Electron Gun Generation and Application in Welding, Lithography and Treatment of Pollutants

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Abstract. As a matter of fact, electron gun has already been widely adopted in various fields. In general, the electron gun is a device used to form an electron beam. In recent years, electron guns have been adopted in welding, lithography and treatment of pollutants. With this in mind, this study will introduce the principle of the electron gun and its application in the three fields respectively. In the electron gun, the cathode is electrically heated in a vacuum to emit hot electrons. Applying a strong potential to the anode, the emitted electrons are accelerated at a given energy, thus forming an electron beam. This has led to the widespread use of electron beams. By studying the rapid development of electron beam applications generated by electron guns, it is shown that electron guns have excellent prospects for development. Overall, these results shed light on guiding further exploration of electron gun development.

Keywords: Emissions, electron beam welding, electron beam lithography, electron beam treatment.

1. Introduction

Early electron guns were invented to form electron microscopes, the cathodes of which were made of tungsten wires or Lanthanum hexaboride crystals. Both of the two electron guns are thermionic emission. It uses thermal energy to emit electrons from the cathode. The electron gun was then changed to a field emission [1], which is used to generate electron beams that are up to three orders of magnitude higher in current density or brightness than conventional thermionic emitters. Another available way is Light Release, a new electron gun that uses the photoelectric effect to replace the cathode with a photocathode [2]. A high-bright electron beam will be produced by using the photocathode. In free-electron lasers and ultrafast electron diffraction, electron beams are commonly generated by photocathodes. Negative electrodes in light detection devices like photomultipliers, phototubes, and image intensifiers are commonly used by photocathodes.

Currently, the cathode of the electron gun has become primarily plasma. Plasma-cathode electron guns provide electron beams with transverse dimensions ranging from a few millimetres to about one metre, pulse durations ranging from nanoseconds to direct current, and electron energies of a few gigaelectronvolts to several hundred gigaelectronvolts [3].

In recent years, electron guns are important with wide applications in various industries, such as scientific research and computer monitors. This component is responsible for generating and accelerating electron beam, which can be reprocessed for a variety of applications such as accelerators, medical, processing industries, lithography and computer and television monitors. After a cursory introduction to the development of electron guns, this study will focus on the principles and classification of electron guns and three applications in welding, lithography and computer and television monitors.

2. Basic Descriptions of Electron Gun

In certain vacuum tubes, electronic components called electron guns produce narrow collimated electron beams with precise kinetic energy. The classification of electron guns is determined by the type of electric field generated (Direct Current or Radio Frequency) and the emission mechanism (thermionic, photocathode, field emission, plasmas source). Thermionic emission electron gun is one of the common type. Tungsten (W) filaments and lanthanum hexaboride (LaB6) single crystals are widely used as cathodes. Thermionic emission guns can produce stable currents up to 1 μA. These guns are widely used in scanning electron microscopes [4]. The gun has a lifespan of approximately 100 hours. The electron source is large and has a low brightness ($10^5 A/cm^2 sr$). The use of these guns in scanning electron microscopes results in a resolution of up to 3 nm, and higher resolutions are not possible. Fig. 1 shows the basic structure of the scanning gun. In order to produce hot electrons, the cathode of a W-filament with a diameter of about 0.1 mm is electrically heated to 2800 K in a vacuum 10^3 Pa.

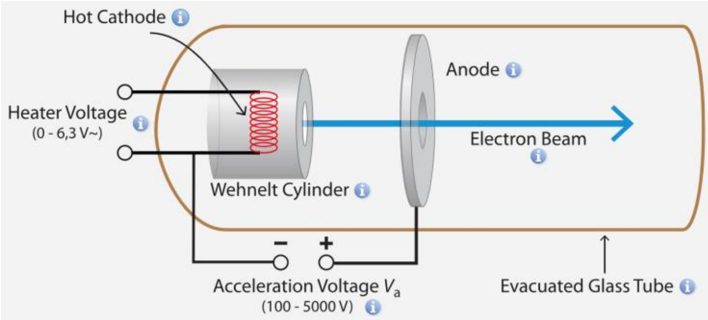

Figure 1. Thermionic emission gun

The cathode ofa FEG is made up of Tungsten (W) single crystals. The end of the transmitter produces a strong electric field that ejectselectrons from the solid surface. An ultra-high vacuum of Pa is usedto operate the electron gun to prevent residual gases fromcontaminating the tip [4]. The virtual light source has a diameter of 5 to 10 nm and the brightness of FEG is approximately $10^8 A/cm^2 sr$). Therefore, the FEG can be used for high-resolution scanning electron microscopy, and the lifetime of the FEG is several years. The energy distribution of electrons emitted from the cathode is very small (approximately 0.3 eV), which is also a characteristic of FEGs. Therefore, High resolution images can be obtained at low accelerating voltages by using FEG. FEG is therefore favourable for high-resolution imaging. The extraction anode's voltage controls the emission current.

GaAS is the main material used for the photocathodeElectrons from the valence band photoexcitation to theconduction band rapidly heat up at the base oftheconduction band and diffuse to the surface with energydetermined by body temperature, so photocathodes can beused to achieve higher peak currents [5]. By increasing thebrightness of the electron source, the acceleration in the field combined with the electrons generated by the short laser pulse hitting the photocathode can produce a perfectly strong pulse. Today, lasers are capable of generating very short pulses (as short as less than 1ps), Photocathodes are capable of producing high current densities (thousands of kA/cm^2) and RF cavities can maintain electric fields up to 100 MV/m. A sketch is given in Fig. 2.

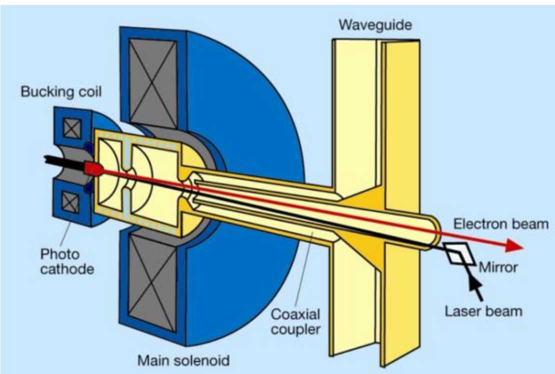

Figure 2. Photocathode electron gun

The basis of a plasma cathode electron gun is aninseparable cathode. The cathode is a low-pressureglow discharge chamber with cold electrodes. Onone of the electrodes there is a hole (emissionchannel) through which electrons leave the gasdischarge plasma. The accelerating voltage is locatedbetween the cathode unit and the anode [6]. The gunis static and pulsed, with an accelerating voltage of 20-40 kV and a beam current of 0-150 mA. An important characteristic of the plasma cathode electron gun is the stability of the spatial beam characteristics when the beam current is regulated.

3. Application

3.1. Electron Beam Welding

Electron guns produce an electron beam that can be used for welding. This welding technology can be used in automotive manufacturing, machining, aerospace and other fields. The technology can produce solder joints from 0.025 mm to 300 mm thick. Electron beam welding joins metallic materials by meltingthe joint area. This technique utilises electron beam emitters,also known as electron guns. These guns have a beam powerofup to 100 kilowatts [7]. The tungsten cathode is thecathode that is the most commonly heated directly, and Athigh voltages in the range of 10 to 200 kV speeds in excessof 100 km/s. The electron gun uses an accelerating andfocusing electrostatic field to bundle electrons emitted fromthe cathode into an electron beam. A sketch is shown in Fig. 3.

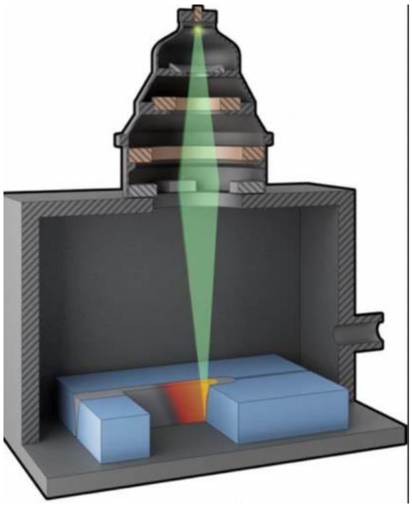

Figure 3. Electron beam welder

At ground potential, the electron beam generator consists of a cathode, a control electrode, and an anode diaphragm. The anode diaphragm is used to guide the beam and it spreads out in a conical shape until it reaches the magnetic sphere of the focusing lens. After focusing by a system of focusing lens, electrons circulate through a system of winding coil, through which the electrons are electromagnetically deflected in a quasi-inertial-free form and thus led to the workpiece [8]. Strongly focused electron beams in the range of 0.1 - 0.8 mm in diameter bombard the weld joint area, The structure of the weld joint area melts due to the conversion of kinetic energy of electrons into thermal energy. At energy densities of up to 10^{12}W/cm^2, the structure in the solder joint area is absorbed and melted. There are three specific welding machines [9]. The universal high pressure welding machines are equipped with a welding gun that can be fixed inside or outside the work room. These devices are used to weld a wide range of products and components. An electron beam vacuum welder with a local chamber is attached to the frame to be welded. The electron gun is placed on the outside of a small chamber of very small volume and covers only part of the flat or ring joint being welded. The vacuum is confined to the small chamber alone. NVEBW is another type of non-vacuum electron beam welding machine. The vacuum system moves the beam towards the workpiece, i.e. The vacuum to atmospheric pressure is gradually reduced by the system of nozzles. The NVEBW machines are equipped with high-efficiency pumps and special electron beam discharge orifices.

3.2. Electron Beam Lithography (EBL)

Electron beam lithography is a modern technology that utilizes an electron beam that has been extracted, focused and accelerated to 20kV. E-beam lithography is currently used primarily to support the integrated circuit industry. The flexibility of E-beam lithography makes it ideal for creating masks that can be used in other technologies, including X-ray lithography. It also allows complex patterns to be written directly onto the wafer. Electron beam lithography involves a process that is almost similar to photolithography. Both technologies use different photoresists and chemicals to develop the exposed portion. The EBL instrument is the result of scanning electron microscopy working in reverse, it is used to write rather than study. As a result, the operating principle's nature makes it limited in its field of view and throughput [10]. An EBL instrument is made up of three basic components, like a scanning electron microscope: an electron gun, a vacuum system, and a control system [11] A sketch is shown in Fig. 4. The generation of electrons is initiated bya cathode or electron emitter. The electronsare then accelerated by a static field to obtaina higher kinetic energy and form a beam ofhigh energy electrons. A guidance system thatconsists ofelectrodynamic and magneticfocusing lenses and a deflection system isused to guide the electron beam to a workingpoint on the substrate.

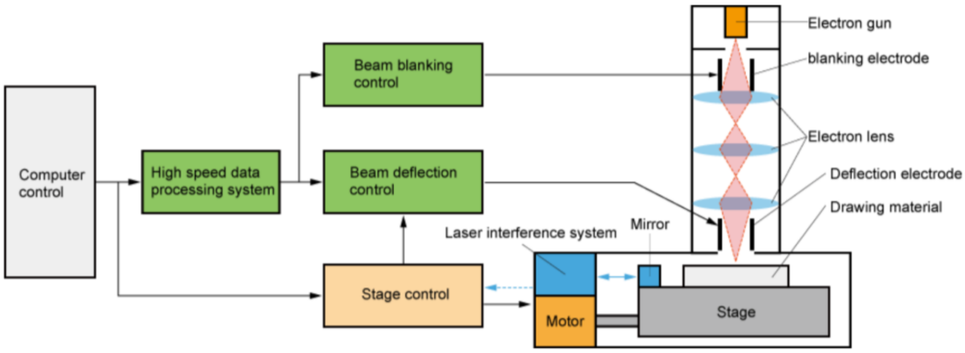

Figure 4. Electron beam lithography

In a high vacuum environment, the electron beam can only be generated and propagated without restriction to the substrate. The application of electron beam processing has an impact on the materials used in the electron gun and the application, the vacuum requirements are typically between 10^{-3} and 10^{-8} mm Hg. There are two methods of getting the actual pattern using the EBL instruments which are raster scanning and vector scanning. A raster scanning system scans the exposed beams in one direction at a fixed speed while moving the substrate under the beam via a controlled stage to make a pattern on the substratum. The electron beam fading in and out thousands of times during each scan causes the design pattern to form. This has the same effect as raster scanning on a television set. The aim of vector scanning solutions is to increase flow by diverting the exposure beam only to areas of the substrate that require exposure. The beam's skip over areas that are not patterned saves a lot of time.

3.3. Electron Beam Treatment of Water Pollutants

Electron beam treatment of wastewater usually purifies wastewater of various pollutants Includes untreated sewage, chemical discharges, oil leaks and spills, agricultural chemicals and so on, because the decomposition of pollutants by reaction with highly reactive substances (hydrated electrons, OH radicals and H atoms) formed by the radiolysis of water. The application ofelectron beam treatment to wastewater is amethod ofpurifying wastewater as shown in Fig. 5 [12]. Theoperation consists of discoloration and destructive oxidation oforganic impurities in sewage. A pilot plant with a daily capacity of 1000 m3 ofwastewater has been constructed using a 1 MeV, 40kW electron gun. In order to irradiate the water uniformly, Anozzle injector with a width of 1500 mm was utilized. The injectoris used to inject wastewater into the electron beam irradiation zoneto ensure sufficient penetration depth. The injection rate can be varied depending on the dose and doserate. After passing through the irradiation zone, the wastewater isdirected to the biological treatment system.

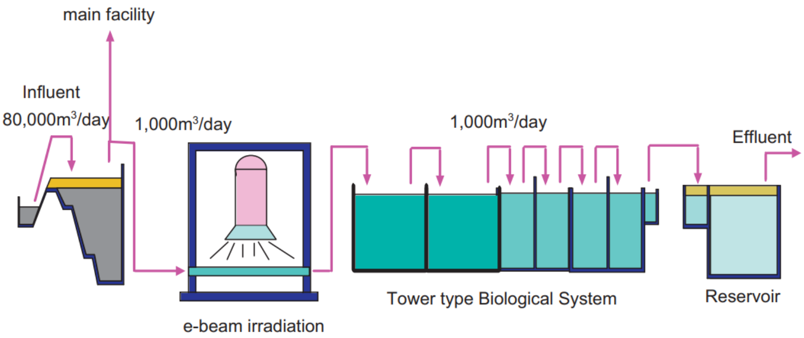

Figure 5. Electron beam treatment process

Wastewater can be effectively purified by biological treatment [13]. Typically, the increase in the biodegradability of organic systems in water after radiation treatment is due to the radiotransformation of non-biodegradable compounds. The increase in the biological treatability of wastewater after initial electron beam treatment is due to the radiotransformation of biodegradable compounds. Electron beam treatment improves the biodegradation process in the initial stage when the main pollutant is biodegradable, but it does not significantly affect the total biodegradability of the pollutant. The total organic carbon, chemical oxygen demand and biological oxygen demand of the unirradiated wastewater showed an approximately linear decrease during the biological treatment process, whereas the electron beam treatment wastewater showed a faster decrease in the initial stage of the biological treatment, and a decreasing trend in the treatment process.

4. Limiations and Prospects

Current electron guns require long stabilisation times and high detection currents and it is not suitable for elemental analysis using wavelength dispersive X-ray spectroscopy or for crystal orientation analysis using electron backscatter diffraction. Moreover, the emitted current may fluctuate even when the electron gun is in an ultra-high vacuum environment. Some electron gun applications such as television monitors are facing the problem of ageing. In recent years, research into the emission source of electron guns has led to improvements in the type of gun and to more stable, high-energy electron beams. By manipulating the parameters of the electron gun and controlling the resulting electron beam, the application of electron beams has also become more and more widespread.

5. Conclusion

To sum up, the electron gun produces an electron beam that can perform welding, lithography, and sewage treatment. In these applications, electron beam is more accurate than other methods. Although electron beams emit currents in a vacuum environment that can trigger fluctuations and lead to certain dangers. However, it is nevertheless worthwhile to study the versatility of the electron beam technology. The use of known applications allows for the extension of electron beam applications to a wider range of areas.

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