PLASMA - CHAOS, PERFECTLY FOCUSED

How can plasma save 70% of power consumption in the annealing process and eliminate the chemicals from wire production?

Ancient Greeks acknowledged matter in four distinct elements: Earth, Water, Air, and Fire.

Nowadays, when speaking about the states of matter, we usually mention just three states: solid, liquid and gas.

The excited, and probably the most exciting, state of the matter is plasma (flame or fire as explained by ancient Greeks). Plasma has not yet quite found a way to our consciousness. This is ironic when we take into account the fact that 99.9 percent of our universe, including our sun, exists in this state of matter.

Today, plasma is found in a vast range of applications, from light tube to LASER, from welding to special coatings applications such as the production of cutting tools or surgical implants. Semiconductor technology benefits greatly from plasma technology as well. It is the ability to focus plasma on a small area and reproduce it under the same conditions that allows manipulation with small chip structures (micro structures). Plasma based etching, coating and material manipulation processes allow chips to become smaller by orders of magnitude.

What are the distinct characteristics that differentiate plasma from gas, and how do we generate Plasma?

Plasma is ionised (exited) gas. We are used to imagining gas as free atoms and molecules chaotically flying through space. We can generate plasma by inducing energy into gas, to the extent that some atoms break into ions and electrons. This is what happens when we light a matchstick – the flame is excited gas or plasma.

In Plasma, gas particles (atoms and molecules) constantly collide and exchange energy by switching to higher and lower energy states. When colliding, some particles begin to emit light, others become ionised - divided into free (positive) ions and free (negative) electrons.

Electrically charged particles make plasma different from other states of matter. Charged particles can be accelerated in the electric field to a desired speed and directed to a target.

In Plasma Annealer the electric field accelerates ions towards the wire surface (positive electrode) and electrons towards the edge of the heating chamber (negative electrode). Shown in Figure 1, the electric field in the heating chamber accelerates charged particles between the outer wall of the heating chamber and the wire. On their way to the opposite electrode, the particles collide with other atoms and molecules. The less they collide (or the less interrupted their journey) the faster they accelerate and the larger their impact on the wire surface. To achieve high impact heat treatment one has to apply a vacuum to the heating chamber.

The Plasma Annealer heating chamber is filled with low-pressure inert gas to prevent a chemical reaction between the gas and the wire. The wire is fed through the sealing system and the heating chamber continuously thereby exposing the wire surface to ion bombardment.

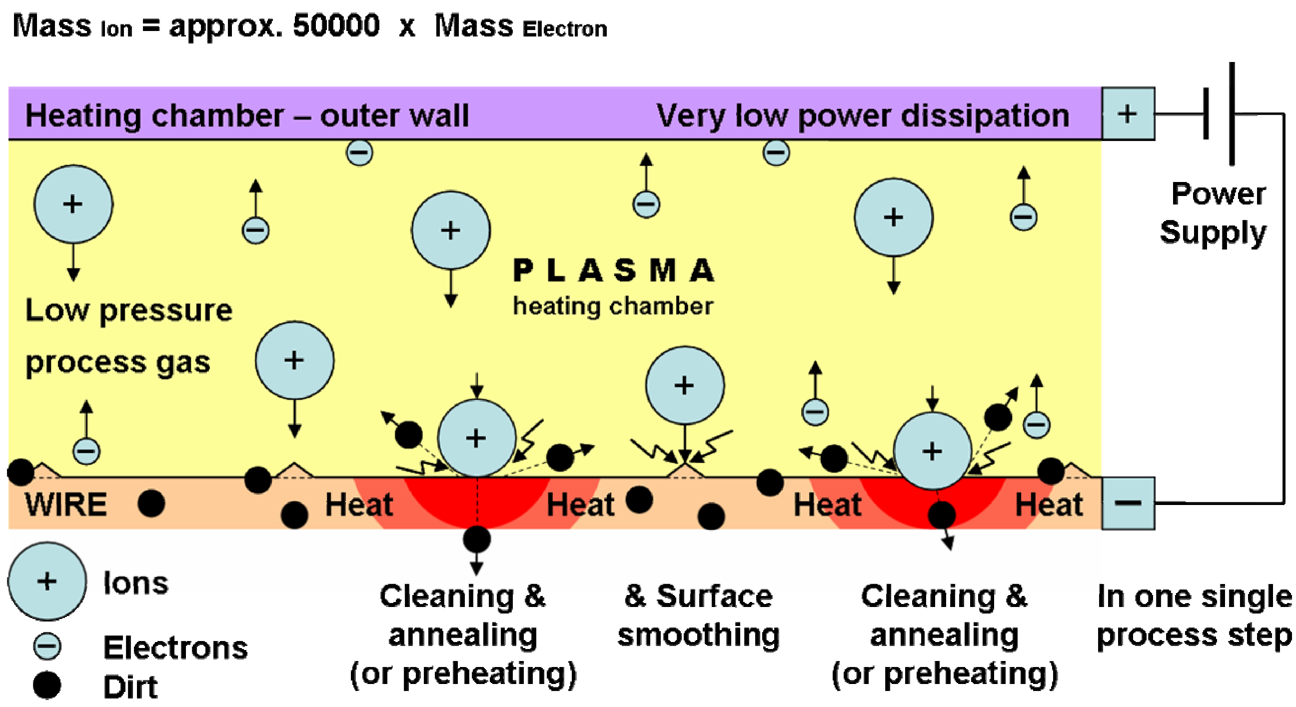

Figure 1: Plasma treatment process inside the heating chamber.

The effect of such bombardment is threefold: (1) efficient heating, (2) surface smoothing and (3) effective surface cleaning.

(1) Colliding ions release their energy into the surface and heat the wire. In the heating chamber the ions are directed to the wire surface, whilst the electrons head towards the outer wall of the heating chamber. As ions are approximately 50,000 times heavier than electrons, they make a considerably higher energy impact on the wire than that caused by the electrons on the chamber wall. In fact, the energy conducted to the chamber is negligible compared to the energy conducted to the wire. Effectively all of the power conducted into the plasma is transferred to the wire (and not the walls of the heating chamber). The unique benefit of plasma treatment is the concentrated impact on the wire surface (directional and focused heating) resulting in a very efficient heating process. As with the microwave oven, the heating chamber remains cool during the process. Less heat transmission to the surroundings also means a friendlier working environment.

The fact that the heating process concentrates on the wire alone makes plasma treatment very effective for high temperature applications such as heat treatment and annealing of tungsten.

The Plasma Annealer can be started and stopped in a matter of seconds. In practice this means that it only takes a few minutes to set-up the process for a wire with a different diameter and of different material. Once the sealing system is adjusted for a different wire dimension and the process control unit is loaded with a new treatment recipe from the database, the new wire is strung in the Plasma Annealer.

Moreover, the plasma assisted heating process can be easily and instantly regulated through the electric potential in the heating chamber. The intensity of the wire treatment can be regulated to a desired value within milliseconds by adjusting the voltage in the heating chamber. In practice, this leads to another benefit of plasma technology. The heat treatment process and resulting mechanical properties of the wire can be controlled in-line, directly through the electric potential and pressure in the heating chamber. Typically, the tensile strength of plasma treated wire varies +/- 2 N/mm from the set value.

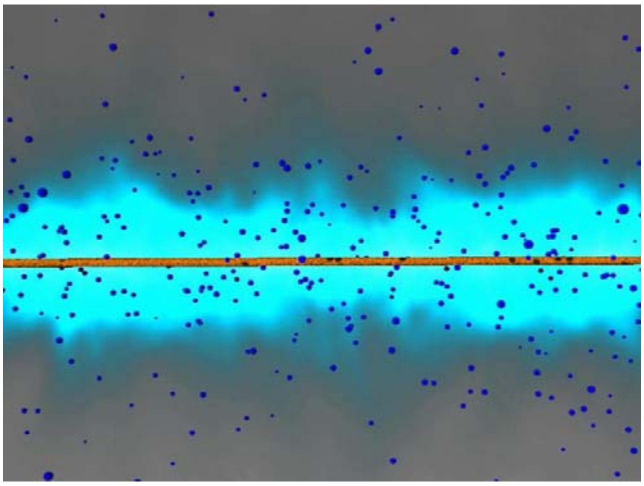

Figure 2: Demonstration of the plasma effect – ion bombardment of the wire.

(2) Plasma treatment results in a smoothing effect on the wire surface. Like lightning striking a tree in a field, ions are directed to the tips of the irregularities. The density of ion bombardment is highest on sharp edges and nibs on the wire surface, concentrating on the tips of irregularities until they melt away. This leads to a smoothing effect causing a reduction in macro-roughness and increased micro-roughness of the wire surface. In some cases the wire with a damaged or rough surface can be improved in quality, and can even reach the standards of magnet wire surface.

(3) Plasma treatment is also an effective cleaning process. The ions bombarding the wire break down dirty deposits and oxide layers on the wire surface. One can imagine the cleaning process as sand blasting at atomic scale. Plasma treatment can therefore replace the deoxidising, degreasing or other wire cleaning processes, whilst eliminating the chemicals from the wire production process. The dirt blasted away burns into ashes and falls off from the surface. The ashes collect on the bottom of the heating chamber and in the vacuum pump filters.

The materials where plasma technology is less competitive are those that require long annealing time, in other words those that need to be exposed to high temperature for a long time. For such applications, high-speed in-line annealing is likely to be unsuitable, due to the required length of an inline cooling system necessary for such an application.

Figure 3: Plasma wire heat and surface treatment machine for high-speed applications with 2 electrodes, flexible sealing system and combined (gas and water) cooling system.

Plasma technology can radically improve economics of the production process, for most wire production applications. This is a result of production process simplification, replacement of batch annealing and introduction of in-line process, abolishment of the chemicals used for cleaning, improved cleanliness of the end product and outstanding product quality through accurate physical properties of the material in the end product.

The outstanding cleaning and smoothing capabilities of the technology can benefit applications in the fields such as medical, aviation, aerospace and other precision wire manufacturing as well as galvanising, extrusion, enamelling, and winding/magnet wire manufacturing. These benefits, together with the applications of plasma technology, will be explored further in the next edition of Wire Industry.

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