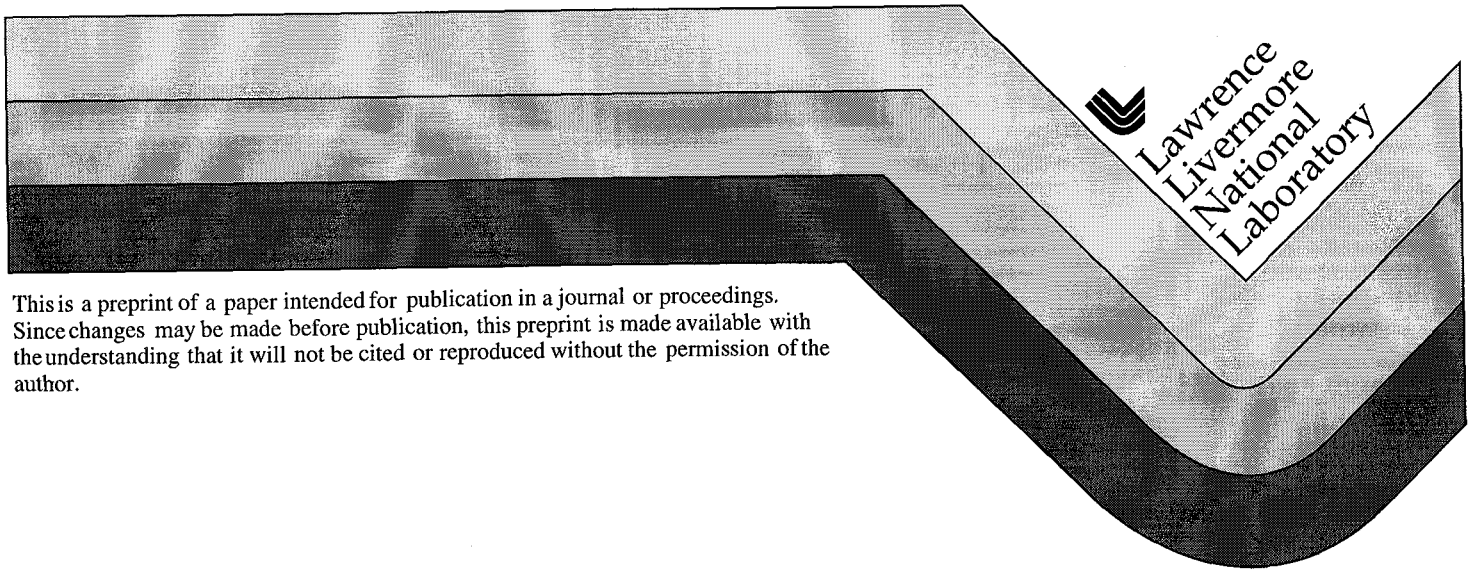
UCRL-JC-126767
PREPRINT

High Current Pulsed Positron Microprobe

R.H. Howell
W. Stoeffl
A. Kumar
P.A. Sterne
T.E. Cowan
J. Hartley

This paper was prepared for submittal to the
11th International Conference on Positron Annihilation
Kansas City, MO
May 24-30, 1997

May 1997



This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

High Current Pulsed Positron Microprobe

R. H. Howell, W. Stoeffl, A. Kumar, P. A. Sterne, T. E. Cowan, J. Hartley

Lawrence Livermore National Laboratory, Livermore CA 94550 USA

We are developing a low energy, microscopically focused, pulsed positron beam for defect analysis by positron lifetime spectroscopy to provide a new defect analysis capability at the 10^{10} $e^{+}s^{-1}$ beam at the Lawrence Livermore National Laboratory electron linac. When completed, the pulsed positron microprobe will enable defect specific, 3-dimensional maps of defect concentrations with sub-micron resolution of defect location. By coupling these data with first principles calculations of defect specific positron lifetimes and positron implantation profiles we will both map the identity and concentration of defect distributions.

Introduction

Positron annihilation lifetime spectroscopy is a valuable tool for determining the size and concentration of defects in metallic, semiconductor and insulating systems. Characteristic positron lifetime values provide detailed information about defect structure. The location where this spectrographic information is obtained is defined by the annihilation site of the positron. By controlling the implantation location and energy of a pulsed, microscopically focused positron beam we will perform positron annihilation lifetime spectroscopy to determine defect concentration and size over spatial volumes of 0.025 mm^3.

3-Dimensional mapping of defects requires several separate qualities for the positron beam. 3-D spatial sensitivity requires a highly focused, < 1 micron final spot size, and variable, 1-50, keV positron energy. Maximum implantation depths for these energies range from 1 to 10 microns depending on sample density. The location of buried features can be located with high precision by sweeping the energy and location of the positron beam in small steps. The size and concentration of the defect species at the end of the positron range are then determined by positron annihilation lifetime spectroscopy measurements which are correlated to defect size through validated theoretical calculations. To perform positron annihilation lifetime spectroscopy requires pulsing the focused beam with a pulse duration less than 100 ps. To obtain high counting rates our positron pulsing rate will be 20 MHz and multiple detectors will be used for the annihilation gamma rays.

Microprobe

Many of the beam characteristics described above have been obtained in separate systems [1-3] and a design for an efficient, low source strength microprobe has been reported [4]. The LLNL microprobe design integrates new features with those of the published designs to achieve a beam system with improved efficiency and pulse duration. A schematic of the elements of this system is shown in Fig. 1.

In an optical system the overall brightness of the beam limits the final conditions of focus or pulse duration. This limitation has been defeated in positron optical transport systems by resetting the initial conditions through thermalization in one or more intermediate steps at which new initial conditions are established. This brightness enhancement technique produces highly focused beams with high transmission efficiency. The energy spread of the beam is a second critical parameter for pulsing systems. The ultimate time compression of a pulse is limited only by time of flight spreading from the energy distribution.

The initial linac beam consists of bright pulses of high intensity and short duration. The first step of the 3 dimensional scanning pulsed positron microprobe will be to trade the short time duration for narrow energy. The initial high current linac beam has an energy width of 4 eV in 3 μs pulses at 300 Hz. This beam is transported in a magnetic field to a penning trap pulse stretcher which is the first element of the microprobe. We will trap the positron pulses and slowly raise the trap voltage so that the highest energy positrons will spill over a fixed voltage barrier. The stretcher will convert the 4 eV, 3 μs beam pulse into a ~20 meV, 300 ms beam pulse with average energy set by the endcap voltage. This provides a significantly reduced energy distribution for input to the first pulsing electrodes and makes it practical to benefit from an ideal pulsing shape generated by a fast programmable Tektronix AWG2041 waveform generator to obtain high efficiency, sub nanosecond pulses in a single stage. This pulsed

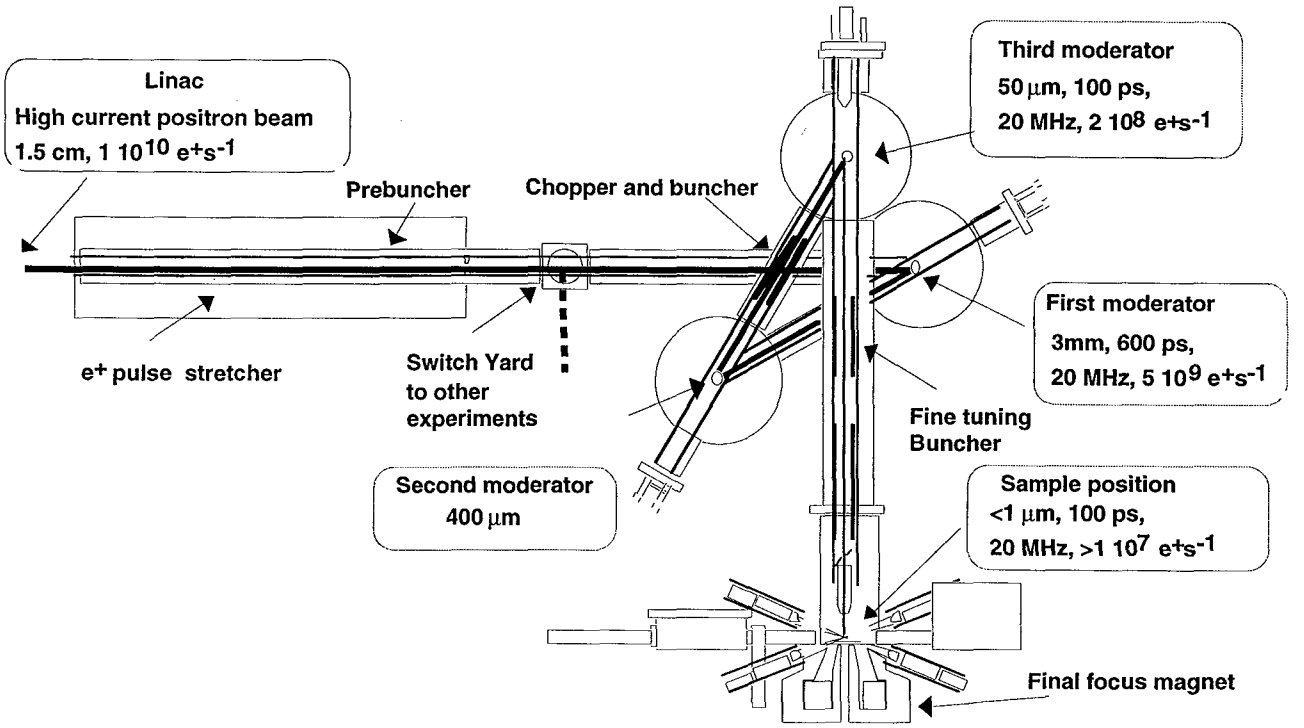


Figure 3 Schematic of the main elements of the 3-D pulsed positron microbeam system. The final beam of more than 10^7 e^+s^{-1} will be less than 1 micron diameter and 1 to 50 keV. Beam position will be scanned in the lateral dimensions by piezoelectric sample motion and scanned in depth by energy variation to provide a 3-dimensional map of defect concentrations and size.

beam will then be accelerated to 3 keV and extracted from the magnetic field of the penning trap after an abrupt termination of the magnetic field. After extraction the beam will be accelerated and electrostatically focused on the first brightness enhancement moderator. It will also be possible to divert the beam to other experiments at this location. The beam incident on the first remoderator is expected to be 3 mm in diameter and have 5 10^9 e^+s^{-1} in 600 ps pulses at 20 MHz. We are now testing the operation of the penning trap stretcher, first pulsing section and magnetic filed extraction.

Farther stages of focusing and pulsing includes a resonant buncher driven by a Rohde & Schwartz SMT02 sine wave generator to complete the pulse compression to 100 ps and to focus the beam on a final remoderator. The beam at the source of the microprobe column will be 50 micron diameter and 2 10^8 e^+s^{-1}. Following the final remoderator is a final stage similar to published designs [5] with variable acceleration and focusing to a one micron beam spot to reach the final beam characteristics of >1◊10^7 e^+s^{-1} , 1-50 keV, 20 MHz, 100 ps. Lifetime spectra will be obtained in an array of BaF_2 detectors opperated in coincidence to supress backgrounds from scattered positrons at the sample. Contributions from annihilations at the re-moderator crystals and other sites will be separated in time to arrive at the detectors 20 ns before the arrival time of the positrons on the sample.

When completed we anticipate using the 3D scanning defect microprobe to study defect distributions in metals and alloys, in homogenous systems such as semiconductor devices, and in thin film and composite polymeric materials. With the microprobe we will determine the spatial defect distributions in 3 dimensions near microscopic features such as grain boundaries, cracks, precipitates, and buried interfaces.

We wish to thank Drs. W. Triftshäuser, G. Kögel, P. Sperr, and D.T. Suzuki for their valuable conversations on beam pulsing and focusing. This work was performed under the auspices of the US Department of Energy by LLNL under contract No. W-7405-ENG-48.

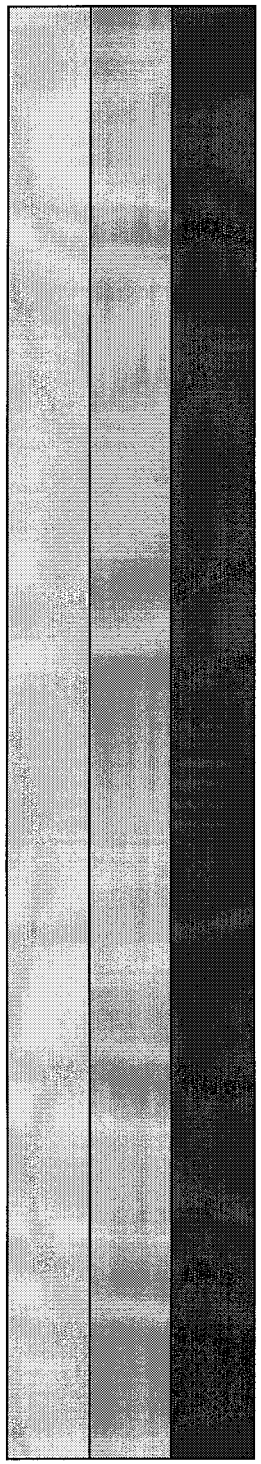
REFERENCES

1. P. Willutzki, J. Störmer, G. Kögel, P.Sperr, D. T. Britton, R. Steindl and W. Triftshäuser, Materials Science Forum 175-178, 237 (1995)

2. R. Suzuki, T. Mikado, M. Chigaki, H. Ohgaki, and T. Yamazaki Applied Surface Science 85, 87 (1995)

3. G.R. Brandes, K. F. Canter, T. N. Horsky and P.H. Lippel and A. P. Mills, Rev. Sci. Instrum. 59, 228 (1988)

4. A. Zecca, R. S. Brusa, M. P. Duarte-Naia, G. PP Karwasz, J. Paridaens, A. Piazza, G. Kögel, P. Sperr, D. T. Britton, K. Uhlmann, P. Willutzki and W. Triftshäuser, Europhys. Lett. 29, 617 (1995)

5. K. Uhlmann, D. T. Britton and G. Kögel, Meas. Sci. Technol. 6,932 (1995)

Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551