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Some Getter Numbers

1 Introduction

This is a brief stab at understanding the balance of gas load and getter capacity. A lot of this may be wrong- that's the point of writing it down for others to read, so please read critically. Also there are places to be filled in as well as corrected.

2 Getter Capacity

2.1 Getter Materials

There are 2 SAES getters we are considering: ST707 [1] and ST122 [2, 3].

2.1.1 ST707

1. Composition: ST707 is 70% Zirconium, 24.6% Vanadium, and 5.4% Iron.
2. Activation: Two hours at 350C activates it to 90% or more.
3. Non-activation: Giannantonio et al [4] baked for 3 days at 200C before activation. The spec is less specific, quoting only limits: less than $< 20\%$ for two hours at 200C and less than $< 40\%$ at 200C for 10 hours [1].
4. Getter mass per area: ST707 strip has a getter mass of 20 g/m for a double-coated 30 mm (3cm) strip (70 microns per side) [1], i.e. calculating the density from the mass in a meter-long strip:

$$\sigma_{707} = (20\ \ \text{g})/(3\ \text{cm} \times 100\ \text{cm}) = 67\ \text{mg/cm}^2 \tag{1}$$

2.1.2 ST122

1. Composition: Nominally 70% Ti and 30% ST707 [2] [1]
2. Activation: Know only that 6 hours at 350C is approximately 90%
3. Non-activation At 200C the activation is $< xxx\%$ for two hours and $< xxx\%$ for 10 hours (i.e. I don't know);
4. Getter mass per area: ST122 is a mix of Ti and ST707. The total getter mass of a 100 micron thick layer is [2]:

$$\sigma_{122} = 20\ \text{mg/cm}^2 \tag{2}$$

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[1] We can also solve for the fraction of Titanium by putting in the densities for Titanium ($\rho = 4.43$) Zirconium ($\rho = 6.49$) Vanadium ($\rho = 5.8$), and Iron ($\rho = 7.9$), with the result that ST122 is 86% Titanium and 14% ST707, with a (guesstimated) uncertainty of approximately 5%. The original paper for ST122 also quotes approximately 70% Titanium [?], although the claim on the patent allows between 10 and 90% [?]. In any case, it's at least 2/3 Titanium.

2.2 Number of Titanium or Zirconium atoms per milligram

This may not be useful, but may help to set a scale for adsorption.

2.2.1 Titanium: A=48

Following Herring [6], the molecular mass of Ti is 48 grams/mole, so that one mg of Ti (the major component of ST122) contains

$$N_{Ti} = (1/48 \text{ moles/g}) \times (10^{-3} \text{ g/ mg}) \times (6.02 \times 10^{23} \text{molecules/mole}) = 1.25 \times 10^{19} \text{atoms/mg} \tag{3}$$

2.2.2 Zirconium: A=91

One mg of Zr, which is the major component of ST707, contains 48/91 of the number for Ti above:

$$N_{Zr} = 6.6 \times 10^{18} \text{ atoms/mg} \tag{4}$$

3 Getter Mass in the LAPPD Configuration

We assume the configuration is the ‘Getter Necklace’ around the 8” by 8” MCPs, approximated as a square with sides 8” long (the true length will be closer to 8.13” per side). We take the strip transverse dimension to be 1/4”.

3.1 ST707

Consider one strip of ST707 around the perimeter 1/4” wide by 32” long, coated both sides. The area is

$$0.25 \text{ in} \times 32 \text{ in} \times (2.54 \text{ cm/in})^{2‘} = 52 \text{ cm}^2 \tag{5}$$

3.1.1 In grams

The total amount of getter is:

$$\mathrm{M_{getter}} = 67 \text{ mg/cm}^2 \times 52 \text{ cm}^2 = 3.48 \text{ gm}, \tag{6}$$

i.e. 3.5 grams per strip.

3.1.2 In atoms

Assuming that all the atoms sorb like Zr (a factor of 0.7 at most):

$$\mathrm{M_{getter}} = 3.5 \text{ g} \times (1000 \text{ mg/ g}) \times (6.6 \times 10^{18} \text{ atoms/mg}) = 2.3 \times 10^{22} \text{ atoms} \tag{7}$$

3.2 ST122

Consider one strip of ST122 around the perimeter 1/4” wide by 32” long, coated both sides. The area is again:

$$0.25 \text{ in} \times 32 \text{ in} \times (2.54 \text{ cm/ in})^{2‘} = 51.6 \text{ cm}^2 \tag{8}$$

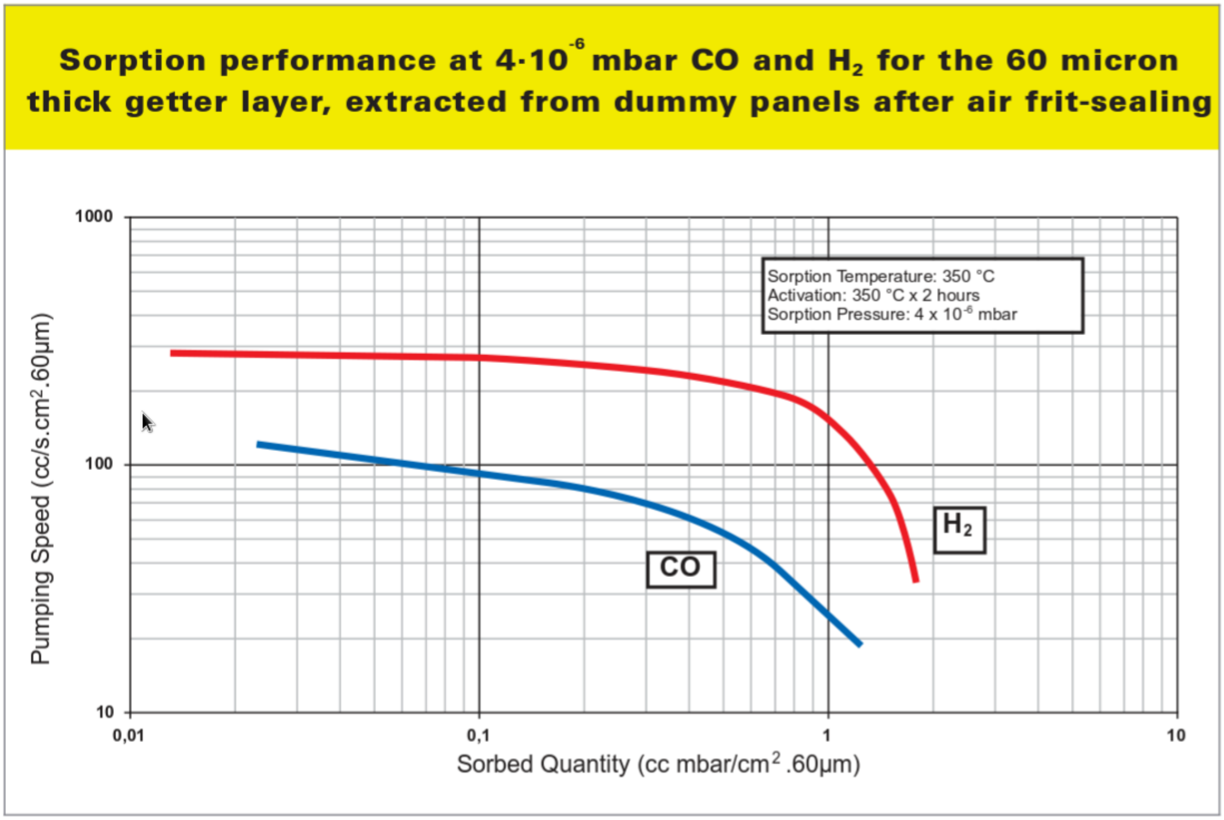

Figure 1: The pumping speed vs sorbed quantity for a 60-micron layer of ST122 for CO and H2, with a 2-hour bake at 350C for activation. Note that the sections above describe getters with two layers 150 microns thick, i.e. a factor of 6 total if it's linear.

3.2.1 In grams

From the ST122 spec [2] the density of getter in a layer 100μ m thick is 20 mg/ cm^2

The density per unit area of a double-sided strip with 150 μ m thick layer on each side is

$$\rho = 20 \text{ mg} \times (300\mu m/100\mu m) = 60 \text{ mg/ cm}^2 \tag{9}$$

The amount of getter per strip is:

$$\text{M}_{\text{getter}} = 60 \text{ mg/cm}^2 \times 51.6\text{cm}^2 = 3100 \text{ mg} = 3.1 \text{ gm}, \tag{10}$$

i.e. 3.1 grams per strip, very similar to that for ST707.

3.2.2 In atoms

Treating ST122 as being all Titanium, the number of atoms is:

$$\text{M}_{\text{getter}} = 3.1 \text{ gm} \times 1000 \text{ mg/ g} \times 1.25 \times 10^{19} \text{ atoms/mg} = 3.9 \times 10^{22} \text{ atoms} \tag{11}$$

4 ST122: Pumping CO

Figure 1 shows the pumping speed versus sorbed quantity in cc-mbar/cm^2 for a 60-micron ST122 layer activated at 350C for 2 hours (we know only that 6 hours gives 90%).

Consider the curve at Sorbed Quantity= 1 cc mbar/cm^2. An LAPPD getter strip made of ST122 would have an area of 52 cm^2 and a thickness of 300 microns, for a net factor of $(52 \times 300/60) = 260$. Converting cc-mbar to molecules of CO (see Appendix A):

$$260 \text{ cc-mb} \times (2.69 \times 10^{16} \text{ molecules/cc-mb}) = 7.0 \times 10^{18} \text{ molecules} \tag{12}$$

Note that the getter still has a pump speed of 4.1 l/s at this point, so this is a lower limit. If we extrapolate the CO curve as a straight line to a pump speed 10-times lower, the sorbed quantity is approximately 6 times larger, but it's not clear what the full saturation quantity is.

5 Pumping Water

5.1 ST707

In Table II Giannantonio et al [4] quote numbers for SAES CapaciTorr pumping using 378 grams of ST707 augmented by Zr powder (Zr is the dominant component of ST707). They baked at 200C for 3 days, seemingly without activating the getter. They then activated at 540C for 45 minutes, well beyond what we will do. We will assume that although the absolute numbers change, the relative pumping speeds of H2O and CO remain constant. They quote 650 l/s for H2O, 500 l/s for H2, and 200 l/s for CO. This predicts a factor of 3.25 faster pumping of H2O for us assuming the ratio doesn't change with activation temperature.

Giannantonio et al also quote a capacity of 20 bar-liters for CO. If we assume that the capacity scales as the pumping speed (I think this is reasonable- both H2O and CO should depend on the surface area), the capacity for water in molecules per gram is then:

$$(20\text{bar-liters})/(378 \text{ g}) \times (6.02 \times 10^{23} \text{molecules/A})/(22.4 \text{liters/mole}) = 1.42 \times 10^{21}/A \text{molecules/g} \tag{13}$$

For water A=18, so the capacity per gram of ST707 is 7.9×10^{19} molecules per gram.

One strip has 3.5 grams of ST707, for a total capacity of

$$\text{Total Sorbance of 1 strip} = 2.8 \times 10^{20} \text{H2Omolecules} \tag{14}$$

7.1×10^{21} H2O molecules. This may have to be derated somewhat by the lower activation temperature, but the ST707 spec claims greater than 90% for 2 hours at 350C.

5.2 ST122

For ST707 Giannantonio quoted a capacity for CO [4]. For ST122 I've been unable to find either the capacity or a ratio of water/CO pump speeds.

6 Water Gas Load

The MCP plates have very large surface area due to the 65% Open Area Ratio. We need to get most of the water off before activation, as is shown below.

6.1 Mono-layer of Water on the MCPs

The molecular weight of water is 18, and density is 1.0 gm/cc, so there are $6.02/18 = 3.34\ 10^{22}$ molecules/cc. Measurements of the thickness of a double molecular layer of water give 0.7 ± 0.1 nm [9]. The surface density of water molecules is then

$$\sigma_{H2O} = 3.34\ 10^{22}\text{molecules/cc} \times (7 \times 10^{-8}\ \text{cm}) = 2.34 \times 10^{15}\ \text{molecules/cm}^2 \tag{15}$$

Each MCP has an area of $6.5\ m^2 = 6.5 \times 10^4\text{cm}^2$ [8], giving a total water load of

$$(2\ \text{MCPs}) \times (2.34 \times 10^{15}\ \text{molecules/cm}^2) \times = 6.5 \times 10^4 cm^2 = 2.7 \times 10^{20}\ \text{molecules.} \tag{16}$$

7 Conclusions

1. A getter-necklace of ST707 activated at 350C for 2 hours is predicted to have a capacity of 2.8×10^{20} water molecules (Equ. 13).
2. A double molecular layer of water on two LAPPD 20-micron MCPs contains 2.7×10^{20} molecules (Equ. 16).
3. For ST122 we do not have the same information. It seems unlikely that ST122 is much worse than ST707.
4. For both ST707 and ST122 there are enough atoms if every atom sorbed a water molecule: and 3.3×10^{22} Zratoms and 3.9×10^{22} Ti atoms vs 2.7×10^{20} water molecules. It would be good to understand what fraction of sites are occupied at full sorb.
5. ST707 comes in the more easily used format of strips, has a higher activation temperature so that a dewatering bake at 200C seems to have no effect, and we have some on hand. I suggest we go with it.

8 Acknowledgements

I thank Dean Walters for very helpful suggestions and detailed references to the literature. Many thanks to Eric Spieglan and others for discussions. Bernard Adams found a number of mistakes as well as making some good suggestions. All of the remaining mistakes are my own.

9 Appendix A: Conversions

9.1 cc-millibar to Molecules

$$22.4\ \text{liter-bar} = 6.022 \times 10^{23}\text{molecules} \tag{17}$$

$$22.4 \text{ liter-bar} \times (10^3 \text{ cc/liter}) \times (10^3 \text{ mb/bar}) = 6.022 \times 10^{23}\text{molecules} \tag{18}$$

$$1 \text{ cc-mb} = 6.022 \times 10^{23}\text{molecules}/(22.4 \times 10^6) = 2.69 \times 10^{16} \text{ molecules} \tag{19}$$

9.2 cc-Torr to Molecules

1 Torr = 1.3 millibar, so there are 1.3 times as many molecules in 1 cc-Torr as there are in 1 cc-mb:

$$(1 \; cc\text{- Torr}) = 1.3 \times (2.69 \times 10^{16}) = 3.54 \times 10^{16}\text{molecules} \tag{20}$$

9.3 liter-Torr to Molecules

There are 1000 cc in a liter, so:

$$1 \text{ liter-Torr} = 3.54 \times 10^{19} \text{ molecules} \tag{21}$$

9.4 Milligrams to Molecules

For a substance with molecular weight A, there are A grams/mole, and so 1/A moles/gram. So:

$$1 \text{ mg} = 1 \times 10^{-3} \times (1/A) \times 6.02 \times 10^{23} \text{ molecules} \tag{22}$$

10 Appendix B: Pumping Hydrogen

10.1 Number of hydrogen atoms absorbed per Zr molecule by ST707

. At a temperature of 20C, the H_2 to Zr mole ratio (I think this is the number of H2 molecules per Zr molecule) is 1.2, i.e. a little *more* than 1 molecule per Zr molecule [7]. The quantity of H_2 absorbed by the Zirconium in ST707 is

$$N_{H2} = 1.22 \times 0.66 \times 10^{19} atoms = 0.79 \times 10^{19} \text{ molecules/mg.} \tag{23}$$

10.2 Capacity for H2 of ST707 in the LAPPD Configuration

From above, the number of H2 molecules that can be absorbed in the 5 grams of Zirconium is

$$0.79 \times 10^{19} \text{ molecules/mg} \times 1000\text{mg/gm} \times 5\text{gm} = 4.0 \times 10^{22} \text{ molecules.} \tag{24}$$

This doesn't look consistent with the curve for H in Figure 1, although that is for ST122 and not ST707, and it isn't fully activated. The curves for a 500C activation show a much bigger difference between H and CO.

References

[1] http://psec.uchicago.edu/getters/St 707 Brochure.pdf; http://psec.uchicago.edu/library/mechanical_assembly/

[2] http://psec.uchicago.edu/getters/SAES_ST122_FED_HPTF_and_PLASMA_HPTF_datasheets.pdf; see also: Technical Specification of ST122/NCF-A4-450/50/300/2X23.4/D-UE on the same page.

[3] E. Giorgi and B. Ferrario, IEEE Transactions on Electron Devices, Vol 16, no. 11 Nov. 1989; http://psec.uchicago.edu/library/mechanical_assembly/

[4] Giannantonio, R.; Succi, M.; and Solcia, C. ”Combination of a cryopump and a non-evaporable getter pump in applications” J. Vac. Sci. Technol. A 1997, 15, p. 187

[5] The atomic weights of Zirconium and Titanium are 91 and 48, respectively, for a ratio of 1.9.

[6] D. Herring, Getter Materials; Vac Aero; http://psec.uchicago.edu/getters/danherring_getter_info.pdf

[7] I. Hsu and B.E. Mills, SAND2010-5402. http://psec.uchicago.edu/getters/sandia_ST707_getter_data_1 Note that the Zr is only 70% of ST707 (by weight?).

[8] Jason McPhate, https://psec.uchicago.edu/blogs/lappd/?p=1712

[9] A. Opitz, M. Scherge, S.I.-U Ahmed, and J.A. Schaefer; *A comparative Investigation of Thickness Measurements in Ultra-thin Water Films by Scanning Probe Techniques*, https://arxiv.org/pdf/cond-mat/0512109.pdf