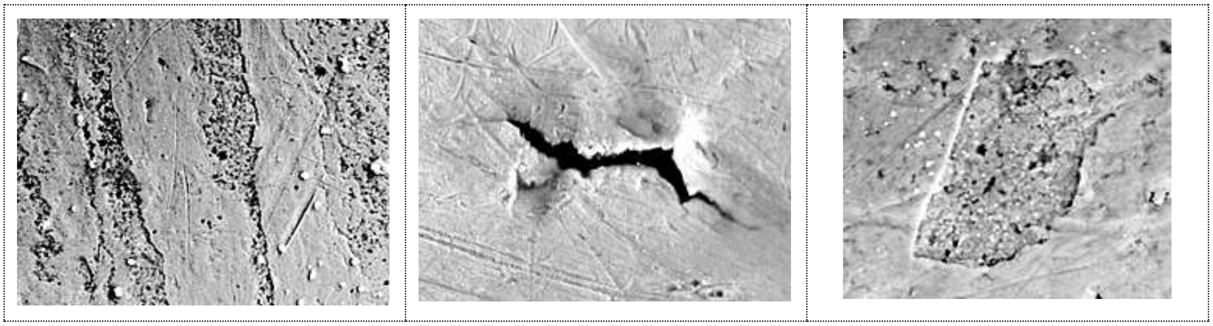

Figure 4. Defects in gilding: defects are located along the strip, hole, hole edges

Gold may appear as a sheet or as a layer. You can see it where there are some gilding defects (Figure 4). It is better to cross out unnecessary lines (see Table 2).

Table 2. Gilding methods and gold appearance

	Gilding methods	The appearance of gold
1	Foil	~~sheet~~
2	Leaf gilding	think sheet
3	Solder gilding	~~sheet~~
4	Diffusion gilding	think sheet
5	~~Fire gilding~~	~~coating~~
~~6~~	~~Depletion gilding~~	~~coating~~
~~7~~	~~Pieces of gold from gold chloride~~	~~pieces~~

Finally, the number of bonds between gold and thread can be everywhere or at separate points, often or rarely. You can see where there are gilding defects again, but not in this case. In this case, nothing is visible (see Table 3).

Table 3. Gilding methods and adgesia

	Gilding methods	Bonding points
	Foil	~~rarely~~
1	Leaf gilding	~~rarely~~
2	Solder gilding	~~rarely~~
4	Diffusion gilding	often?
5	Fire gilding	~~everywhere~~
6	Depletion gilding	~~everywhere~~
7	Pieces of gold from gold chloride	everywhere

When the diffusion coefficient is estimated the error can be several orders of magnitude. The diffusion coefficient is equal to the amount of a substance passing through a unit area per unit of time due to the thermal motion of molecules with a concentration gradient equal to unity. There are four types of diffusion, they are called surface diffusion, grain boundary, interdiffusion, and tracer diffusion, each type has its own coefficient. We are only interested in diffusion through the surface (the first one), which creates the gilding. Five to ten minutes (contact time) is ~ 10^2 seconds, i.e., the diffusion coefficient must be at least 10^{-3}, and the diffusion coefficient is 10^{-8} — 10^{-10} for copper and gold (Butrymowicz, 1974). In addition to temperature and pressure, the bond area also exists and can also be added to the equation as another (dimensionless) coefficient that is proportional to the contact area. Moreover, this coefficient can be anything, for example 10^{-6}.

What should be the T (temperature), P (pressure), t (connector time) and A (bond area) for gold to bond with another metal to make a gold thread? High temperature (T) destroys the film of deposited air and impurity (in our case) and increases the diffusion rate, while pressure (P) reduces interatomic distances. We live at a pressure of about 0.1 MPa (or 1 bar, or 10 meters of water). The elephant, as well as the lady's heel, generates 0.5 MPa, the blow of the jeweler's hammer generates several MPa, the hydraulic machine generates several hundred MPa. The sheet must be cut into strips, the binding force must be greater than the cutting force of the sheet, the metal underneath and their bond. The estimate of the quantity can only be empirical. The dependence of the gold-gold bond on temperature and pressure (excluding the bond area, most likely some kind of erosion was taken as an average) is shown in Figure 5 (Humpston & Baker, 1998).

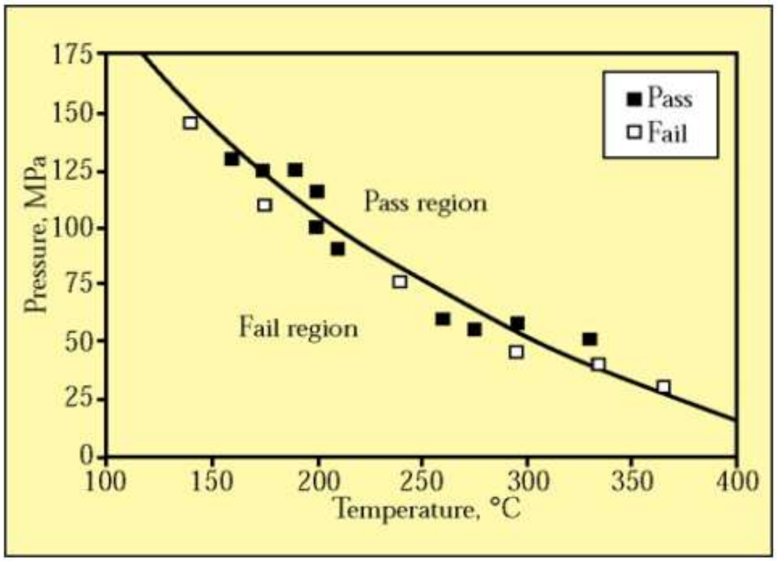

Figure 5. Bonding gold to gold (Humpston, Baker, 1998)

Why was diffuse gilding used for threads? An individual can do as he wants, but in history if not the only method has been used for many centuries, there must be advantages to this method. We see three ones: consumption of gold, adhesion of gold and ease of use (when the metal is only a sheet). We compared the properties of diffuse gilding with gilding and amalgam gilding (see Table 4).

Table 4. Comparison of the three methods of gilding

Characteristics / gilding methods	Leaf	Diffusion	Mercury
Innovation	30-40th century BC	12th century BC	4th century BC
Adhesion	1	2	3
Gold consumption	2	1	3
Ease of gilding a sheet of metal	2	1	3
Toxicity	0	0	3

To evaluate adhesion numerically you need to specially prepare but an analog method (more or less) is suitable here. Mercury amalgam has very large adhesion, gold leaf has very small adhesion. Diffusion gilding is located in the middle.

1-2 µm was the thickness of the leaf in Modern ages, while the thickness of the gilding in the studied samples was 0.1-0.2 µm. The thickness of the amalgam layer was 2-10.

When gilding metal in the form of a sheet, all three methods are approximately the same. The easiest way is to gild with mercury, then gold leaf in complexity, and finally diffusion, when it is necessary to heat and forge, but again, all three methods are about the same.

Mercury amalgam is unmatched in toxicity (60 people were poisoned with mercury during the gilding of the Dome of the Cathedral of St. Isaac of Dalmatia in St. Petersburg).

An example of diffuse gilding is a disc (Figure 6) from the British Museum (Oddy et al., 1981). Shooting with an electron microscope showed that the silver foil (12 um thick) on one (front) side is covered with 3 µm of gold, and on the other (back) side of the gold layer there are deposits of corrosion products, including silver, sulfur and chlorine. The "legs" of gold penetrate into silver (Fig. 5b). This is a property of silver, rather gilded in the laboratory, where a sheet of gold was polished into a sheet of silver at room temperature. The gold content also changes: 45% on the surface of the part and 10% on the surface of silver.

Figure 6. (a) British Museum # 134907; (b) "Legs" of gold

4. Cutting methods

A metallic thread is a flat (width to thickness ratio of about 30) wire, gold-plated on one or both sides. Suppose some wire pulls through the rollers had to be divided into several parts and run through the rollers again. The edge of such a wire would be "naturally rounded", but the edge is straight. Suppose otherwise: the wire was not divided into parts and simply passed through a die to obtain the so-called Profile Wire.

Lemma 2. If the wire is rolled with simple straight rollers (non-profile), its edge will be "naturally" rounded ((Wire Facts: Edges and Corners) and others).

Note that the cut adhesion is higher than the adhesion of the gold plating, otherwise the gold may peel off. The cutting edge of the blade is a few µms. The depth of the deformations is approximately equal to the width of the blade, so it is better to drag the blade rather than press it (Lemma 2). Cutting off the metal tape with (blunt) scissors or a knife would have left marks, but these were not detected during the investigation (Lemma 3). In addition, hand scissors would create an increase or decrease in the width of the thread.

Lemma 3. Then the blade is sharp (Reyssat, 2012) and the angle between the blade and the cutting plane is small (Atkins, 2009), so blade will leave very few marks

The sheet will be cut into strips to produce gold thread (spin as it was called), i.e., will be twisted in a spiral around the core. Biringuccio writes in his book that it was "women who are much more patient than men" who knew how to cut into narrow strips with long, flexible and sharp scissors, as long as the length of a strip of gilded silver. Note that the word "scissors" (forbici) is found only on this page (p. 141) and it is not a fact that Biringuccio was allowed everywhere he wanted. The earliest known scissors appeared in Mesopotamia 30-40 centuries ago.

Lemma 4. Traces characteristic of scissors at the edge of the cut will remain if you cut something off with scissors (two blades with a decreasing angle between them) (Petraco, 2011).

Lemma 5. If, when cutting the sheet along with scissors of length A, the error in the width of the strip is equal to B, then the angular error is 360 B / A in degrees. For example, if A = 40 cm (very long scissors) and B = 10 µm (it is real), then the angular error is 0.009 degrees. If there is nothing beyond measure then the angular resolution is equal about 2 * (angular error) or 0.02 degrees. Naked eye resolution of any human is 0.2-0.3 degrees; scissors are impossible when cutting.

There are many views on the problem according to which the cutting method considered to be the main one is not suitable. Another sequence of actions during manufacturing is possible in our opinion:

- drawing a wire from a metal rod Ø1-1.5 mm,
- forging or rolling wire into a sheet 20-25 centimeters wide,
- covering with a sheet of gold (on one or both sides),
- heat,
- forging (or rolling),
- cutting into two strips of any width each using rollers and a blade,
- cutting the resulting strip into two new strips,
- cutting is finished when the strip width is ½-¼ mm as required.

Figure 7. One of the possible methods for cutting metal sheets in the 15-17th centuries

If the cutting was like in Figure 7, the master divided the sheet in half over and over again until a width would be about 1/4 millimeter. We will assume that the angle between the two rollers is small, and the rollers themselves are perfect and free from defects (both have been used for centuries). Other reasons are important too, such as the curved sheet and the master's ability to draw the middle. It is difficult to say anything about the first one, but the second error is 10-20 times less than the strip width (when you are looking for 5, 4 and 6 are hardly possible, rather 4.5 or 5.5). Until, of course, the limit of the naked eye (about 60 µm) is reached.

5. Conclusion

As a result of research, the author almost proves that diffusion was used for gilding threads in the 17-18th centuries. Comparison of diffusion gilding with leaf and mercury amalgam was made. It is assumed that the main invention that changed the manufacturing technology of metal threads was not wire pulling, but rollers and, consequently, a method of parallel and non-deforming cutting into strips. Moreover, it was jewelers who were the first to use rollers, and metallurgists added them much later. It was assumed that not scissors were used, but rollers and a cutting blade were used to force the lamellae to move strictly parallel. The blade should be positioned at a slight angle to the plane in order to cut with minimal effort and not leave marks that are not there. The widths of the two new lamellas were not the same. The latter assumption can be proved by measuring the width of the lamella over a length greater than the longest scissors.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public commercial, or not-for-profit sectors.

The author declares no competing interests.

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