Nuclear Instruments and Methods in Physics Research A 645 (2011) 102–112

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Development of a transmission positron microscope

M. Matsuya [a,*], S. Jinno [b], T. Ootsuka [a], M. Inoue [a], T. Kurihara [c], M. Doyama [d], M. Inoue [d], M. Fujinami [b]

[a] JEOL Ltd., 1-2 Musashino, 3-Chome, Akishima, Tokyo 196-8558, Japan
[b] Department of Applied Chemistry, Chiba University, Yayoi, Inage, Chiba, Chiba 263-8552, Japan
[c] High Energy Accelerator Research Organization, Oho, Tsukuba, Ibaraki 305-0801, Japan
[d] Teikyo University of Science and Technology, Uenohara, Yamanashi 409-0913, Japan

ARTICLE INFO

Available online 13 January 2011

Keywords:
Optics
Positron
Electron
Microscope
Brightness
Scattering

ABSTRACT

A practical transmission positron microscope (TPM) JEM-1011B has been developed to survey differences in the interaction of positron and electron beams with materials, and is installed in the Slow Positron Facility of High Energy Accelerator Research Organization (KEK). The TPM can share positron and electron beams, and can also be used as a transmission electron microscope (TEM). Positron transmission images up to magnification 10,000 × (resolution: 50 nm) and positron diffraction patterns up to 044 family were successfully obtained by the TPM comparing them with those of electrons. The differences in material transmittances for both beams have been measured, and can be explained by the calculated results of the Monte Carlo simulation code PENELOPE-2008.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Quantum theory expected positrons before their existence was confirmed experimentally, although there are some different viewpoints for the discovery of positrons [1,2]. A short review of them is given here as it is worth mentioning the basic properties of electrons and positrons which will be used in a transmission microscope.

Based on a relativistic wave equation derived in 1928 [3], Dirac proposed the *hole theory* in which a vacuum is occupied by electrons with every *negative energy* states [4]. If one of these electrons would be eliminated, a hole of electrons would be created, and this hole would appear to us as a particle with positive energy and positive charge $e = 1.602\times10^{-19}$ C in an electromagnetic field. It was predicted further that this particle would have a chance to annihilate with an electron if they collide [5]. Next, Weyl showed that the rest mass of this particle must be equal to that $m = 9.108\times10^{-31}$ kg of an electron [6,7]. Following Oppenheimer [9], Dirac concluded that this particle [4,8] would not be a proton, and that this particle would be stable in high vacuum and would be amenable to observation such as an electron if this particle could be produced, and he called this particle as an *anti-electron* [7].

In 1932, Anderson [10] reported a positively charged particle comparable in mass and magnitude of charge with an electron during the course of photographing cosmic-ray tracks, and he named this positive electron as *positron* [11]. Blackett and Occhialini [12] confirmed the existence of this positive particle and concluded that positive and negative electrons would be created by absorbed γ-rays near the nuclei.

On the basis of the quantum theory of the fields, Bethe and Heitler [13] obtained the cross-sections, which describe the angular intensity of radiated photons. The radiation of photons is well known as Bremsstrahlung (breaking radiation). This theory holds for the reverse process, which creates a pair of positron and electron from a photon, and the required energy difference in this process is based on the hole theory. Finally a theory of second quantization and many-particle theory were able to explain positrons without using holes or negative energy states [14,15]. As stated earlier, we can treat a positron as an electron with positive charge except that positrons annihilate with electrons.

Mott [16] has obtained the cross-section for elastic scattering of electrons by the nuclei based on the Dirac equation [3]. Grounded on its formulae, Bartlett and Watson [17] numerically calculated the elastic scattering intensity of an electron for a heavy element (Hg). In conjunction with this work, Massey [18] obtained the angular distribution of positrons elastically scattered by the Hg nuclei replacing atomic number $+Z$ (=80) by $-Z$ (= −80) in the formulae. Using a computer code, Doggett and Spencer [19] have tabulated the elastic differential cross-section (DCS) for electrons and positrons with energy range $E = 50$ keV–10 MeV for $Z = 6$–92. For the practical simulation of an elastic DCS $d\sigma/d\Omega$ (Ω is a solid angle), we can use the code system ELSEPA reported by Salvat et al. [20].

Regarding the inelastic collisions, Bethe [21] has derived the formulae based on the quantum theory. Mϕller [22] has

* Corresponding author. Tel.: +81 42 542 2689; fax: +81 42 542 1924.
E-mail address: matsuya@jeol.co.jp (M. Matsuya).

0168-9002/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.nima.2010.12.228

formulated the interaction of an incident electron with atomic electrons, which would be regarded as free at rest. In a similar manner, the formula for an incident positron was obtained by Bhabha [23]. Founded on these results, Rohrlich and Carlson [24] have investigated the positron–electron differences in energy loss provided that the formula for small energy transfer is applicable for both positrons and electrons because the energy loss is mainly determined by the oscillator strength of the atom. For an angle range $\theta = 10^{-5}$–10^{-1} rad, Lentz [25] has obtained the DCSs $d\sigma/d\Omega$ for electrons by comparing elastic and inelastic scatterings. These results are qualitatively very helpful for us to estimate scattering contrasts by a transmission electron microscope (TEM). For the full angular DCSs applicable to wide energy range for positrons and electrons, an optical data model by Fernadez-varea et al. is useful [26].

When estimating transmittance of a specimen for positrons or electrons, multiple scattering should be taken into account as well as elastic and inelastic DCSs on a single scattering. On the basis of Goudsmit and Sauderson theory [27], Berger [28] has reported differences in the multiple scattering of positrons and electrons using the Monte Carlo code ETRAN. Negreanu et al. has summarized practical methods of this calculation [29].

In general, the brightness of commercial positron sources has a very low value, which is 10^{-19}–10^{-16} times compared with that of typical electron sources. So the concept of brightness enhancement for a positron beam developed by Mills [30] is the important factor to realize the positron microprobe with a practical beam intensity. The enhancement is based on the positron reemission from the solids with negative work functions for positrons. The materials of the solid, the devices and optics of the reemission and their applications were studied and summarized by many researchers [31]. Modern topics of this subject are given by Fujinami et al. [32] and Oshima et al. [33].

Under the background described earlier, Doyama et al. [34] has proposed a positron microscope for positron defect studies in 1985. This type of instrument will be very important in basic science and physics. After that, House and Rich constructed the prototype of named *transmission positron microscope* (TPM), and a positron image with magnification of $55\times$ was shown [35]. However, any difference or any similarity in images for positron and electron beams was not reported. After their work, we have not found any investigation in which the difference was measured by a TPM. Doyama et al. [36] have also given some plans for a positron–electron microscope. Later, they have presented a comparison of positron and electron images of an organic specimen using imaging plates [37].

From the progress that has been made so far, we have developed a practical transmission positron microscope (TPM) JEM-1011B, and some results at early stage were reported [38–40]. In this paper, a design concept and each apparatus of the TPM system will be given, focusing on its optics. Then, basic performance and experimental dada will be presented to show the differences or similarities in the interaction of positron and electron beams with materials. The difference in material transmittances for both beams will be given and compared with the Monte Carlo simulation based on the scattering theory.

2. System design and apparatus

We have utilized a positron source and the beam transport system in the Slow Positron Facility at KEK [41] in Tsukuba, Japan. In this facility, a new line has been added for a TPM system. The beam line branches off before an experimental station for positronium time-of-flight (Ps-TOF) spectroscopy, and leads to a brightness enhancer set on a mezzanine floor. Fig. 1 shows an overview of the brightness enhancer [32] and the end of the beam line on this floor. Fig. 2 shows the lower end of the brightness enhancer and the TPM (JEM-1011B), which is remodeled on the basis of a TEM (JEM-1011). A schematic diagram is shown in Fig. 3 for an optical system from the brightness enhancer to an image detector of the TPM. In the following, a positron and an electron are sometimes abbreviated as e^+ and e^-, respectively, for simplicity.

2.1. Positron source [41]

Positron beam with intensity 10^7 e^+/s is generated at 50 Hz by a 56 MeV linac in which an electron beam with 200 nC/bunch

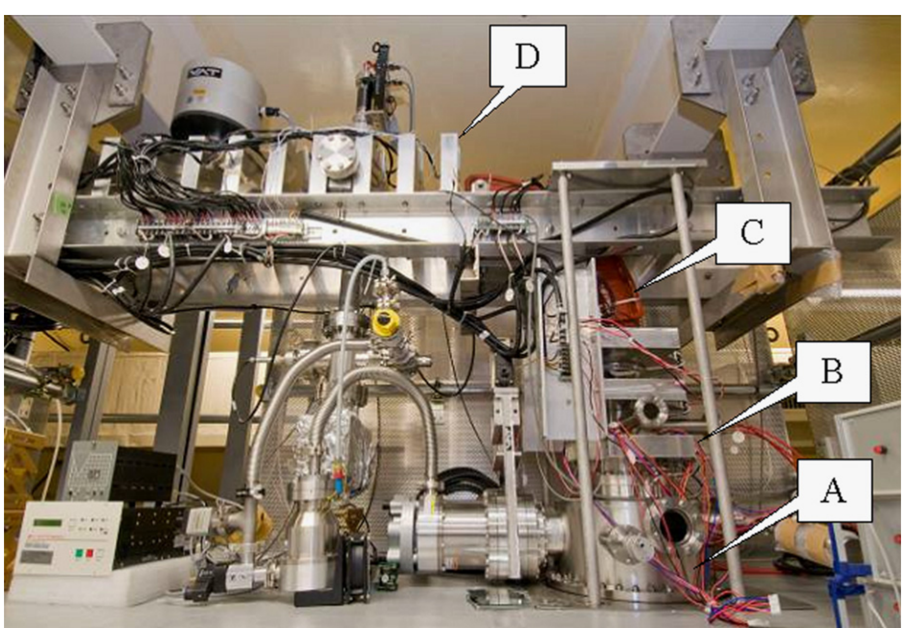

Fig. 1. An overview of the brightness enhancer and the end of the beam line. (A) Brightness enhancer. (B) Final Helmholtz coil. (C) 90° bending solenoid. (D) Helmholtz coils.

Download English Version:

https://daneshyari.com/en/article/1824979

Download Persian Version:

https://daneshyari.com/article/1824979

Daneshyari.com