The production of electron-multiplier channel plates

G. Eschard and R. Polaert

The concept of an electron multiplier with a single continuous dynode has led to the rapid development of channel multipliers. These devices have important applications; in particular they can be used in sensitive photoelectric tubes for image intensifiers and as particle detectors in space research \cite{1,2}. The amplification produced by these channel electron multipliers results from the secondary emission which occurs when a semiconductor surface is bombarded by electrons. Unlike the multiplying surface of the electron multipliers with separate dynodes, that of the channel multipliers is continuous, and is formed by the partially conducting inner wall of a glass tube. A potential difference is applied between the ends of the tube, producing a uniform electric field inside. When an electron or ionizing particle strikes the inner surface of the tube, several secondary electrons may be emitted. These electrons are accelerated into a parabolic trajectory by the electric field, strike another point on the inner wall, and in turn give rise to the secondary emission of a shower of electrons. The number of times this collision process is repeated depends on the length and diameter of the tube and the magnitude of the applied voltage. The ratio between the number of electrons at the output to those at the input of the tube may be as great as $10^7$.

In practice, the single multiplier tube is replaced by a bundle or stack of very narrow tubes. By taking a section of the bundle a device known as microchannel plate is obtained. These novel components can be used, for example 1) in photomultipliers, where they improve the speed of response by cutting down the overall transit time of the electrons \cite{3}; 2) in image-intensifier tubes, where they give very high gains in a small volume and with low supply voltages \cite{4,5}; 3) in cathode-ray tubes, where they can be used to increase the writing speed.

This article first considers the number and size of the channels in a plate and the choice of the material. Some methods of producing these plates are then outlined.

Dimensions of the microchannel plates

For the plates used in image intensifiers the number and diameter of the microchannels are determined by the required definition and the dimensions of the image. For example, an image with $400 \times 400$ lines and a side 40 mm in length requires the use of a plate with at least $64 \times 10^4$ channels, and a channel diameter of less than 40 microns. For accurate calculation it is necessary to take into account the thickness of the walls, the quality of the stacking of the channels, the electron-optical system in front of and behind the plate, and the grain of the screen.

The length of the channels (i.e. the thickness of the plate) is determined by the desired electron gain. Theoretical calculations show that the gain of a multiplier is mainly a function of the ratio of the length to the diameter of each channel. This ratio lies between 40 and 60.

Choice of material

The basic material is glass. It is used in the form of a tube and is chosen because it can easily be drawn out and has stable properties under high-vacuum conditions. However, glass is usually an excellent insulator, and for this application the conductivity must be increased \cite{6}. There are two methods of achieving this. A conducting layer can be deposited inside the tube; this method is difficult to put into practice because of the small diameter of the channels. Alternatively a glass of special composition is used, which has either a bulk or a surface conductivity.

Production technology

The formation of a bundle of several million glass channels of microscopic dimensions can be carried out in various ways. 1) The channels can be made by piercing a glass disc with thousands of holes. This can be done by photoetching methods or by electron bombardment. 2) A glass tube can be drawn out to obtain a tube with a microscopic internal diameter. This hollow fibre is cut into regular lengths which are finally assembled into a bundle. 3) A glass tube with a solid core is drawn and compressed. Only the last two methods have been developed into useful manufacturing techniques.

Drawing a hollow glass tube

A glass tube which has been brought to its softening temperature can be drawn out into a hollow fibre of
microscopic diameter. This fibre is wound on a drum and then cut into regular lengths, which are assembled into a bundle using enamel as a sealing material.

For this operation two production processes are used. The first, known as the “direct drawing” process, is generally used to obtain hollow fibres with a diameter of more than 200 \( \mu \text{m} \). The second process consists of drawing in two or three stages, bundling being carried out after each stage to facilitate the regular arrangement of the fibres.

This latter method is preferred for the fabrication of hollow fibres with a diameter of less than 100 \( \mu \text{m} \). Such fibres can also be obtained by direct drawing, but in that case the wall thickness will be too large with respect to the channel diameter. This can be explained as follows. When the tube passes through the hot zone of the drawing furnace, the viscosity of the glass decreases. The glass can then be pulled, but at the same time the relative thickness of the tube wall increases because of surface tensions, which increase as the radius of curvature becomes smaller. This is undesirable since it is important that as many as possible of the electrons accelerated at the entry of the channel plate should be able to strike the interior wall of the channels and take part in the multiplication process. The thickening of the walls diminishes the useful area of the channel plate and reduces the efficiency of detection. We have developed a method of maintaining a small excess gas pressure inside the glass tube during the drawing process, and this results in a tube with a useful cross-section of 80%.

To ease assembly of a very large number of fibres of small diameter it is preferable to proceed in several stages as stated above. The glass tube is first drawn out until the inner diameter of the hollow fibre is less than 1 mm. This fibre is rolled on a drum, and then cut into pieces of constant length which are assembled, enamelled and arranged in a hexagonal mould. This is placed in a furnace to seal the fibres; the arrangement of the fibres is perfectly regular if they all have the same diameter. The number of fibres contained in the hexagonal mould is determined by the relation:

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N = 1 + 3m(m + 1),
\]

where \( m \) is the number of adjacent fibres arranged along one side of the hexagon.

The second drawing operation is then performed to reduce the fibre diameter even more, but this time it is no longer possible to wind the bundle on a drum. It is simply pulled along by the movement of two belts pressed against each other.

To ensure that the final dimensions are uniform it is vital that the input velocity of the tube, the output velocity of the fibre, and the furnace temperature should all be held constant during both drawing processes.

**Fig. 1** shows the cross-section of a channel plate obtained by this process.

**Use of a tube with solid core**

If a tube with a solid core is used the core is dissolved away after the plates have been cut. This technique offers several advantages: the fibres are less fragile, manipulations are easier, the fibres can be subjected to strong pressure in order to compress them without fear of crushing or deforming them, all the channels

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maintain the same diameter, and they therefore have the same electron gain.

In the application of this technique a metal core or a soluble glass core can be used. In the first case a metal wire of the exact diameter of the desired channel is placed inside a glass tube. The tube is then passed through a furnace and drawn out so as to cover the metal wire and assume the required wall thickness. The resulting fibre is then wound directly on to an octagonal drum with the turns touching. The coil is cut into eight parts which are put together to form a rectangular block. Finally the metal contained in each channel is dissolved by chemical or electrolytic means.

The channels obtained in this way are perfectly regular, as shown in fig. 2.

The alternative process is to draw a tube with a core of soluble glass. This is an adaptation of the practice used for making optical fibres\(^7\). In contrast to the latter process the glasses are not chosen for their difference in refractive index but for the solubility of the glass forming the core of the fibres and for the electrical properties of the multiplier glass. As in the production of optical fibres the drawing of the multiplier channels is generally done in several stages. The regularity in diameter is not quite as good as in the metal-core method, but is still quite satisfactory.

Measurement and control of the diameter of the glass fibres

The above description has shown the need for precise control of the diameter of the fibres during the drawing process. This is necessary to obtain a regular arrangement of the fibres, and to obtain an identical electron gain in all channels.

Measuring the diameter is difficult because as the glass leaves the furnace it is fragile, hot and moving rapidly. For the hollow fibres in any case it is impossible to make the measurement by mechanical contact. The technique developed at LEP is purely optical; see fig. 3. The fibre passes through one of two uniform parallel beams of light intercepted by two photoelectric cells.

![Fig. 2. The cross-section of a microchannel plate produced from a glass tube with a metal core. Channel diameter 80 microns.](image)

![Fig. 3. Method for continuous measurement of the diameter of the fibre leaving the drawing furnace. F cross-section of fibre; the movement of the fibre is perpendicular to the plane of drawing. L lamp with condenser C and stabilized power supply V. Pr prism dividing the light between photocells P1 and P2, whose outputs are compared in meter M. Part of the beam directed on to P1 is intercepted by the fibre F. Lateral displacement of F within the “window” W of 4 × 25 mm is permitted.](image)
opaque and transparent fibres, but the diffraction and refraction effects are different. The system must therefore be calibrated under the conditions of use.

Control of the diameter of the fibres is obtained by amplifying the error signal generated by the diameter reader. This signal controls a servomotor which drives a speed control. In this way the speed of drawing and any consequent variation in diameter can be corrected. The time constant of the control system is about 0.7 s. Part of this interval represents the time elapsing as the fibre is pulled from the drawing zone to the place where its diameter is measured.

A new method of measurement, which is based on dielectric losses caused in a resonant microwave cavity, is now being developed. The fibre is made to pass through a cavity forming part of a transmission circuit, and the resulting mismatch gives a very accurate indication of the amount of material present in the cavity at any moment. By combining this method with the optical measurement it is possible to obtain a continuous check on both the diameter and the thickness of the fibre.

Conclusion

The technology for producing microchannel plates, in whose development LEP have cooperated closely for several years with the Mullard Research Laboratories at Salfords, England, and the Philips Research Laboratories at Eindhoven, has certain parallels with that for optical fibres. The distinctive feature is that the channel diameter has to be very uniform: this diameter is important because it determines the electron gain. To achieve this uniformity the equipment must incorporate extremely accurate control of the diameter, the furnace temperature and the speed of drawing.

A good demonstration of the capabilities of these microchannel plates is provided by a particular photomultiplier of original design. This photomultiplier, which is illustrated and more fully discussed in another article in this issue \[8\], consists of a microchannel plate placed between the photocathode and the anode, which is the open end of a coaxial line with an impedance of 50 Ω. This arrangement gives a transit time of less than 0.1 ns for the electrons. In a conventional photomultiplier the electron transit time is usually 15 ns or longer. The performance of the new photomultiplier opens up new prospects in the measurement of the duration of light pulses.

Another example of the application of a microchannel plate is given in fig. 4. This shows an image intensifier, in which the photocathode is mounted immediately in front of the channel plate. A very high electron gain is thus achieved in a simple arrangement. The photocathode of this tube is activated by means of the transfer technique described in another article in this issue \[8\].

Summary. The principle of operation of channel electron multipliers is outlined. Some applications of arrays of these multipliers in plates consisting of several million channels are considered and their physical and electrical properties summarized. The chief methods of producing these channel plates are described. The basic material is generally glass in the form of tubes several millimetres in diameter, which can be reduced to the final diameter by direct drawing. The tubes are then stacked and compressed to form the channel plates. Intermediate steps may be introduced with two or three successive drawings. Other methods involve filling the tubes with a substance which is dissolved at the end of the drawing and stacking operation. To ensure the uniformity of channel diameter (which is necessary for a uniform electronic gain) all of these methods require very precise control. An optical device is described which enables the diameter of a tube or a glass fibre to be measured continuously and to be kept constant to within about ± 1%.

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