Vacuum 101 (2014) 212–216

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Copper coated carbon fiber reinforced plastics for high and ultra high vacuum applications

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ARTICLE INFO

Article history:
Received 14 August 2013
Received in revised form
30 August 2013
Accepted 31 August 2013

Keywords:
Vacuum chamber
Carbon fiber reinforced plastic
Copper coating

ABSTRACT

We have used copper-coated carbon fiber reinforced plastic (CuCFRP) for the construction of high and ultra-high vacuum chambers. The vacuum performance is found to be comparable to typical stainless steel used for this purpose. In test chambers we have reached pressures of 2×10^{-8} mbar and measured a desorption rate of 1×10^{-11} mbar l/s m^2; no degradation over time (2 years) has been found. Suitability for baking has been found to depend on the CFRP production process, presumably on the temperature of the autoclave curing. Together with other unique properties of CuCFRP such as low weight and being nearly non-magnetic, this makes it an ideal material for many high-end vacuum applications.
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1. Introduction

Many of today's technologies and research techniques depend on processes and methods in high or ultrahigh vacuum. Traditionally vacuum chambers are most often made of a variety of metals especially of various grades of stainless steel. However, in certain applications stainless steel can be problematic as it is magnetic or at least magnetizable, has a relatively high weight, and is electrically conductive.

At the Paul Scherrer Institut, Switzerland an experiment to search for a permanent electric dipole moment of the neutron (nEDM) is running [1], while a ten time more sensitive next generation experiment is being setup. The measurements are performed inside a magnetically shielded room in vacuum and are extremely sensitive to any perturbation or inhomogeneity of the magnetic field. It is of paramount importance to avoid all magnetic or magnetizable materials within the vacuum chamber. Even parts made of non-magnetic stainless steel or aluminum are disfavored as electrical conductivity leads to Johnson-Nyquist noise [2]. The spectral density of Johnson-Nyquist noise is proportional to the thickness of a conductive layer, hence we studied vacuum and magnetic properties of micrometer thin copper coatings on high performance carbon fiber reinforced plastic (CFRP).

2. Requirements and samples

Any material of and within the vacuum chamber has to fulfill among others the following stringent requirements:

- No measurable magnetic impurities and magnetizability (local magnetic moments $M < 5$ nA m^2 before and after contact with strong magnet).
- Low magnetic spectral noise density (≤ 20 fT/$\sqrt{\text{Hz}}$)
- Very low bulk electric conductivity ($\sigma < 10^4$ S/m), or a very thin conductive layer on insulator ($d < 20$ μm).
- No helium permeability.
- Desorption rate below 10^{-10} mbar l/s m^2.

Carbon fiber reinforced plastics are known to have excellent mechanical properties and can be tailored to design. This allows to reduce weight and still excel in strength of shape. Three different samples (Fig. 1) were produced to investigate the properties of copper-coated CFRP: A square plate ($100 \times 100 \times 5$ mm^3), a custom designed and tailored vacuum chamber made from high performance CFRP, and a

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http://dx.doi.org/10.1016/j.vacuum.2013.08.021

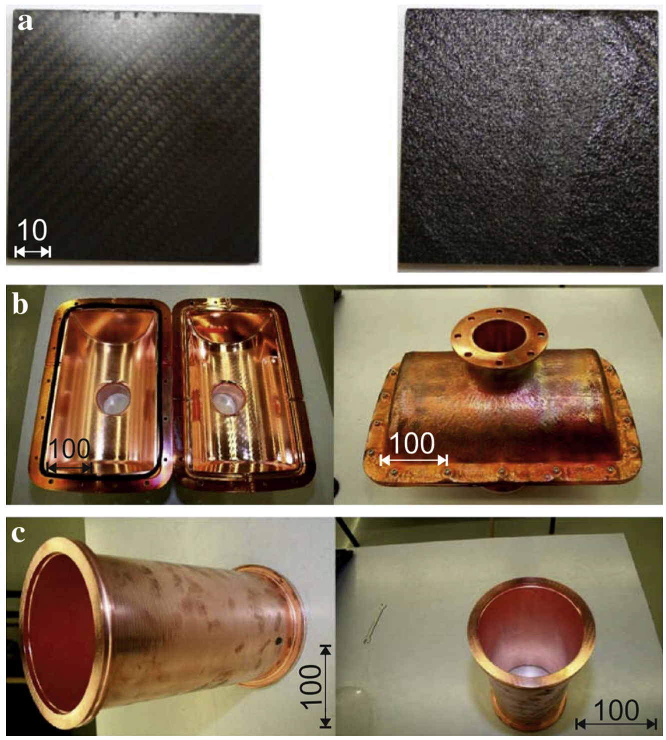

Fig. 1. a. CFRP sample before coating (front and backside), b. Cu coated CFRP vacuum chamber, c. Cu coated CFRP vacuum tube. Three different test pieces were used to investigate the vacuum properties of copper-coated CFRP. The square CFRP sample (a) was first characterized without coating, later with. A custom made model (b) of a possible later application was made using one aluminum negative to make two half shells. A standard, “off-the-shelf”, CRFP tube (c) was fitted with two custom made ISO-K DN160 flanges to demonstrate that the technology can be used to produce standard vacuum parts (all scales inserted in the pictures are in mm).

standard vacuum tube made from lower grade CFRP with inside diameter 150 mm[1] with two ISO-K DN160 flange.[2]

The suitability of the material with respect to its magnetic properties was shown in the BMSR-II of the PTB in Berlin [3]. Fig. 2 compares the noise spectrum of a CFRP plate, a copper-coated CFRP plate, and an aluminum electrode. Both CFRP samples showed no dipole structure and a peak to peak magnetic field of $B < 40$ pT in a distance of ∼3 cm even after magnetization with a strong permanent magnet. We consider the material suitable for our magnetic requirements and will concentrate on the vacuum properties in this article.

3. Sample characterization

3.1. CFRP plate

In an initial step we determined the out-gassing characteristics of the sample plate without coating. The plate was cleaned in an ultrasonic bath of pure ethanol. Then the out-gassing rate of the CFRP plate was measured in a stainless steel vacuum chamber connected to a turbo pump (TPH 330, Pfeiffer) and roughing pump (SC 5, Leybold) with a pump speed of 200 l/s. The pressure, which in our geometry using a 10 × 10 cm^2 (∼200 cm^2 surface) sample easily relates to the out-gassing rate, was measured using an ionization gauge (TPG 300/IKR 020, Balzers). Fig. 3 shows three

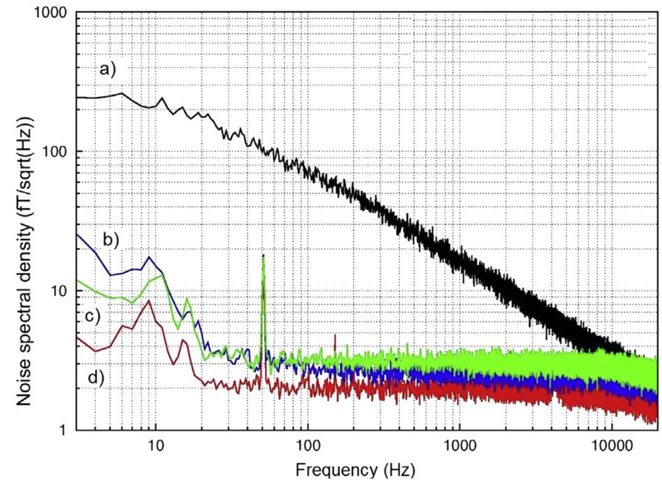

Fig. 2. Comparison of spectral noise measurements using an array of SQUIDS at PTB [4]. The noise spectrum of the actually used Al electrode (thickness 30 mm (a) was an order of magnitude larger than of both CFRP samples: b) uncoated CFRP, c) 500 nm Cu on CFRP. The system noise (d) is shown as reference. Note, that this CuCFRP sample was produced using magnetron sputtering; galvanically coated CFRP typically has a Cu-layer thickness of ∼20 μm and hence a slightly higher noise spectrum.

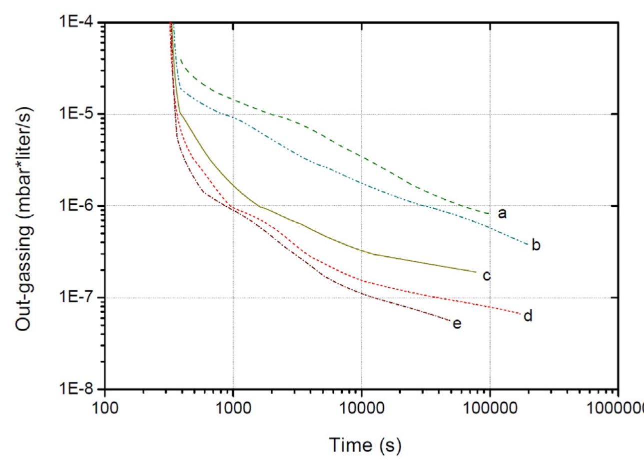

Fig. 3. Out-gassing of a 10 × 10 cm^2 CFRP sample in a test vacuum chamber. a) First vacuum pumping after cleaning in purified benzine; b) second vacuum pumping after leaving sample in air for 24 h; c) after baking for 24 h at 100 °C and exposing to air for 1 min. The last two curves have been measured after coating the sample galvanically with 20 μm of copper: d) First vacuum pumping after coating, e) second after baking the sample at 100 °C and exposing it to air for 2 h.

measured curves for the uncoated CFRP plate: (a) sample directly after cleaning, (b) after a first vacuum pump down and subsequent exposure to air for 24 h, and (c) after baking for 24 h and 1 min exposure to air.

Next the sample was coated by Galvanic Wädenswil[3] using a proprietary galvanic procedure. This unique technique avoids any aggressive or implantation preparation processes, guaranteeing the conservation of the surface quality and maintaining the non-magnetic properties of the sample. The curves (d, e) on Fig. 3 show the out-gassing of the coated sample. The copper coating reduced the out-gassing by a factor of ten to less than 7×10^{-8} mbar l/s which further improved by a factor of two after baking the sample at 100 °C.

We also characterized the composition of the residual gas for a coated and an uncoated sample plate using a quadrupole mass

[1] Produced by C-Tech, PO Box 71-131, Rosebank, 1348, Auckland, New Zealand.
[2] All custom made parts were produced by Pauco Plast http://www.paucoplast.ch/, using LTM12/CF 0300 LTM12/CF 0700.

[3] http://www.galvanic.ch/.

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