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Study of tungsten based positron moderators

O.G. de Lucio [a,*], M. Pérez [a], U. Mendoza [a], J.G. Morales [a], J.C. Cruz [a], R.D. DuBois [b]

[a] *Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, 01000 México DF, Mexico*
[b] *Missouri University of Science and Technology, Rolla, MO 65409, USA*

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ABSTRACT

Positrons and how they interact with matter has a growing interest in many fields. Most of their uses require the production of slow positron beams with a well-defined energy, but since these particles are usually generated by means of a radioactive source, they are fast and with a broad distribution of energies. For this reason it is necessary to moderate them to lower energies via inelastic collisions. Then, they can be accelerated to the desired energies. This requires the use of a moderator. Tungsten is one of the most commonly used moderator materials because of its reasonable efficiency and relatively low cost. In this work we present different methods of producing transmission tungsten-based moderators, with particular interest in a combination of tungsten thin foils and grids. We also show results about the characterization of these moderators by ion beam analysis and microscopy techniques along with their relative moderation efficiencies.

1. Introduction

The use of positrons is a way to learn about the basic properties of antimatter, as well as a tool to expand our knowledge of the mechanisms of how matter and anti-matter interact. In order to achieve this goal, the production of well-defined low-energy positron beams is a determinant factor, not only in Atomic Physics, but also for several experiments of interest in fields ranging from condensed matter physics, astrophysics, chemistry, biology, medicine and materials research.

Positron beams are commonly generated by means of a radioactive source such as ^{22}Na, through a β^+ decay process. The positrons leaving the source are usually fast and present a wide distribution of energies. Therefore any experiment using that beam should take into account the deconvolution of the energy distribution to provide useful information. An alternative to this method would be the use of a physical process in which the energy of the positrons is reduced and the energetic profile becomes narrower. Such process is known as moderation and it represents a powerful tool for having useful beams. Moderation is based on the fact that a negative work function Φ_+ exists for many solids. A small fraction of the particles implanted into a moderator material are thermalized close enough to the surface to be able to resurface again in a time shorter than the annihilation lifetime. If this happens, the positrons are emitted from the moderator with a kinetic energy equal to the thermally broadened work function. It is known [1,2] that positrons could be trapped in defects present in the material during the diffusion process. Therefore, it is important to prepare such material so only a small number of defects is present; in the case of metals this can be accomplished by annealing.

An important parameter of a moderator material is the energy of the re-emitted positrons (ideally of a few meV, actually $\sim$1 eV), which is strongly influenced by factors related to the structure of the moderator material. An example is the layer composition of the crystalline phase of the moderator. Another important factor is the conversion efficiency, commonly defined as the ratio of the number of thermal positrons emitted by the moderator to the number of high-energy particles entering the moderator. This efficiency is influenced by the fraction of positrons actually arriving at the emitting surface, the probability of the particles to be emitted and the geometric configuration of the moderator.

Over the past decades different moderators for several applications have been developed (see [3] and references therein); currently there is a variety of moderators routinely used in different laboratories to produce slow positron beams. For instance, it is possible to mention solid noble gas moderator [4,5], silicon carbide moderators [6], and tungsten moderators in different forms, like thin films or foils [7–9], arrays of meshes [10–12], single-crystal foils [13], multiple wires [14] or filaments [15], and even with different geometries [16]. Tungsten moderators have lower conversion efficiencies (10^{-4}), when compared to a noble gas moderator (7×10^{-3}) [4]. However it has become one of the most commonly used materials in positron moderator construction, mostly because

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* Corresponding author.

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the relatively low cost, high positron work function and basically no need for maintenance.

The aims of this work were, then: to produce different transmission positron moderators (tungsten thin films and mesh arrays, and tungsten nano-particles embedded in a polymer); to characterize such moderators by different techniques, like ion beam analysis (IBA) and electron and atomic microscopes; and to measure their relative positron conversion efficiency in the presence of a positron emitting source.

2. Experimental procedure

2.1. Preparation of tungsten thin films

For this work, tungsten films were prepared by sputtering. In brief, technical details on the sputtering system employed are as follows: the sputtering system is composed by a 20″ diameter by 20″ height cylindrical sample-preparation chamber. Vacuum is achieved by means of a turbomolecular pump, allowing a base pressure of 6×10^{-6} torr. For growing the W thin films we employed a circular sputtering source of 2.5″ diameter. Process gas is argon; pressure in the system is recorded and controlled by means of a capacitive sensor (MKS baratron) and a proportional gauge. Substrate is placed at the center of the chamber, and the distance between sputtering target and substrate planes can be adjusted. For this work the distance was changed from 4 cm up to 11 cm. It was observed that uniformity of the films depends strongly on the distance to the sputtering target, an extensive description of this can be found in [17]. Once the experimental conditions are set, it is possible to achieve different thicknesses of the tungsten films by varying the exposure time. In this system, it is possible to grow tungsten films with thicknesses ranging from 10 nm in about 2 min up to 0.5 μm in about 60 min.

2.2. Preparation of tungsten nanopowder embedded in Parlodian™ membranes

As a second positron moderator we considered the use of tungsten nanopowder embedded in Parlodian membranes. This material is composed of nitrocellulose in amylacetate, typically as a 2% solution. In a previous work [18], we described in detail the properties of such material and the preparation of the moderator. In brief: we used tungsten (IV) oxide, in the form of a nanopowder, with a particle size <100 nm, as reported and certified by Aldrich Chemistry. By means of an ultrasound cleaner the tungsten nanopowder was dissolved and homogenized in the Parlodian solution. The membrane was cast then, by pouring the solution into distilled water. Hydrophobic properties of the Parlodian allow it to form a membrane with the tungsten nano particles embedded into it. Once the membrane is cast, it is taken out of the water and dried. As shown by the microanalysis, it is possible to control the distribution of tungsten on the Parlodian membrane by varying the nanopowder concentration. The choice of this compound for building a positron moderator was taken since it is a material commonly used in electron microscopy studies. Thus, it should have a resistance to a radiation similar to the one to which it will be exposed.

2.3. Preparation of tungsten mesh arrays

In previous works, which involve the use of positrons for experiments of interest in Atomic Physics, we have been using arrays of a selected number of tungsten meshes. This system has proven to be a reliable positron moderator [19–21]. The moderator offers a large exposed area of the wires conforming the mesh, has a good transparency (80–90%) and handling is much easier since it offers fairly good resistance to mechanical stress exerted on it. The meshes go through a thermal treatment in order to improve the moderator properties of the material. For this work we employed a 100 × 100 wires/inch with a wire diameter of 0.001 inch and an open area of about 80%, tungsten wires in the mesh had 99.95% purity, according to the manufacturer. We varied the number of meshes forming the array, and preliminary results indicated that 6–8 meshes produce an optimum array. Thermal treatment consisted in applying an electric current, flowing normal through the array surface and for about the same time (5 min) in all the arrays constructed. During the treatment of some grids, argon was added, so we could test its influence on the moderator efficiency. Although average temperatures in the meshes when heating were about 2300 °C, we were able to anneal some of the tungsten wires, at least locally, so impurities and defects in the material are effectively removed.

3. Results

Moderators constructed during this work were characterized by means of ion beam analysis (IBA) techniques; microscopy techniques such as atomic force microscopy (AFM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). Also, and in order to measure the relative positron conversion efficiency, each one of the moderators were placed inside of our positron production and transport system (described in detail in [22]), in which they were positioned right in front of a ^{22}Na radioactive source under the exact same conditions; moderated positrons are then ejected from the material by applying an electric potential (750 V), and then follow the electrostatic transport system until they arrive to a channeltron detector used to record them, which

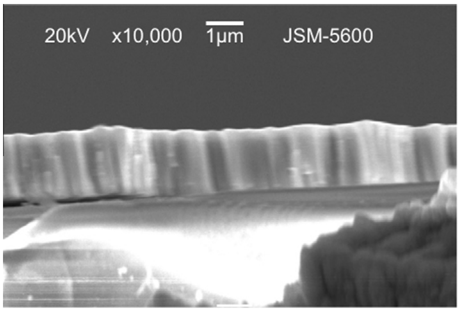

Fig. 1. SEM image showing a transverse section of a tungsten thin film deposited onto a glass substrate by magnetron assisted sputtering.

Table 1
Description of the moderator systems studied and their relative positron conversion efficiency, measured as the number of positrons arriving at the channeltron detector.

System	Relative positron conversion efficiency (particles/second) ±3%
Untreated mesh array	13,000
Treated mesh array (in vacuum)	23,000
Treated mesh array (Ar atmosphere)	12,000
Parlodian membrane with embedded W	4000
Tungsten thin film in untreated mesh	40,000
Tungsten thin film in treated mesh	55,000