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Progress report on the development of a very high sensitivity parametric transducer for the Mario Schenberg Gravitational wave detector

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Abstract. We have constructed the Mario Schenberg gravitational wave detector at the Physics Institute of the University of Sao Paulo as programmed by the Brazilian Graviton Project, under the full support of FAPESP (the São Paulo State Foundation for Research Support). We are ready to do a first test run of the spherical antenna at *4.2K* with three parametric transducers and an initial target sensitivity of $h\sim10^{-21}Hz^{-1/2}$ in a *60Hz* bandwidth around *3.2kHz*. The parametric transducers to be used on the Mario Schenberg detector consist of reentrant klystron copper-aluminum cavities covered with a thin layer of niobium on the walls and on the oscillating membrane. The gap between the central conical post and the membrane is about *40μm*. Here we present a progress report on this transducer development related with niobium layer deposition in the transducer cavities and on the design of silicon membranes for the last transducer mechanical mode.

1. Introduction

The Mario Schenberg gravitational wave detector is almost completed at its site at the Physics Institute of the University of São Paulo, in São Paulo city, Brazil, under the full support of FAPESP. We have made a first cryogenic run for an overall test, in which we measured the mechanical Q (figure of merit) of some of the five spherical antenna quadrupole modes, which are spread in the 3172–3240 Hz range due to the broken symmetry caused by the axial hole machined inside the spherical antenna. Values close to Q = 2.7 million were found around 2 K [1]. This 1.15 ton and 65-cm-diameter CuAl6% antenna will have a strain noise power spectral density of 2×10^{-23} $Hz^{-1/2}$ when it reaches the standard quantum limit of sensitivity, at about 20 mK [2]. It will be operating in coincidence with the

Dutch Mini-GRAIL antenna and some long baseline laser interferometer detectors [3], searching for high frequency events in the 3.0–3.4 kHz frequency bandwidth.

Parametric transducers used in gravitational wave detectors convert mechanical vibrations into electrical signals at much higher frequency, amplifying the signal energy by the intrinsic parametric gain. One kind of parametric transducer, which will be used in the Brazilian Mario Schenberg detector [4, 5], was developed by both the Japanese and the Australian groups [6, 7]. We will use parametric transducers, each of them composed, among other parts, by a re-entrant (klystron) cavity pumped at a microwave frequency around 10.0-10.5 GHz (which is in the X-band). This transducer consists of a copper-aluminum klystron cavity covered with a thin layer of niobium on the walls (bulk niobium transducers might present problems for the adequate cooling down below the critical temperature of niobium) having a central post with a narrow gap between its top and an oscillating membrane (with *10mg* mass), mechanically coupled to the gravitational wave antenna at its resonant frequency [8, 9]. The electrical resonant frequency of the cavity is very sensitive to the gap distance.

The transducer will have two mechanical modes tuned to 3.2 kHz, one will be composed by a 53 g intermediate mass and the other by a 10 mg (membrane) mass. When coupled to the 1.15 ton spherical antenna, which has an effective mass of about 287 kg in each of its fundamental quadrupole modes [10, 11], the transducer will amplify the amplitude oscillation of the spherical antenna by a factor of (287 kg/10 mg)1/2 ~ 5 k.

We will install nine complete transducer-amplifier systems and the data acquisition hardware. Six of the positions follow the truncated icosahedron configuration and the other three, used for redundancy, calibration, and tests, were chosen to have the same 'latitude' as the ones close to the "equator" and the same 'longitude' as the ones close to the "north pole".

Our plan is to make a test with nine transducers attached to the antenna at 4.2 K, trying to reach a strain noise power spectral density of 2 × 10–21 $Hz^{-1/2}$, in a 50 Hz bandwidth around 3.2 kHz by the end of 2005.

The performance of the transducer depends on some parameters, as cavity's *Qe* and electrical coupling, among other parameters [12]. Figure 1 shows the several components of the Mario Schenberg detector.

2. The Microwave Reentrant Cavity

The main reason to use a thin layer of niobium covering the walls of the copper-aluminum cavity is that below *9.1K*, niobium is superconductor and the superconducting surface reduces the electrical losses in the transducer. $Qe's \sim 10^9$ have been measured in niobium cylindrical cavities at *4.2 K* [13]. Evidently we do not expect such high Q values for these reentrant cavities. However, we have already measured values of electrical Qs as high as 1-2 x 10^5 [9].

To cover the walls of the copper-aluminum cavity with a thin layer of niobium we can use a special coating over metallic material applied by Electron Beam – Physical Vapor Deposition (EB-PVD). In order to do this we used the facilities of the Divisão de Materiais AMR-CTA.

The EB-PVD process allows attaining coatings with unique properties. It can be adjusted so that the deposit has a columnar grain structure perpendicular to the interface. This morphology maximizes the resistance to strains that arises from differences of the thermal expansion coefficients. Other advantages are better interaction with the substrate, greater thermal cycle tolerance and, hence, greater lifetime compared to the plasma spray process [14]. In this process, we used an electron gun with accelerating voltage of 23,5kV and beam current 0.8A. The deposition time was between *20* and *60 minutes*, producing films with thickness between *2μm* and *40μm* (Figure 2). The vacuum system has an ultimate pressure of 10^{-6}*torr* (~10^{-4}*Pa*) [15], which is measured and maintained by a thermocouple and programmable temperature controller.

Figure 3 shows a copper-aluminum klystron cavity with the walls covered with a thin layer of niobium using the process EB-PVD.

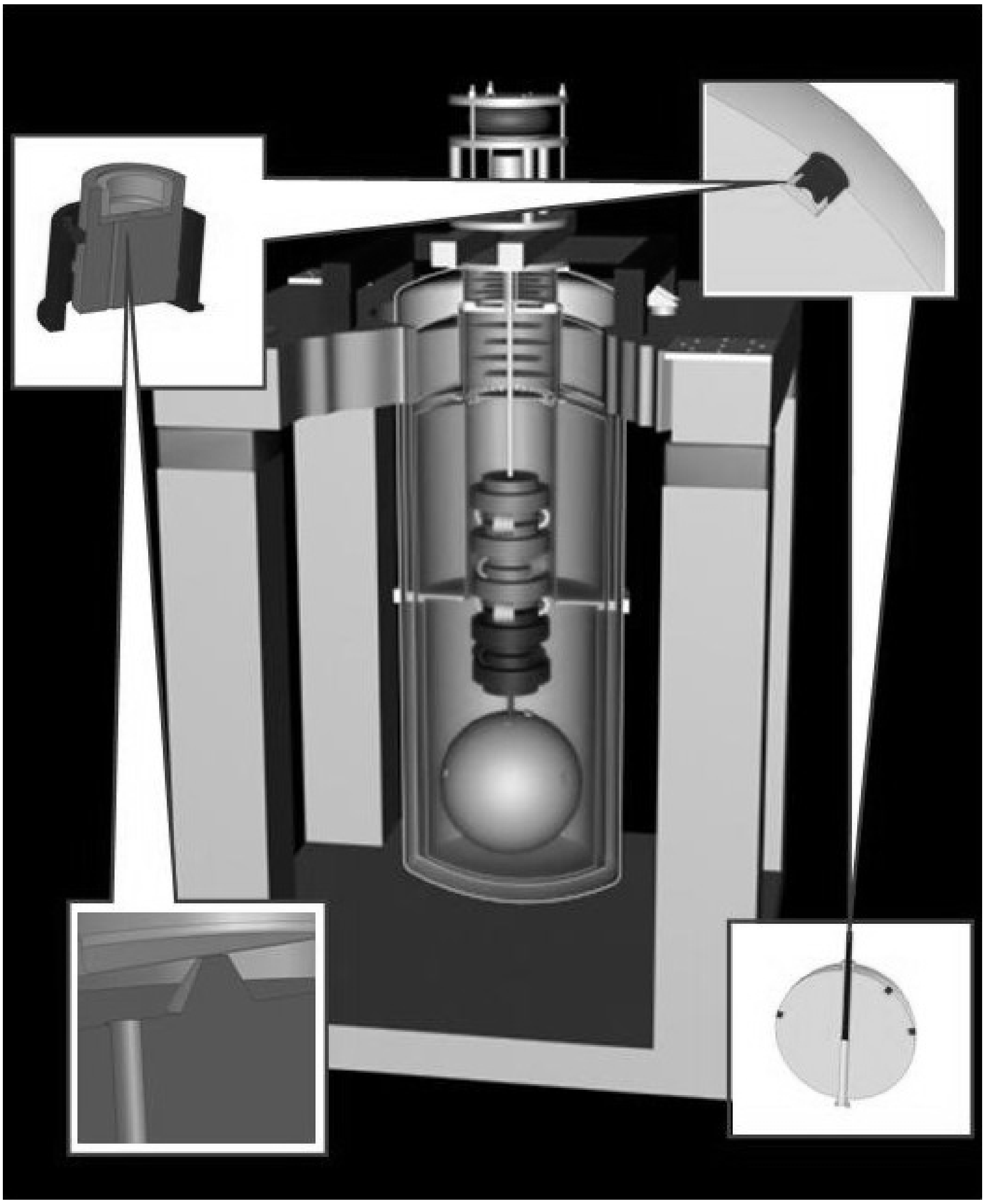

Figure 1 - Mario Schenberg Detector. The resonant mass (sphere) will be kept in vacuum, isolated of the mechanical noises. Nine parametric transducers (see details in references [4] and [5]) will be used to monitor their fundamental modes of vibration (six of the positions follow the truncated icosahedron configuration on the top hemisphere and the other three, used for redundancy, calibration, and tests, were chosen to have the same 'latitude' as the ones close to the "equator" and the same 'longitude' as the ones close to the "north pole"). When coupled to antenna, the transducer-sphere system will work as a mass-spring system with three modes, where the first will be constituted by the antenna effective mass (*287.5 kg*); the second will be constituted by the own mechanical structure of the transducer (*53g*); and the third way will be constituted by a membrane that will close the transducer cavity reentrant (*10mg*) and oscillating in *3.2 kHz*.

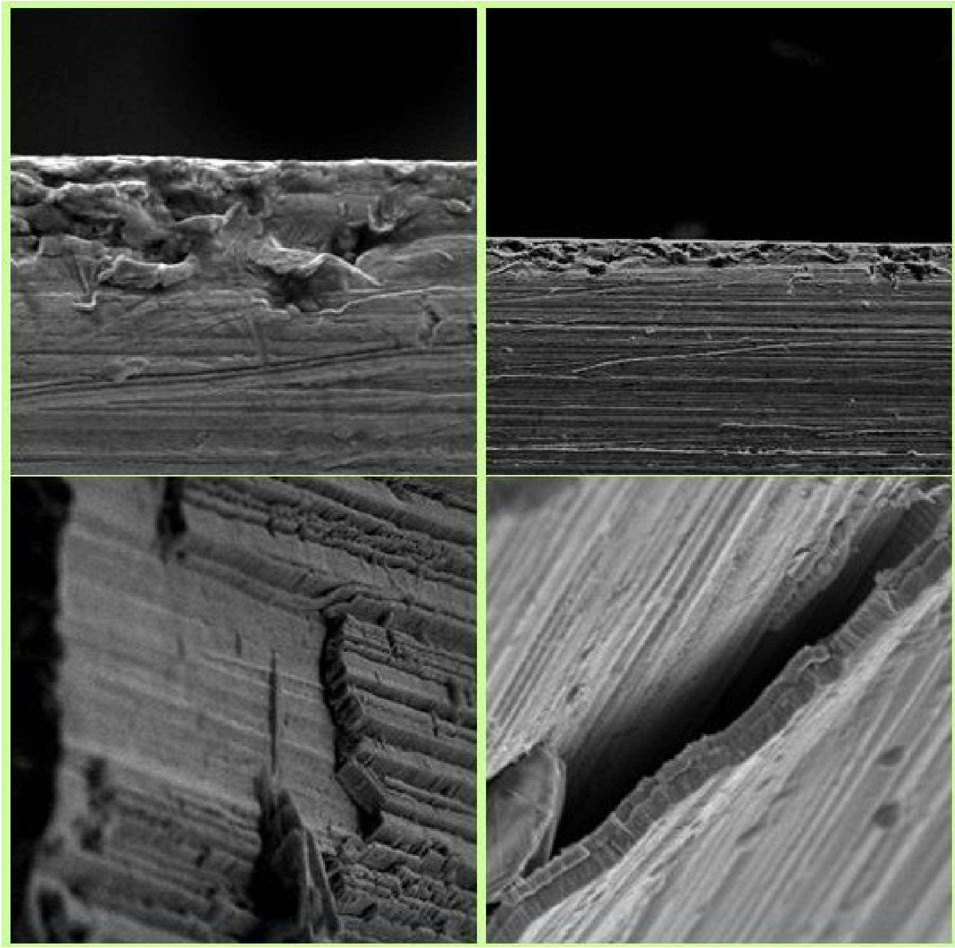

Figure 2 – The image of the copper-aluminum cavity with a thin layer of niobium. The layer was applied by EB-PVD. In this process, we used an electron gun with an accelerating voltage of *23.5kV* and a beam current of *0.8A*. The deposition time was between *20* and *60 minutes*, producing films with thickness between *2μm* and *40μm*.

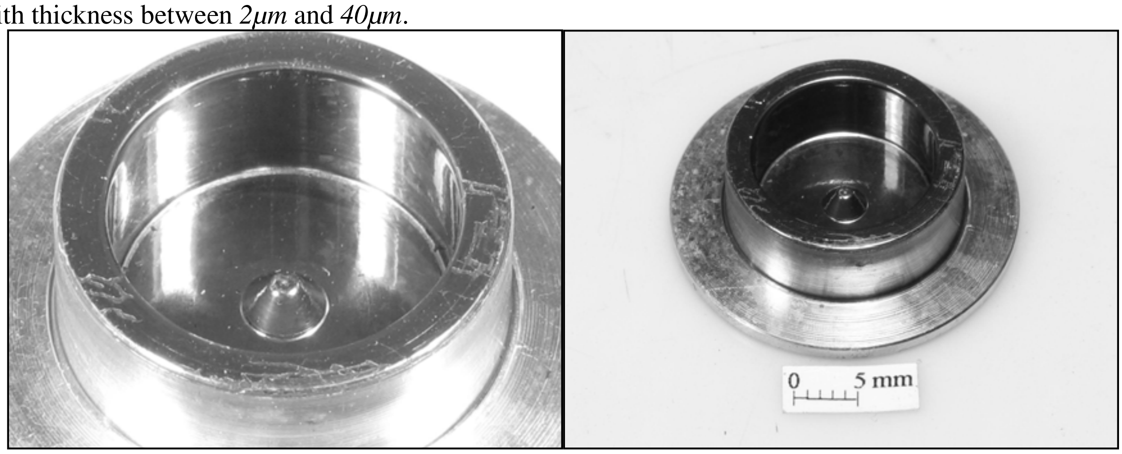

Figure 3 - Copper-aluminum klystron cavity covered with a thin layer of niobium.

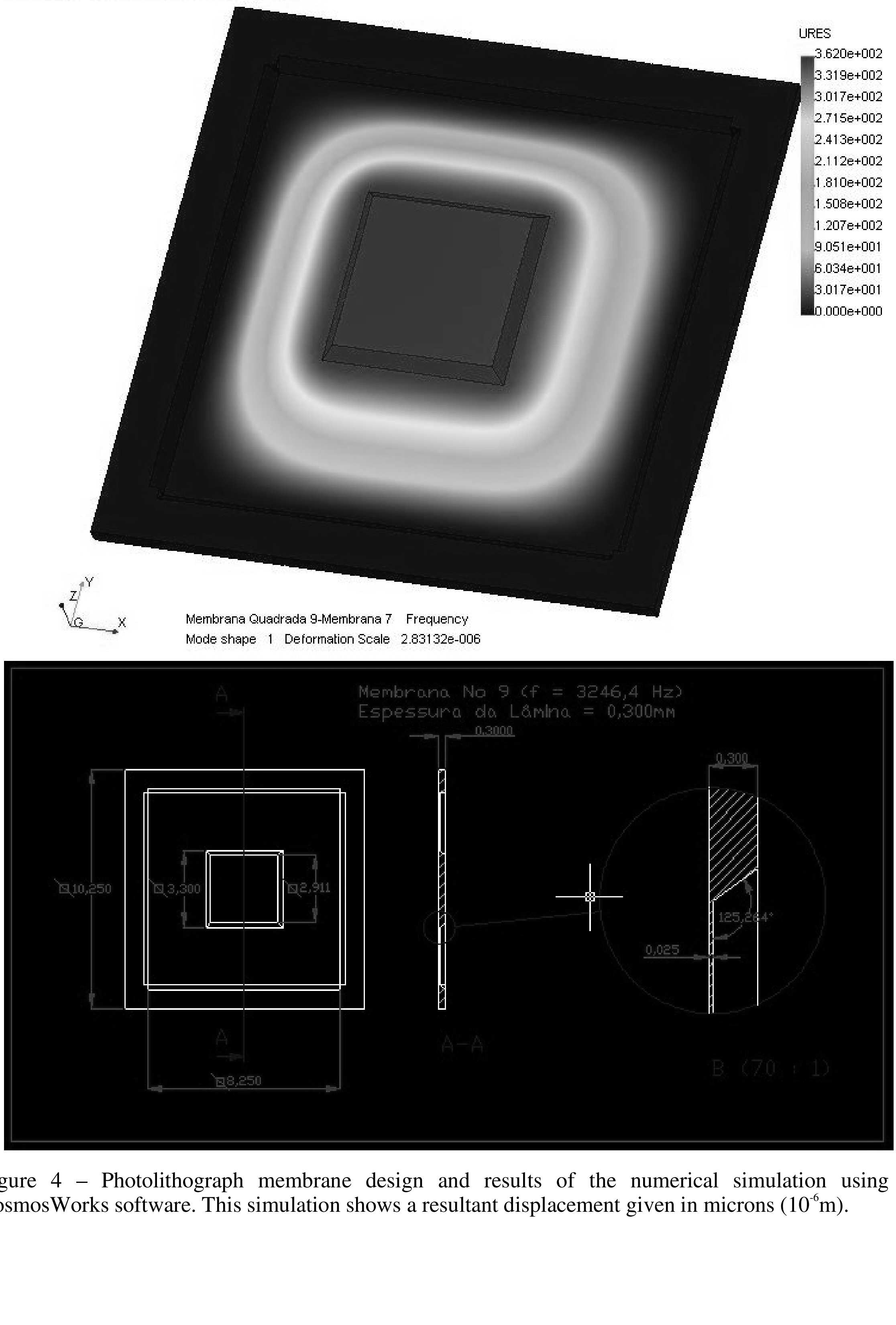

Figure 4 – Photolithograph membrane design and results of the numerical simulation using CosmosWorks software. This simulation shows a resultant displacement given in microns (10^{-6}m).

3. The Oscilating Membrane

The construction of membranes with *10mg*, to be used in the Schenberg detector, is challenging. Numerical simulations (with CosmosM and CosmosWorks) showed that their thickness should be *0.04mm* for resonance frequency in *3.2 kHz*, if they are made with *CuAl (6%).* Several solutions had been tested in their construction, among them mechanical machining, EDM, and chemical polishing. However, it was not possible to obtain thickness smaller than *0.2mm*, which corresponds to resonant frequencies of about *16 kHz* for the membranes.

A solution proposed to this problem is to construct membranes starting from chemically eroded silicon sheets, and subsequent niobium evaporation in one of their surfaces. We intend to use the facilities of the Laboratório Associado de Sensores (LAS/INPE). The corrosion speed differs among the crystallographic silicon plans, thus taking into account such differences we are developing a photolithograph. Figure 4 shows the photolithograph design and results of the numerical simulation.

4. Next Steps

The transducer tests will be carried out directly on the Schenberg sphere. However, the Schenberg antenna is not reaching a stable temperature below the critical temperature of niobium (*9.1K*) unless we heat sinks the antenna to the liquid helium reservoir. For this reason we are going to test three transducers with gold coated cavities. We want to measure how much vibration this heat sink introduces in the antenna.

5. Conclusion

We are developing high sensitivity transducers made with high electrical Q niobium coated microwave cavities and high mechanical Q silicon membranes. They will be tested directly on the spherical antenna. The goal of the first set of transducers to be tested is to measure the noise introduced by the process of heat sink the antenna in order to guarantee its stable operation below the critical temperature of niobium.

6. Acnowledgments

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