

Development of Variable Vacuum Capacitor (VVC) with Current Carrying Performance Exceeding 200 Arms

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Abstract

For impedance matching in a Radio Frequency (RF) power source circuit needed for a membrane process using RF plasma, a Variable Vacuum Capacitor (VVC) is mainly used. In semiconductor manufacturing, miniaturization and high layering are progressing steadily RF power supply circuits are required to have a higher output, and VVCs are required to have an even higher current. The VP115 type uses a new material for current-carrying bellows, which is essential for large currents to reduce loss and improve cooling efficiency. As a result, while maintaining the size of the conventional product, the maximum allowable current value has been increased.

1 Preface

Fig. 1 shows the structure of the Variable Vacuum Capacitor (VVC). The VVC is composed of a ceramic envelope to insulate the space around electrodes, a pair of opposed envelopes to form an electrostatic capacity, vacuum sealing bellows, and a screw actuator shaft intended to vary the opposed

area of electrodes⁽¹⁾. The company's unique double bellows structure is adopted for the high-current VVC. In addition to vacuum sealing bellows, current carrying large-bore low-loss bellows is allocated to secure high-current performance.

We focused on materials, shapes, and cooling systems for current-carrying bellows and promoted the development of even higher-current models. As a result, we developed three groups of products by 2022 where the product size is kept the same as conventional products (VP110 type) as also the maximum permissible current of 250 Arms (air-cooled at 13.56 MHz), exceeding the former permissible current of 170 Arms (air-cooled at 13.56 MHz). This paper introduces our pursuits toward a goal to establish more advanced high-current models in order to realize low-loss bellows and improvement of cooling efficiency.

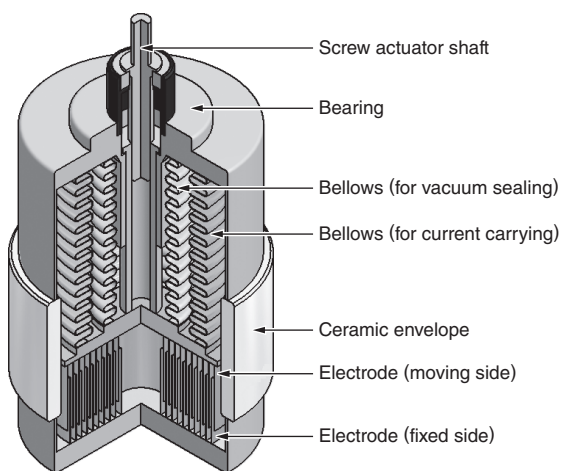


Fig. 1 Structure of VVC

The double bellows construction composed of the vacuum sealing bellows to sustain the vacuum and the current carrying bellows (unique structure by our company) is shown. In the case of an application to RF, a current caused by the skin effect flows through a high-current bellows.

2 Background of Demand for High-Current VVC

In recent years, there has been a demand for semiconductors with ever higher functionality and energy savings. In semiconductor manufacturing, along with miniaturization, high layering is in progress.

In technical innovation of multilayer for memory cells represented by the 3D NAND flash memory,

for example, power source matching devices with a high frequency above 13.56 MHz are demanded to realize depth etching of a high aspect ratio. In this connection, the feature of higher current and higher withstand voltage is expected for the VVC. Since there is a limitation of footprint, on one hand, for RF source equipment, matching devices, and manufacturing machines, the VVC is required to have higher currents while maintaining its regular size. We developed the VP115 type with the permissible current of 250 Arms exceeding the former maximum level (170 Arms), while the regular size of VP110 type is unchanged. We are now offering more advanced products focused on high currents conforming to the requirements of the compact design for the semiconductor market.

3 Our Activities for High-Current VVC Performance

Major challenges for VVC development lie in current carrying bellows. The maximum permissible current of the VVC is specified to be a current that can be carried continuously when the VVC surface temperature is below 125°C (Δ100°C at room temperature of 25°C) while a maximum current is carried. To realize a high-current VVC, low heat generation and low loss are required for the bellows. Heat generation of the VVC while the current is carried is defined by the expression below.

$$P_{loss} = (ESR_f + R_c) (I_{RF})^2 \dots \dots \dots (1)$$

Given the current carried in the VVC is I_{RF} A Arms and the resistance like a fastening resistance is R_c , heat generation during VVC current carrying appears mainly around the Equivalent Series Resistance (ESR) in the form of ohmic loss P_{loss} W. For this reason, it is essential for the current carrying bellows to reduce ohmic loss by examining raw materials and shapes. In the case of the VP115 type, the diameter of the current carrying bellows is increased in double bellows construction and a copper-based raw material is adopted because its conductivity is higher than that of conventional raw materials to lower the ohmic loss of the bellows. Fig. 2 shows an example of the ESR – Frequency characteristics of the VP110 and VP115 types. Regarding the ESR characteristics of the VP115, the effect of loss reduction was confirmed. In addition to the ESR characteristics, an increase in VVC currents is also an important factor. For the VP110

type, cooling was effected by mounting the cooling flange on the outer surface of the envelope. For the VP115 type, however, the cooling mechanism is allocated inside the vacuum vessel so that direct cooling of the heat-source bellows is realized. Fig. 3 shows the relationship of the maximum permissible current – cooling capacity.

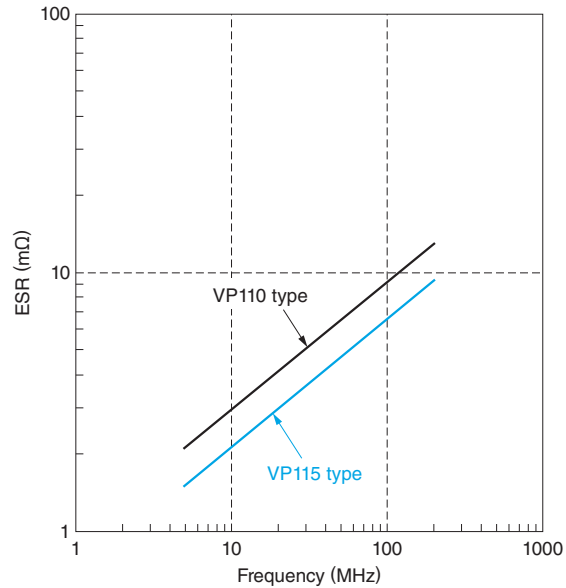


Fig. 2 Example of ESR – Frequency Characteristics

Compared with the ESR characteristic of the VP110 type, the ESR value of the VP115 type is reduced by approximately 30%.

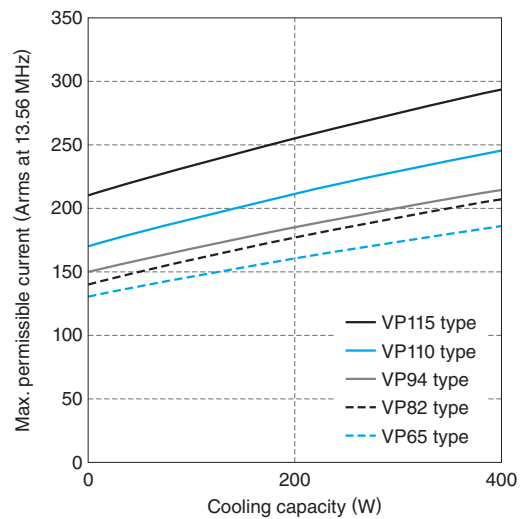


Fig. 3 Relationship of Maximum Permissible Current – Cooling Capacity

The relationship is shown between the permissible current value (Arms) of each VP type and the cooling capacity (W). Compared with the VP110 type, the permissible current value of the VP115 type is improved by approximately 40 Arms.

4 Postscript

This paper introduced the application of a copper-based raw material having an outstanding conductivity to the current-carrying bellows and the improvement of the permissible current value resulting from direct cooling of the bellows. Regarding the performance characteristics needed for the bellows, there are multiple factors of development not relating only to the reduction of ohmic loss but also to the shape of bellows enough to withstand repeated expansion and contraction, mechanical strength of raw materials, and adequate adoption of a low spring constant that does not affect the rotation torque of the screw actuator shaft.

The development of bellows is an important theme for product competitiveness against compet-

itors, and we will continue to research and develop new technologies including low-loss current-carrying bellows for even higher currents. Furthermore, in addition to the high current, demand is also expected for increased capacitance, high-speed, high-precision adjustment and we intend to develop new products to meet the expectations of our customers. We would like to express our deepest gratitude to the many people involved who have given us great cooperation during the development of this product.

· All product and company names mentioned in this paper are the trademarks and/or service marks of their respective owners.

《Reference》

(1) Tatsumi, Takahashi, Murayama: "Large-Current Variable Vacuum Capacitor (VVC)", Meiden Review Vol.177, No.3/2019, pp.25-27