SIAMITE® Lab-Created Ceramic - breakthrough gem reflection material

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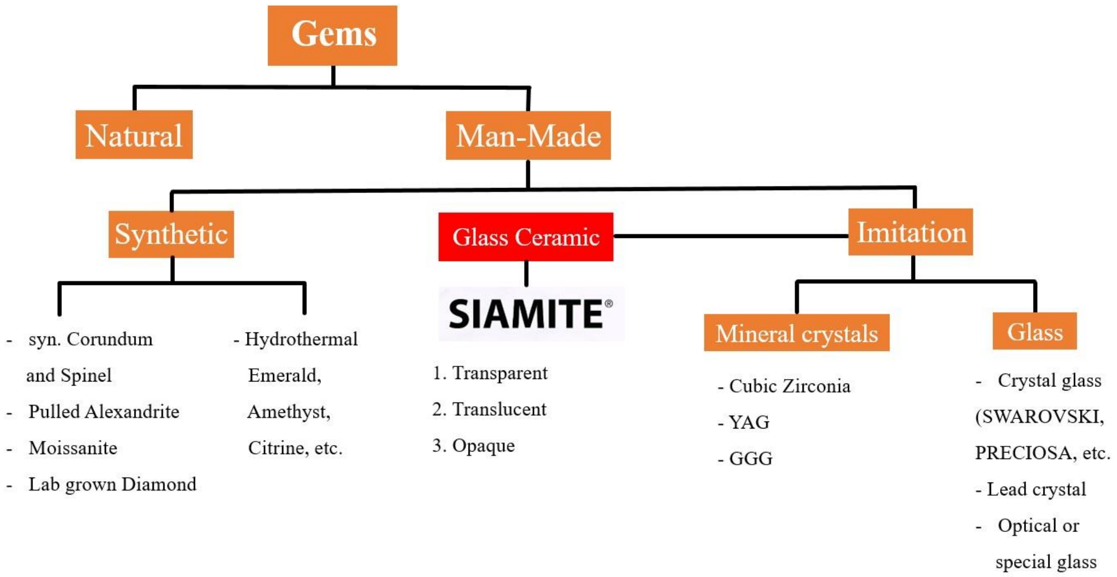
Gems are an essential component of jewelry. Along with natural ones, man-made stones are also widely used. These artificial materials are divided into **Synthetic Crystals** and **Imitation gems**.

There is no generally accepted classification of artificial stones used in the jewelry industry, but it can be roughly depicted in the form of the following scheme:



The physical and optical properties, crystal structure and chemical composition of the **Synthetic gemstones** are the same as those of their natural counterparts: sapphire, ruby, spinel, moissanite, lab-created diamonds, alexandrite, hydrothermal emerald, amethyst, citrine, etc. **Imitations** include **glass** (crystal glass, special optical glass), **man-made minerals** that have no analogues in nature (Cubic Zirconia, YAG, GGG, etc.), **ceramics**, **organic** and some other materials. **Ceramics** are inorganic polycrystalline materials obtained from molded mineral masses in the process of high-temperature sintering.

Natural and man-made gemstones are the **mineral crystals** (synthetic and imitations) which have a fixed proper chemical composition and a crystalline grid. Morphologically, the crystal is characterized by the presence of flat faces and sharp edges and corners.

Glass can be defined as **an amorphous solid or completely frozen liquid.** Crystal glass and special optical glass, even from very famous brands (Swarovski, Preciosa, Murano,…) are not crystals, but rather a type of glass It is because crystal glass does not contain a crystalline structure.

1.Traditional imitation gems and the analogy of their production methods with the genesis of natural gemstones.

Geologists and especially petrologists and mineralogists initially studied and tried to understand the conditions and mechanism of origin of natural gems. Once the genesis of gems became clear, some experimental scientists were able to artificially synthesize crystals of many natural minerals, first in laboratories and then in factories. So, it’s not surprising that the technologies used to produce man-made stones are very similar to the genesis of natural gems.

Usually, when a molten material is cooled it solidifies in a crystalline state at the freezing point and the crystal size primarily reflects the rate of cooling. If the melt is cooled below its normal freezing point without crystallizing, it goes into a supercooled liquid state and then solidifies into glass. This is typical of natural processes as well as industrial or laboratory gemstone production.

Natural gemstones are part of rock-forming minerals. They were formed because of such geological phenomena as magmatism, metamorphism, and related pneumatolytic & hydrothermal processes.

Magmatic, or igneous rocks are formed through the cooling, crystallization and solidification of magma or lava. When magma solidifies into rock deep within the Earth's crust, the crystals grow large in size and form coarse-grained crystalline intrusive or plutonic rocks (granite, diorite, gabbro). Large crystals of amethysts, citrines, topaz, beryl, and other gems crystallize from hot hydrothermal solutions that separated from magma in the last stages of its crystallization.

Metamorphic rocks are solid due to recrystallization of pre-existing igneous and sedimentary rocks when immersed to great depths in areas of high temperatures and pressures. Greenland rubies, Brazilian and Ural emeralds and many other gems are genetically related to metamorphic rocks.

The production of many **man-made minerals** is very similar to the slow crystallization of magma at depth. The molten original charge is cooled to the crystallization point and this temperature is maintained until the melt (sapphire, ruby, spinel, YAG, GGG, pulled alexandrite, cubic zirconia, …) or hydrothermal solution (hydrothermal emerald and quartz) is completed.

Industrial production of glass (for costume jewelry, bottles, lamps, lenses, window or building construction…) consists of the following stages: preparation of batch (silica sand, limestone, and others); melting in furnaces; casting with **rapid cooling** until solidifying, and annealing.

A similar process occurs in nature. When magma reaches the earth's surface it is then called lava. Lava may be erupted at a volcano on land or underwater. Under such conditions, cooling is faster, and the resulting volcanic rocks (basalts, andesites, rhyolites, etc.) are usually characterized by a combination of volcanic glass, small crystals (microlites) and larger ones. Lava that cools extremely quickly (underwater) may not form crystals at all. The resulting rock is called **volcanic glass** or **obsidian**.

2.Glass-ceramics - a new class of imitation gems: its advantages compare with mineral crystals and crystal glass.

The main problem inherent in all man-made minerals is color variation (except colorless). This is because the composition of the melt or solution at the end of the crystallization process is different from the initial one. **Colored glass** does not have such a problem **-** it is very homogeneous. But it is inferior to **mineral crystals** in brittleness, hardness, luster, and is easily destroyed by thermal shock.

Well understanding all the advantages and disadvantages of each of these materials, the author set himself the task of finding or creating a new material that combines only the best properties: uniformity of color like glass, and hardness, density, refractive index, and brilliance as in most natural gems. This search was successfully completed approximately 18 years ago.

Formica Crystal Systems Co. Ltd. was the **first in the world to develop and begin to produce** at its factory in Thailand a completely new for jewelry industry material, imitating gemstones **- glass-ceramic** (protected by US Patent No.: 9,801,435 B2 and 25 other countries)**.** Not classifiable as glass or as crystal (mineral), glass-ceramics represent a completely new class of materials. **Glass-ceramics are ceramic materials formed through the controlled nucleation and crystallization of glass.** It is important to emphasize that this crystallization occurs precisely in a solid body – like the metamorphic recrystallization of rocks in the Earth's crust. We can say that an analogue of transparent glass-ceramics in nature can be partially crystallized obsidians and volcanic rocks.

Glass-ceramics are manufactured in two production steps. In the first step, a batch of exactly defined composition is melted and formed using standard glass manufacturing techniques. In the second step, the glass articles are subjected to a specific heat treatment to produce a glass-crystalline material with properties which are very different from those of original glass. **This breakthrough hybrid material combines the valuable properties inherent in crystals and glass, which cannot be found in glass or crystals alone** **(Holland and Beall 2020).**

Glass-ceramics are developed and implemented in various fields of science and technology. Their composition is highly variable depending on the application and the required properties. Many applications of glass-ceramics are based on their superior resistance to failure due to thermal shock. It is primarily determined by the low thermal expansion coefficient both in the crystalline phase and in the residual glass **(Bach and Krause 1995).** They are used for cookware, electric stove tops, telescope mirrors and missile radome (rocket nose cones) **(Fig.1).**

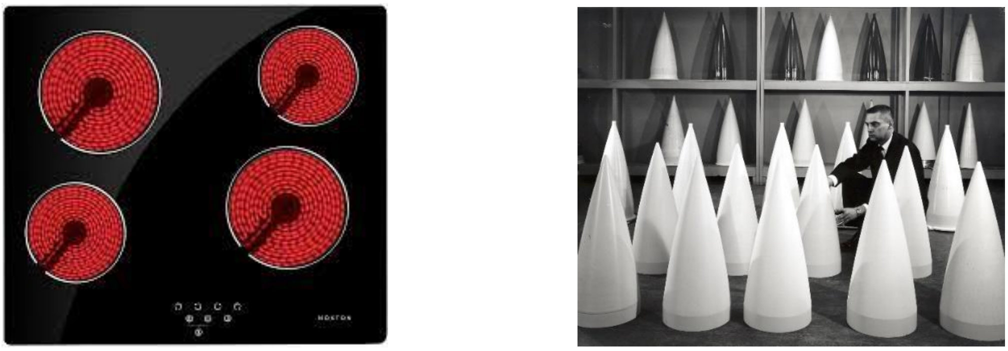


Figure 1. (a) NOXTON glass-ceramic cooktop (www.amazon.com). (b) PYROCERAM R glass-ceramic missile radomes (www.corning.com).

It is known that many natural and synthetic crystals and glasses cannot be used for the **"Setting Stones in Wax"** method because they crack or change color under the influence of a high-temperature melt of gold, silver, bronze, or brass. **Resistance to thermal shocks** was the main reason that forced the author to develop and produce special glass-ceramics for the jewelry industry.
The second very important advantage of glass-ceramics is the relative **uniformity and homogeneity of color**; that is, from the absence of a significant color variation both in rough material and in faceted stones (with rare exceptions). This is due to the nature of this material, its composition and structure.

3.SIAMITE® Lab-Created Glass-Ceramic: chemical composition, physical properties, classification by transparency, spectrum of colors.

From the huge variety of existing types of glass-ceramics, we managed to choose a composition that allows us to obtain a new material with such optical, mechanical, and other physical properties that are as close as possible to the most popular natural gems - emerald, topaz, tourmaline, spinel, garnet, and many others.

Cordierite glass-ceramic of the **SiO_2-Al_2O_3-MgO** system was chosen as the most optimal composition **(Fig.2).**

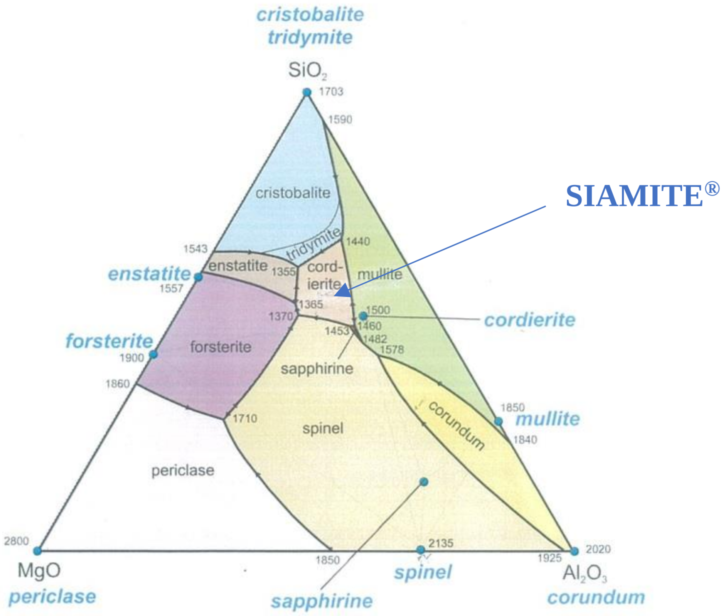


Figure 2. SiO2-Al2O3-MgO phase diagram (Levin et al. 1964).

Formica Group officially registered this new material under the trade name **SIAMITE®** (Reg. No. 5,531,572 in US Patent and Trademark Office). There were two reasons for this: 1) chemical composition of the main components **Si**O2, **A**l2O3, **M**gO – (**SiAM**), 2) production was set up in Thailand historically known as **SIAM.** In addition to the main components mentioned above, the material contains small amounts of alkali as well as some coloring, fining and nucleating agents. However, before the official registration of SIAMITE®, it was named: **nanocrystal and nanogem.** These names are now very common and come from the **nano**sized (about 10^{-7} cm) **crystals** grown inside an amorphous substance.

The presence of nanocrystals of spinel (gahnite), rutile, zirconium titanate and others in SIAMITE® is proven by X-ray diffraction analysis **(Fig.3)**, variations of physical properties,

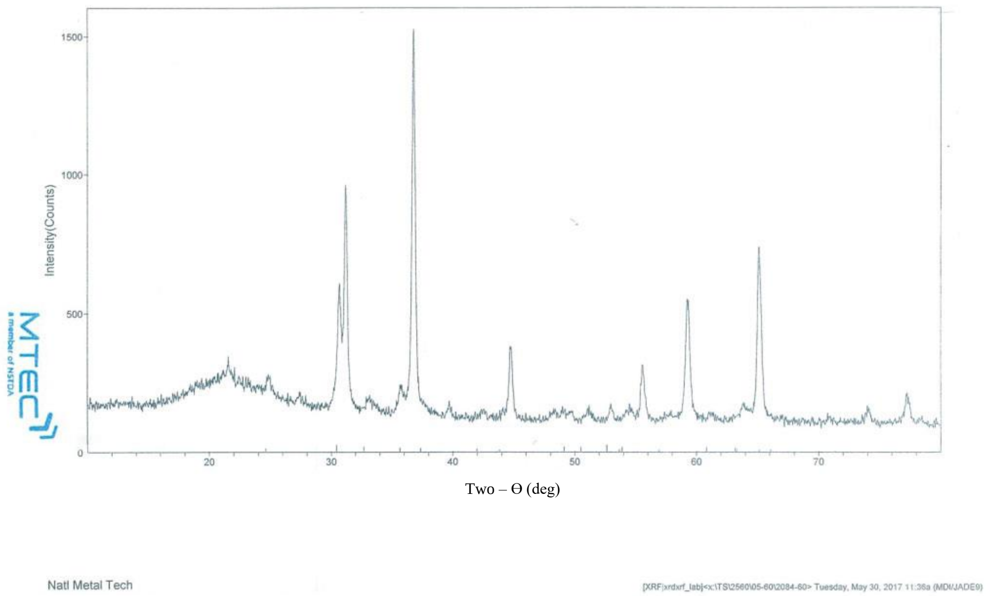


Figure 3. X-ray diffraction pattern of Emerald Green SIAMITE®, confirming the presence of nanocrystals of spinel, rutile and zirconium titanate (analyzed in MTEC, Thailand).

changes in the absorption spectrum, higher density, transformations in the refractive index and enhanced mechanical properties. Special studies revealed that glass-ceramics typically have a 20%-30% increase in hardness when compared to the original glass (**Molla AR, Rodrigues AM, et al. 2017).**

Thus, SIAMITE® is a nanocrystalline glass-ceramic material, comprising nanosized crystals of spinel and other minerals (depending on color) uniformly distributed in the amorphous high temperature aluminosilicate glass matrix. The size and concentration of nanocrystals affect the degree of transparency of the material and its color. As they increase, the transparent material becomes first translucent and then opaque.

According to transparency, SIAMITE®, produced by Formica, is divided into 3 groups: **Transparent, Translucent and Opaque.** In transparent SIAMITE®, the characteristic sizes of nanocrystals - spinel, rutile, zirconium titanate and other minerals do not exceed 10 nanometers (5-10 nm). In translucent varieties (opals or opalites) they increase up to 25 nm, and in opaque varieties they exceed 25-30 nm. Accordingly, the total volume of nanocrystals grows relative to the residual amorphous mass (glass).

The Transparent SIAMITE® catalog consists of 108 color groups, and each of them contains a spectrum of colors from very dark to very light - a total of about 750 colors (**www.formicagem.com**). They completely replicate the brightness, color, and density of the most widely used gemstones: **Topaz** (London Blue, Swiss, Sky, Brown, and Tea color), **Tourmaline** (Pink, Rose, Red, Green), **Garnet** (Demantoid, Tsavorite, Spessartine, Rhodolite, Pyrope, Almandine), **Spinel (**Blue, Gray, Pink, Red), **Aquamarine, Emerald, Sapphire, Ruby, Paraiba**, **Tanzanite, Kunzite, Amethyst, Citrine**, and others. **(Fig. 4)**.

Figure 4. SIAMITE® reflections of the most common natural gemstones.

This is due to their physical properties - hardness of **7-7.5**, density **3-3.3 g/cm3**, refractive index **RI = 1.61-1.63** - very close to the natural gems mentioned above **(Tabl.1).**

Properites	CZ	Crystal-glass	Natural Topaz	Tourmailne	Emerald	SIAMITE®
Hardness	8.0 -8.5	5.5 -6.0	8	7.0 - 7.5	7.5 - 8.0	7.5
Density (g/cm^3)	5.65 - 6.00	2.7	3.00 - 3.30	3.1	2.67 - 2.78	3.00 - 3.30
Refractive index (RI)	2.15 - 2.18	1.5 - 1.55	1.61 - 1.63	1.61 - 1.67	1.57 - 1.58	1.61 - 1.63
Even Color	White CZ only	Yes	Occasionally	Occasionally	Occasionally	Yes
Color Spectrum	Limited	Large	Limited	Limited	Limited	More than 750 Colors
Wax casting	Some color	No	No	No	No	Yes
Brittleness	High	Very High	High	High	High	Low

Table 1. Comparison of the physical properties of SIAMITE® with natural tourmaline, topaz, emerald, crystal-glass (Swarovski, Preciosa,…) and Cubic Zirconia.

The ability to produce many colors, shades and saturations is another unique feature of SIAMITE®. This allows to produce a wide range of imitations of natural gems from different deposits: emeralds from yellowish green to bluish green (Zambian, Brazilian, Colombian, and other types); sapphires from gray blue to violet blue (Australian, Ceylon, ...); amethysts from violet to purple blue and purple (Brazilian, Uruguayan, ...), topaz (London Blue, Swiss Blue, Sky Blue) and so on **(Fig.5).**

Figure 5. SIAMITE® Topaz reflections - Greenish Blue, Swiss Blue, Sky Blue and London Blue color.

And the abundance of choice in saturation allows you to have cut stones of any shape with the same color in the range from 0.8 mm to 20 mm at least **(Fig.6).**

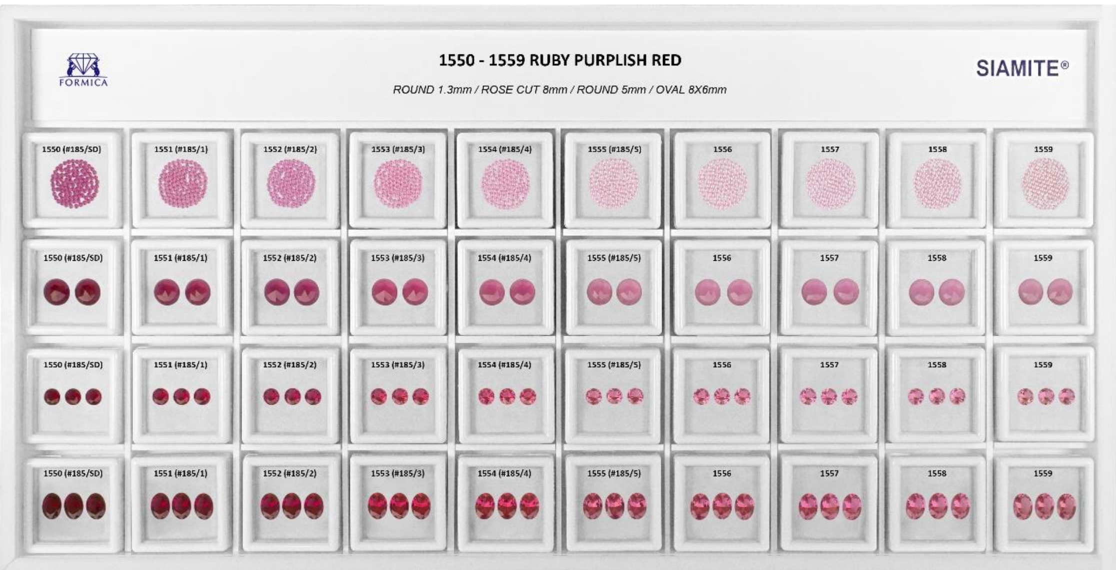


Figure 6. SIAMITE® Ruby reflections of different saturation. Color group 1550-1559. Sizes of cut stones: round 1.3 and 5 mm, rose cut 8 mm, oval 8x6 mm.

Most importantly - all these transparent **gemstones reflections,** regardless of shape and size, are **resistant to thermal shocks.** This is clearly visible in the photo of the silver jewelry tree presented below **(Fig.7).**

Figure 7. Silver jewelry tree produced using the lost wax casting process.

The uniqueness of the properties of glass-ceramics allows you to get an unlimited range of varieties not only in color but in transparency as well. This is achieved by controlling changes in the nanocrystal`s concentration and particle size. Now, the **Translucent and Opaque SIAMITE®** catalog is limited to only 200 varieties but can be greatly expanded if necessary (**www.formicagem.com**). They imitate such decorative gemstones as **moonstone, cacholong, chrysoprase, jade, lapis lazuli, turquoise, black spinel**, and others **(Fig.8).**

Figure 8. Translucent and Opaque SIAMITE® Moonstone, Cacholong, Chrysoprase, Jade, Lapis Lazuli, Turquoise reflection. Cabochon size 12 mm.

It is important to consider that the degree of transparency is determined not only by the size and concentration of nanocrystals of spinel and other minerals, but also by the thickness of the cabochon or cut stone. That is, a stone that is translucent, for example, in 3mm will be almost opaque at 8-10 mm. Accordingly, as the transparency of the stone decreases, its color gradually changes **(Fig.9).**

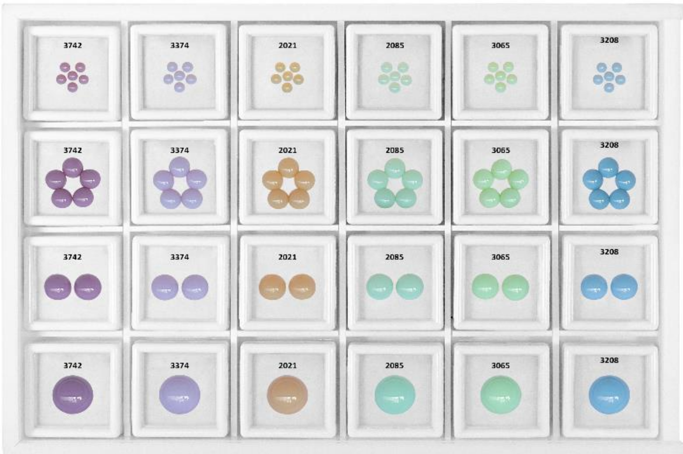


Figure 9. Translucent and Opaque SIAMITE® The transparency of cabochons in a row: 3-6-8-12 mm is gradually reduced

The hardness, density and resistance to thermal shock are approximately the same as those of transparent SIAMITE®.

4. SIAMITE® is a green technology gemstone

SIAMITE® is lead free and in compliance with the strictest regulatory industry norms and laws regarding the restriction or prohibition of certain substances. The production process is virtually waste-free and does not damage the environment - as in any glass production, all low-quality or defective products return to production as additives to the charge. The source of energy is only electricity. Therefore, the production of glass-ceramics is not accompanied by the carbon dioxide emissions into the atmosphere.

Reserves of natural gems are depleted, value has increased, and their mining causes irreparable damage to nature. Nowadays, consumers increasingly realize and become eager to save nature, giving precedence to environmentally friendly products. Recently, a very well-known jewelry brand refused to use natural diamonds and replaced them with lab-grown ones. Colorless SIAMITE® cannot compete with lab-grown diamonds, moissanite, or even cubic zirconia due to its relatively low refractive index. However, colored SIAMITE® are ideally capable of imitating most colored gemstones and therefore allows us to take care of nature and not disfigure it with quarries, trenches, and mines.

Thus, lab-created SIAMITE® glass-ceramic delivers unusual property combinations, such as an extremely low thermal expansion coefficient, optical transparency or translucency, high hardness, fracture strength and toughness, and chemical durability. Available in an extensive assortment of colors, shapes, and sizes, affordable to the masses, SIAMITE® opens a multitude of creative design possibilities through numerous application techniques, making it ideal for use in the jewelry and accessories industries. This new breakthrough gem reflection material indeed has a glorious and bright future!

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