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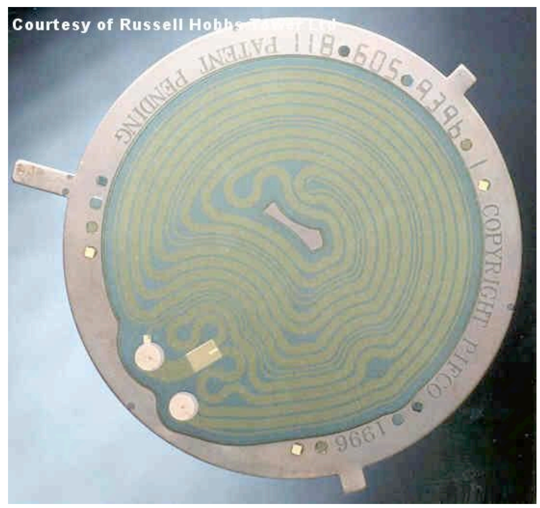
# Application Notes for Thick Film Heaters Made from Dielectric Coated Stainless Steel Substrates

## INTRODUCTION

Insulating dielectric materials can be screen printed onto stainless steel and fired at 850°C to produce a robust substrate that has high resistance to thermal shock. Such substrates possess the normal features of Porcelain Enamelled Steel substrates (PES) but have the advantage of higher processing and operating temperatures. They have been used to make heaters by screen printing thick film resistive elements on the insulated areas for the last ten years.

Temperature sensing elements can also be incorporated using thick film positive temperature coefficient (PTC) resistive materials.




## MATERIALS

### STAINLESS STEEL SUBSTRATES

The EC regulations on steels for the food industry require 12% Cr. Below 12 % Cr the steel is not stainless. Both austenitic and ferritic steels are used to manufacture heating elements. 304 austenitic steel has a higher temperature coefficient of expansion (TCE ~ 18 ppm/°C) compared to the other type of steel that is used – 430 ferritic steel (~12 ppm/°C). Stainless steel compositions are presented in Table 1.

**COMPOSITION OF STEELS**

**(maximum unless range specified)**

| | TYPE | C | Mn | Si | Cr | Ni | Mo | P | S |
|---|---|---|---|---|---|---|---|---|---|
| **304** | Austenitic | 0.08 | 2.0 | 1.0 | 18 - 20 | 8.0 - 10.5 | - | 0.045 | 0.03 |
| **316** | Austenitic | 0.08 | 2.0 | 1.0 | 16 - 18 | 10.0 -14.0 | 2.0 -3.0 | 0.045 | 0.03 |
| **430** | Ferritic | 0.12 | 1.0 | 1.0 | 16 - 18 | - | - | 0.045 | 0.03 |
| **430S17** | Ferritic | 0.08 | 1.0 | 1.0 | 16 - 18 | 1.0 | - | 0.045 | 0.03 |



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## SCREEN PRINTABLE PASTES

**Insulating Dielectrics** ESL 4924 has been developed for use on 430 type ferritic stainless steels. ESL 4916 is the insulating material for 304 type austenitic stainless steels. Both materials are barium, cadmium and lead free. Both insulators have high breakdown voltage and insulation resistance at the correct thickness (see processing section). The insulation resistance of three separately fired layers of 4916 decreases to an unacceptable level at elevated temperatures (400°C). Thicker dielectric deposits are recommended for such high temperature applications.

**Conductors** ESL silver based conductors are recommended as terminations for resistive heating elements. 9912-A, a pure silver, may be used but 9695 (20:1 silver: palladium) is recommended. These conductors can be used on both types of dielectric.

**Resistors ESL** 29XXX resistors are used for the heating elements. These are calibrated on 4924 dielectric using a 178 square pattern. The first X in 29XXX represents the resistivity of the paste (in hundreds of mΩ/sq. e.g. 29115 is a 100 mΩ/sq.paste). The second and third Xs represent the temperature coefficient of resistance (TCR in 100 ppm/°C e.g. 29115 is a 1500 ppm/°C paste). Specially calibrated resistive materials for use on 4916 are available on request.

**PTC sensors** Positive temperature coefficient resistors can be used to fabricate temperature sensing elements.

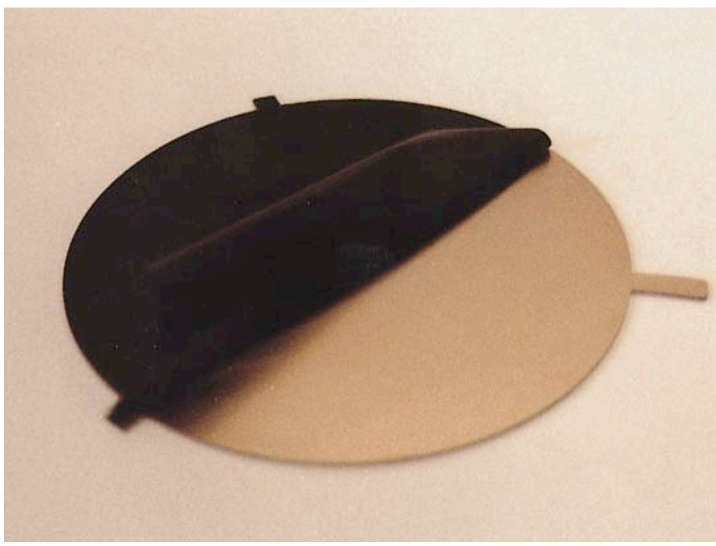
**Overglaze** If a protective insulation is required for the heating element it is recommended that the same dielectric that has been used to insulate the steel be chosen.

## PROCESSING

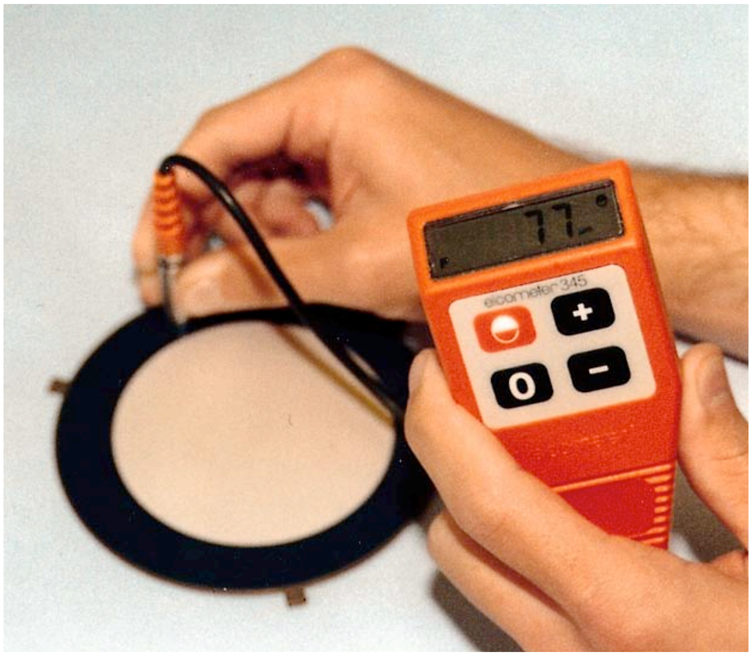
### STEEL PREPARATION

Where steel is supplied with a protective plastic coating no preparation is required.

Uncoated steel must be cleaned to remove contamination (fingerprints, dirt, oil, grease, etc.). Once a clean surface is available further contact with the steel should be made with gloved hands.



## SCREEN PRINTING DIELECTRICS




ESL insulating dielectrics are screen printed onto the appropriate steel using 165 mesh stainless steel screens with 0µm emulsion. Each fired layer should be 25-30µm thick. Measurement is carried out using a coating thickness gauge (e.g. Elcometer 345 is shown in the picture).

Three separately fired layers having >80µm total thickness will produce the required insulation. Cleanliness during print/fire operations is paramount to minimise inclusions, pinholes, etc. which may result in a low breakdown voltage. Pastes are dried at 125°C and fired using a one hour 850°C profile in a belt furnace with ten minutes at peak temperature.

## SCREEN PRINTING CONDUCTORS

ESL conductors are screen printed onto insulated steel using 325 mesh stainless steel screens with 20µm emulsion. They are dried and fired in the same way as dielectrics.

## SCREEN PRINTING RESISTORS

ESL 29XXX resistors are screen printed onto insulated steel using 250 mesh stainless steel screens with an emulsion of 5µm. The calibrated dried print thickness is 21 ± 1µm measured on a 178 square spiral pattern of 2.4mm width. Drying and firing is carried out in the same manner as for ESL dielectrics and conductors.

## SCREEN PRINTING OVERGLAZES

A 165 mesh stainless steel screen with a 0µm emulsion is used to apply the ESL insulating dielectric as an overglaze for the heating elements. Drying and firing is as indicated above. Resistance values may shift after overglaze has been printed/fired.

## HEATER DESIGN

**THE FOLLOWING NOTES ARE INTENDED TO ASSIST CUSTOMERS IN THEIR DESIGNS. THE CUSTOMER HAS THE RESPONSIBILITY OF DETERMINING THE SAFETY AND RELIABILITY OF THEIR DESIGN.**

### POWER DENSITY

Power densities up to 60 $W/cm^2$ at 10-12µm fired print thickness are recommended for all 29XXX resistors.

### CURRENT DENSITY

Current densities up to 3A/mm width of a resistive element at 10-12µm fired print thickness are recommended.

### TCR CONSIDERATIONS

Materials used in thick film heating elements have high TCRs and, consequently, consideration must be made of the difference in resistance at room and operating temperatures.

### CALCULATION EXAMPLE

A customer requires a heating element that is capable of supplying 3KW of power at 240V AC at a controlled maximum temperature of 150°C. The available print area is 120mm in diameter.

$$V = I \times R \text{ Ohm's Law}$$

$$\text{Power} = V \times I$$

$$TCR = ((R_H - R_C) \times 10^6) / (R_C \times (T_H - T_C))$$

Where: $R_H$=resistance at temperature; $R_C$=resistance at start.
$T_H$= maximum temperature, °C; $T_C$= temperature at start, °C

A standard ESL 29115 paste has been chosen for this calculation.

Power at operating temperature = 3000 = 240 x $I$

$I$ at temperature = 12.5A

At 3A/mm the track width is ~4mm.

The resistance at operating temperature is 240/12.5 = 19.2Ω

The TCR of the material is 1500 ppm/ °C

Therefore: $1500 = ((19.2 - R_C) \times 10^6) / (R_C \times (150-25))$

$$(1500 \times (150-25) \times R_C) / 10^6 = (19.2 - R_C)$$

$$0.1875\ R_C = 19.2 - R_C$$

$$1.1875\ R_C = 19.2$$

$$R_C = 16.17\Omega$$

In order to achieve a room temperature resistance of 16.17Ω, a track of 162 squares needs to be made. The track width is 4mm so the length is 648mm. The total area of the track is 2592mm$^2$. The rated power is 3KW so the power density is 115.7W/cm$^2$. This figure is too high, especially as there will be increased power dissipated at switch on. An increased area is required for safe operation. At 5.5mm track width a length of 890mm is needed to achieve the correct resistance (using ESL 29115). The area is now 49cm$^2$ that equates to 61 W/cm$^2$. This is at the upper end of the recommended power density. No account has been made in this calculation of resistance shifts after overglazing. The power at switch on is 3562 W that equates to 72.7 W/cm$^2$ for a short time.

**HEATER LAYOUT**

Ideally, the heater track will be circular and have no 90° corners that may result in hot spots. Trim tracks can be included in the design to make adjustments to as fired resistor values. Spring-loaded contacts are normally used to make connections to these types of heaters.

3 KW rapid boil kettle courtesy of Salton Europe Ltd.