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VACUUM VAPOR DEPOSITION-CONTROL OF COATING PROFILE

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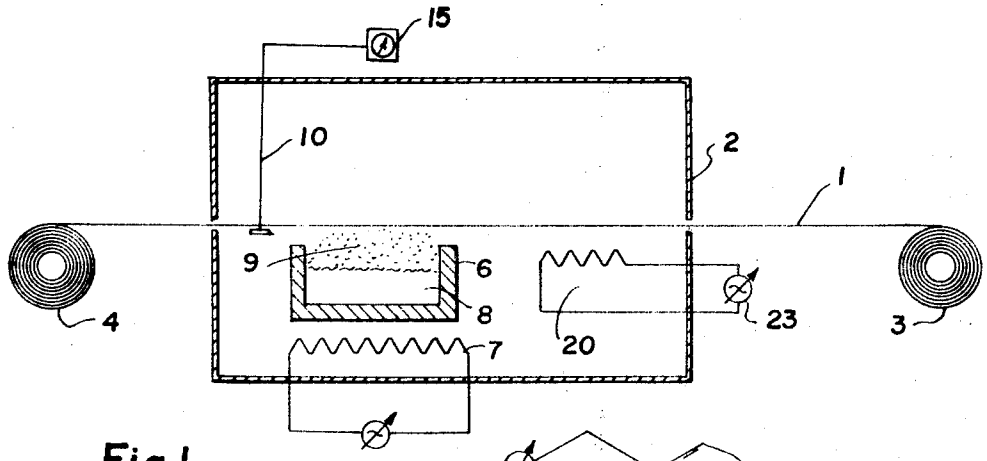


Fig.1.

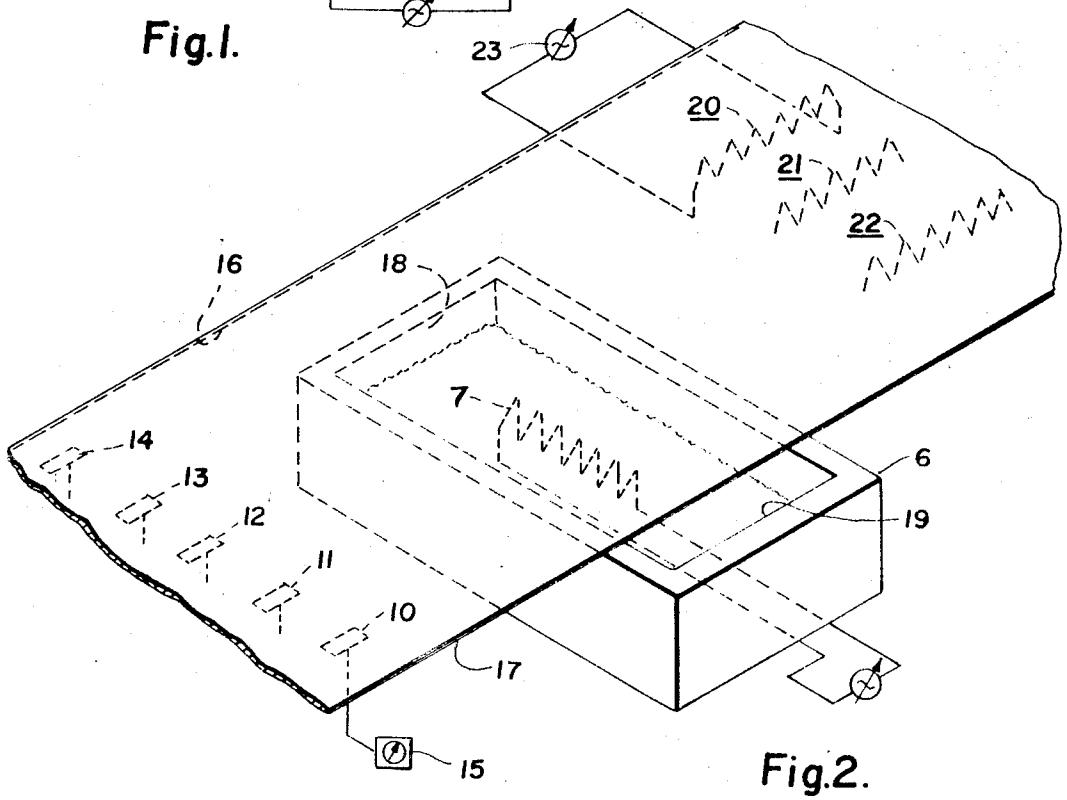


Fig.2.

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VACUUM VAPOR DEPOSITION-CONTROL OF COATING PROFILE

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ABSTRACT OF THE DISCLOSURE

By controlling the temperature profile of a strand in a vacuum vapor coating process, a metal coating having a desired thickness profile is deposited thereon.

This invention relates generally to methods for controlling the relative thickness or thickness profile of a metal coating deposited on a metal strand from its vapor state and more particularly to methods wherein such control is accomplished by the control of the temperature of the strand.

It is known to coat a metal strand with another metal by vaporizing the latter in an evacuating chamber causing it to deposit or condense on the strand; and it is known to coat continuously in this way by passing the strand in the form of a strip continuously through the evacuated chamber adjacent a source of metal vapor. The source of metal vapor is conventionally a crucible containing the metal heated electrically by a resistance heater or by an electron beam. Most often it is desired that a coating of uniform thickness be deposited on the strand although in some instances a coating thickness profile which varies in a controlled manner is sought. Methods used heretofore to produce desired coating thickness profiles have been directed to the use of baffles and nozzles to direct the flow of metal vapor to the strand, but these methods have not proved to be entirely satisfactory.

It is an object of my invention to provide a method for controlling the thickness profile of a vapor deposited metal coating on a metal strand. It is another object of my invention to provide such control by regulating the temperature of the strand. It is yet another object of my invention to provide a method for maintaining constant the thickness of a continuously deposited metal coating on a moving metal strand by continuously controlling the temperature of the strand. It is still another object of my invention to provide a method for maintaining a a desired coating thickness profile across the metal strand by suitably controlling the temperature of the strand. It is another object of my invention to provide such methods wherein the strand is coated while in a vacuum. Other objects of my invention will appear from the description thereof which follows.

I have found that when coating a metal strand by depositing another metal from its vapor state thereon, one of the most significant variables which affects the amount of metal deposited is the temperature of the strand and that areas on the strand which are relatively cold will condense greater quantities of the coating metal than will the warmer areas. The reason for this is that the condensation temperature of the metal vapor is related to the temperature of that portion of the strand upon which it condenses and the condensation temperature is in turn uniquely related to the vapor pressure of the coating metal as dictated by the vapor pressure curve of the metal with lower vapor pressures corresponding to lower condensation temperatures. Thus, if the strand temperature profile varies, then so must the condensation

temperature profile vary and consequently so must the vapor pressure profile vary. The metal vapor cloud to which the strand is subjected in the coating process seeks to be of a uniform pressure and, therefore, the metal vapor located in the high pressure areas developed above the high temperature areas on the strand will be deflected into the low pressure areas developed above the low temperature areas on the strand thus causing a greater amount of metal vapor to be deposited in the low temperature areas. I have also found, however, that even if the temperature of the strand is kept uniform in an attempt to maintain a uniform coating thickness, under some conditions a non-uniform coating will in any event be deposited.

My invention takes cognizance of various conditions which influence the degree of metal vapor deposition on a strand, including that of the temperature profile of the strand, and through the means of controlling said temperature profile enables a uniform coating thickness or a coating thickness of any desired profile to be deposited on the strand.

An embodiment of my invention presently preferred by me is illustrated in the attached drawing to which reference is now made. FIGURE 1 is a schematic sketch of an apparatus arranged to practice my invention according to said embodiment. FIGURE 2 is a schematic sketch partly in perspective of a portion of the apparatus of FIGURE 1.

While my invention is broadly applicable to the vapor coating of any metal on any metal strand, it is specifically adapted to the vapor coating of steel strip of a thickness less than about .065 inch with other metals which can be deposited without heating the strand above about 1000° F. The coating metals of greatest commercial importance, aluminum and zinc, as well as metals such as cadmium and magnesium, can be vapor deposited below said temperature. In this application, I refer to metal strands of less than .065 inch as thin strands.

In FIGURE 1 the strand **1** in the form of a steel strip is passed horizontally through an evacuated chamber **2** from an uncoiling reel **3** to a coiling reel **4**. Reel **3** is suitably driven so as to continuously move the strip through the chamber at any desired speed. Within chamber **2** and positioned below the path of travel of the strip is a crucible **6**, of approximately the same width as the strip, provided with electrical heating means **7** such as an electric resistance heater. In crucible **6** is maintained a pool of liquid metal coating material **8** which gives off vapor **9** at its surface. The metal vapor impinges on the undersurface of strip **1** as the strip moves through the evacuated chamber and condenses thereon. A series of five devices, **10** through **14**, capable of measuring the thickness of the metal coating, is positioned in chamber **2** downstream of crucible **6** in contact with the strip **1** at spaced points across its width. Device **10** is connected to a meter **15** whereby the thickness of the deposited coating may be read. Devices **11** through **14** are likewise connected to similar meters, not shown.

The temperature of the strip at the time it passes over the crucible is in most cases uniform and at the ambient temperature. Although it might be expected that a uniform coating would be deposited on the strip under such conditions, the coating near the edges **16** and **17** of the strip **1** is in fact thinner than the coating on the remainder of the strip. While I do not wish to be bound by the following explanation of this phenomenon, I believe that as the metal vapor **9** rises from the liquid metal surface, the portion of the vapor that is adjacent the insides **18** and **19** of the two end walls of the crucible **6** is subject to drag against the side walls and is therefore not delivered to the strip at as rapid a rate as is the vapor which is not in contact with the insides of the end walls. Also,

because the strip is positioned some distance above the crucible the vapor rising along the inside of the end walls will have a tendency to escape into the evacuated chamber between the edges of the strip and the top of the crucible before it rises sufficiently to condense on the strip. While those conditions might be overcome by using a crucible having a lateral extent greater than the strip, such a solution would not be desirable because the metal vapor emanating from the portions of the crucible which would extend beyond the edges of the strip would be lost to the chamber. Therefore, to compensate for the variation in coating thickness the portion of the strip which is receiving the thickest coating is heated with respect to the edges thereof by means of heaters **20**, **21** and **22** which are positioned along the central portion of the strip upstream of the crucible **6**.

Heating element **20** is positioned approximately in line with coating thickness measuring device **13** and is connected to an individual variable power supply **23** by which the amount of heat being developed by the heating element may be controlled. Heaters **21** and **22** are likewise positioned approximately in line with devices **12** and **11**, respectively, and are also connected to individual variable power supplies, not shown. By this arrangement when the measuring devices indicate that the coating along the edges of the strip, where devices **10** and **14** are located, is not as thick as that on the center portion of the substrate, the heaters are turned on and the portion of the strip which passes above these heaters is thereby heated. Then as the metal vapor condenses on the strip, since the condensation temperature of the metal vapor is the temperature of the strip at the location where it condenses and since the condensation temperature is in turn uniquely related to the vapor pressure of the metal, the space adjacent the heated portion of the strip is at a higher pressure than the space adjacent the edges of the strip. As the metal vapor cloud seeks to establish a uniform pressure across the strip, the metal vapor in the high pressure areas moves into the low pressure areas and as a consequence more vapor is deposited along the edges of the strip than was the case when the strip was of a uniform temperature. The heat developed by the heaters is adjusted until the coating thickness measuring devices indicate that a uniform coating is being deposited. The steel strip thereafter passes through the evacuated chamber and receives a uniform metal coating.

While I have illustrated the use of five coating thickness measuring devices and three heaters, other numbers may be used and as can be readily understood, the greater the number of such devices and heaters, the greater will be the control over the coating thickness profile.

Under some conditions the strip will not be at ambient temperature at the time it enters the evacuated chamber but will possess a temperature gradient across its width. In such cases if a coating of uniform thickness is desired, it will be necessary to control the temperature of the strip in an appropriate manner and this is accomplished by providing a suitable number of heaters suitably spaced across the strip whereby the temperature profile of the strip can be controlled in a desired manner.

In some instances a coating of variable thickness is desired across the strand. For example, a strand having a coating of particular thickness along one of its edges which coating gradually increases in thickness to the opposite edge of the strand is desired for some applications. In this case one heater is provided for each thickness measuring device and it is necessary to drive each heater generally in relation to the coating thickness desired on the portion of the strand which passes thereover. That is to say that generally the thinner the coating thickness desired, the greater must be the temperature of that portion of the strand and consequently the harder must the heating element be driven. Of course, as explained above, there will be a tendency for the coating deposited along the edges of the strip to be thinner in any event.

As can be readily understood from the foregoing discussion, the temperatures per se of various portions of the strand are of only secondary importance in influencing the amount of metal vapor deposited thereon and it is the temperature differences which exist between these various portions, or in other words, the temperature distribution relationship across the strip, which primarily determine the relative distributions of the vapor as it condenses. Therefore, those portions of the strand on which it is desired to deposit more vapor can be cooled with relation to the remainder of the strand to obtain the desired effect. Thus, instead of heating the central portion of the strand in relation to the edges thereof as I have described above in relation to my preferred embodiment in order to obtain a uniform coating, the edges of the strand are cooled in relation to the central portion by providing cooling coils in the evacuated chamber positioned so that only the edges of the strip pass thereover, and a uniform coating in this manner obtained. The degree of cooling is controlled so as to produce a greater or lesser cooling effect as desired.

Thus, it can be seen that the present invention discloses an effective method for controlling the thickness profile of metal coatings deposited from their vapors on metal strands by controlling the temperature of the strand.

I claim:

1. The method of depositing a metal coating having a desired thickness profile from its vapor onto a thin metal strand in an evacuated chamber comprising adjusting the temperatures of portions of said strand in relation to the strand coating thickness profile desired to change the temperature distribution relationship across the strand width, and passing said strand adjacent to the source of metal vapor so as to permit said vapor to condense on said strand and deposit thereon a metal coating having the desired thickness profile.

2. The method of claim **1** wherein the thickness of the metal coating is maintained uniform across the width of the strand by adjusting the temperature of the strand so that substantially the central portion of the strip is at a temperature higher than substantially the edges of the strip.

3. The method of claim **2** wherein the strand comprises steel strip.

4. The method of claim **3** wherein the metal coating is a member of the group consisting of zinc, aluminum, cadmium and magnesium.

5. The method of claim **3** wherein the metal vapor is zinc.

6. The method of claim **1** including the step of continuously moving said metal strand through said chamber at a uniform rate during the temperature adjusting and coating steps.

7. The method of claim **6** wherein the strand comprises steel strip.

8. The method of claim **7** wherein the metal coating is a member of the group consisting of zinc, aluminum, cadmium and magnesium.

9. The method of claim **7** wherein the metal vapor is zinc.

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