बहु-विषयक अनुसंधान

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पॉज़िट्रॉन विलोपन लाइफटाइम स्पेक्ट्रोमीटर के लिए एकीकृत आरएफ प्रणाली

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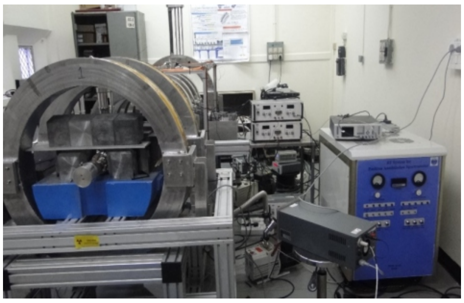

आरसीडी में पीएएलएस कणपुंज रेखा

सारांश

पॉज़िट्रॉन निम्न सांद्रता और उच्च संवेदनशीलता के साथ सामग्री दोषों की जांच कर सकते हैं। पॉज़िट्रॉन एनीहिलेशन जीवनकाल स्पेक्ट्रोस्कोपी (PALS/पी.ए.एल.एस.) बहुलक, सरंध्र सामग्री, धातुओं, अर्धचालकों आदि में परमाणु स्तर के दोषों की जांच के लिए एक सुस्थापित शोध पद्धति है। पारंपरिक PALS/पी.ए.एल.एस. में गहराई चयनात्मकता का अभाव है, और इसलिए गहराई चयनात्मक जानकारी प्राप्त करने के लिए ट्यूनेबल / मिलाने योग्य ऊर्जा धीमी पॉज़िट्रॉन किरण का उपयोग किया जाता है। एक स्पंदित धीमी पॉज़िट्रॉन किरण आधारित गहराई चयनात्मक PALS PALS/पी.ए.एल.एस. को भाभा परमाणु अनुसंधान केंद्र में परिकल्पित और विकसित किया गया है, जो अपने किरण लाइन संरचनाओं को शक्ति देने के लिए एक एकीकृत रेडियो आवृत्ति प्रणाली का उपयोग करता है। बहु आवृत्ति एकीकृत स्वदेशी रेडियो आवृत्ति प्रणाली अपने सिग्नल इनपुट को एक सामान्य स्रोत से प्राप्त करती है और उसके बाद उसे तीन शाखाओं में विभाजित करती है। इनमें से प्रत्येक शाखा में एक रेडियो आवृत्ति शक्ति प्रवर्धक, विभाजक, क्षीणक, चरण परिवर्तक, अलगक /आइसोलेटर, डीसी बाधक, मिलान परिपथ और रेडियो आवृत्ति फांसा युग्मक शामिल हैं जो रेडियो आवृत्ति शक्ति को प्रत्येक स्पंदित पॉज़िट्रॉन किरण लाइन संरचनाओं से जोड़ते है। यह आलेख RCD / आर.सी.डी., भाभा परमाणु अनुसंधान केंद्र के पॉज़िट्रॉन किरण आधारित PALS /पी.ए.एल.एस के साथ डिज़ाइन, विकसित और युग्मित एकीकृत रेडियो आवृत्ति प्रणाली का विवरण देता है।

Multi-disciplinary Research

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Integrated RF System for Positron Annihilation Lifetime Spectrometer

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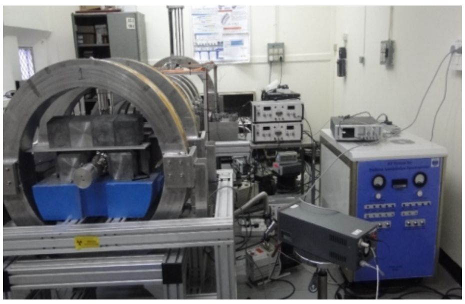

PALS Beam line at RCD

ABSTRACT

Positrons can probe material defects with low concentrations and high sensitivity. The positron annihilation lifetime spectroscopy (PALS) is an established research methodology for investigation of atomic level defects in polymers, porous materials, metals, semiconductors etc. Conventional PALS lacks depth selectivity, and so tunable energy slow positron beams are used to get depth selective information. A pulsed slow positron beam based depth selective PALS is designed and developed in BARC, which employs an integrated RF system to power its beam line structures. The multi frequency integrated indigenous RF system derives its signal input from one common source and thereafter splits the same in three branches. Each of these branches include one RF amplifier, splitter, attenuator, phase shifters, isolators, DC blocks, matching circuits and RF loop couplers that couple the RF power to each of pulsed positron beam line structures. This article gives details of integrated RF system designed, developed and coupled with positron beam based PALS of RCD, BARC.

KEYWORDS: *Amplifier, Annihilation, Attenuator, Atomic-defect, PALS, Positron, Radio Frequency, Splitter.*

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Introduction

A variety of phenomena and material properties on an atomic scale can be studied by positron annihilation spectroscopy. A Positron Annihilation Lifetime Spectrometer (PALS) has been operational in Radio Chemistry Division (RCD), BARC. It is used as a non-destructive probing system for nanometre size voids and defects in solid materials. It uses radio frequency (RF) electronics to power its resonant structures.

In PALS, an implanted positron thermalizes in the sample and gets trapped in a low electron density area (e.g. defects) in a material. It annihilates with an electron in the sample resulting in emission of two gamma rays. In conventional PALS, the time difference between birth of positron (i.e. emission time from a radioactive source, signalled by almost simultaneous emission of gamma ray) and the detection of annihilation gamma rays emitted from the sample is measured to give the life time of the positrons. The positron lifetimes in alloys, metals, semiconductor can be of the order of hundreds of picoseconds (ps). In porous materials, the measured lifetimes can be in the range of nanoseconds.

The conventional PALS using beta-spectrum of positron emitters lacks depth selective information due to continuous energy distribution of emitted positrons from radio isotope sources. In case of DC positron beams, the timing information about the birth of positron is usually lost. Hence, to carry out lifetime spectroscopy, a positron beam is usually pulsed using RF electric fields.

Advancements in this field include, moderating the positrons from beta emitters, pulsing them and accelerating to desired energies to implant positrons as desired and extract depth selective information of defects. These are possible with the use of radio frequency (RF) for pulsing of positrons. Such RF pulsing of positrons gives time resolutions of a few hundred picoseconds, which is ideal for measurement of the lifetimes in metals and alloys.

Description

A modified version of Suzuki's [1] pulsed positron beam is developed at Bhabha Atomic Research Centre (BARC), Mumbai. The PALS beamline comprises of structures viz., chopper, pre-buncher and buncher, and can deliver positron pulses in the range of ≤ 350 ps at the sample position. The radio frequency (RF) power energizes or excites these beam line structures meant for pre bunching and then bunching of the incoming chopped particles. The required integrated RF electronic system for bunching the positron beam up to a few 100s of pico-sec has been designed and developed indigenously except 40 Watt amplifier. Its RF system comprises of RF amplifiers at 37.5 MHz and 150 MHz, RF coupling lines developed using RF components for amplitude and phase matching and respective impedance matching unit and RF couplers.

Indigenous Integrated RF System

The indigenous multi frequency integrated RF system (Fig.1 and 2) [2] consists of three RF amplifiers, splitters, attenuators, phase shifters, isolators, power measurement units, DC blocks, matching circuits and RF loop couplers. The three RF amplifiers, a 37.5 MHz, 40 W amplifier for chopper, another 40 W amplifier for pre-buncher and a 150 MHz, 200 W RF amplifier for buncher cavity have been designed and developed indigenously. For effective RF power transfer from amplifiers to beamline structures, dedicated matching circuits along with loop couplers have been designed, developed and integrated with these RF cavities or structures. Phase and amplitude of the three RF systems has been optimized for effective bunching using the combination of phase shifters, attenuators etc.

To reduce the interference among the RF signals and the detector electronics, various RF interference suppression techniques like filtering, shielding, isolation, proper grounding topology, EM suppression etc. were implemented.

The RF power amplifier 200 Watt at 150 MHz for buncher cavity has been designed around the N channel

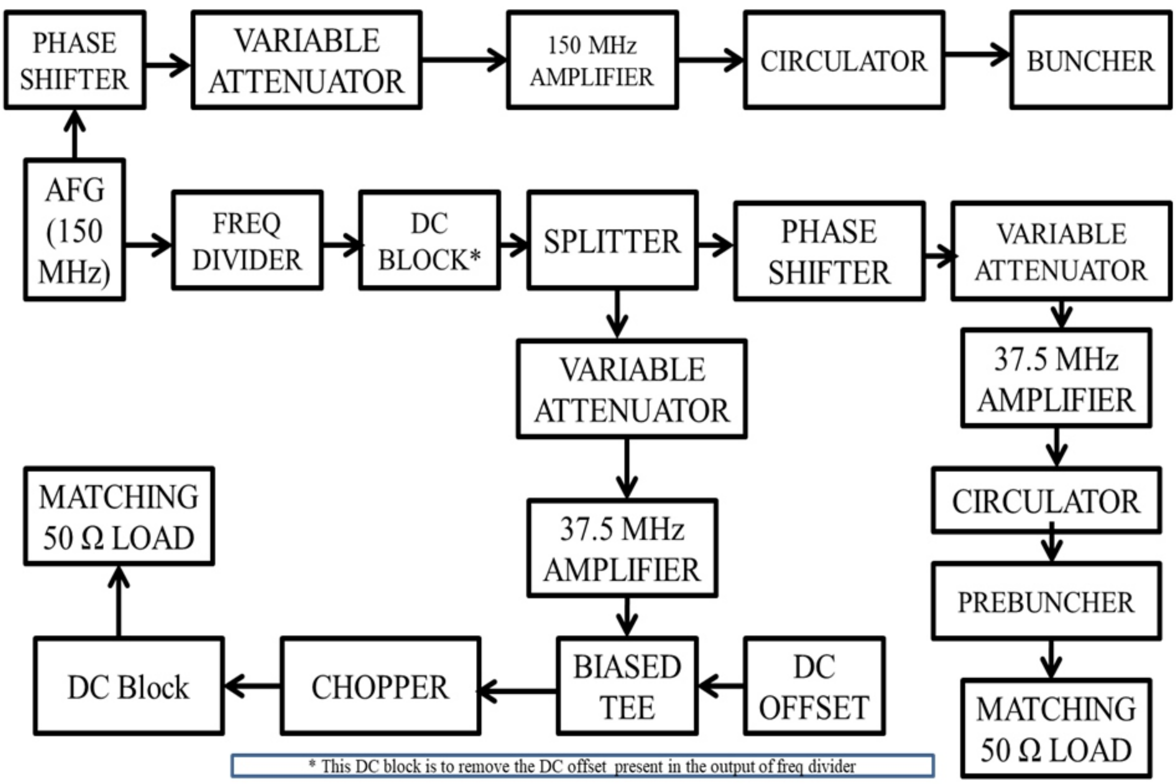

Fig.1: An overall integrated RF system.

Fig.2: Integrated RF system.

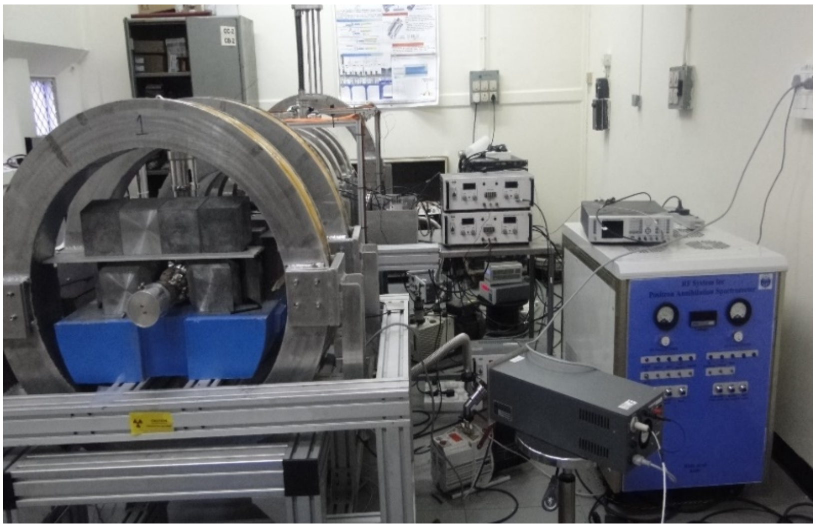

Fig.3: PALS Beam line at RCD.

MOSFET- MRF151G (Gemini package). It is biased in class AB push pull configuration with LC tuned circuits at its input and output to maintain linearity. It has achieved 58% efficiency, and 2^{nd} and 3^{rd} harmonics better than -30 dBc. The RF amplifier was integrated with buncher cavity via a circulator and a loop coupler.

The RF amplifiers for pre-buncher and chopper operate at 37.5 MHz, can deliver a maximum power of 40 Watts with efficiency 50 %, gain 43 dB and 2nd harmonic of -30 dBc. An external matching circuit i.e. a parallel resonant circuit [2] comprising of an inductance in parallel with resistance and distributed capacitance of RF structure was designed, developed and coupled to pre-buncher cavity to match [2] the impedance of pre-buncher cavity with 50 ohm output impedance of RF amplifier. In a similar way, the second RF amplifier at 37.5 MHz was coupled to chopper via another matching circuit [2] of an inductance in parallel with resistance and distributed capacitance of RF structure. Both these parallel resonant circuits maintain the sinusoidal signal wave shape across grids of respective cavities.

Results

The tested parameters of 150 MHz RF amplifier are given in table 1. Initially Table 1: Performance parameters of 150 MHz RF amplifier, chopper, pre buncher and buncher were characterized for their design parameters at low power. Individually, these structures were tested with their respective RF system for characterization and validation of the RF system with respect to beam line structures. The integrated RF system (Fig.1 and 2) was then coupled with beam line structures i.e. chopper, pre buncher and buncher and tested. This ensured desired power transfer from integrated RF systems to beam line components. After integrating and aligning all the structures of PALS (Fig.3), initial testing of the pulsed beamline, inclusive of RF system, was carried out with the electron beam [2].

Table 1: Performance parameters of 150 MHz RF amplifier.

Sr. No.	Operating parameters	Values
1.	Frequency	150 MHz
2.	Output power	200 Watt CW
3.	Input power	6 Watt
4.	Drain Voltage	50 V
5.	Efficiency	58 %
6.	Gain	15.2 dB
7.	1 dB Bandwidth	1 MHz
8.	-1 dB saturation power (W)	210 Watt
9.	2nd and 3rd Harmonic	-30 dBc

After further optimisation of the parameters of the chopper, pre buncher and the buncher, pulsed beamline (Fig.3) was tested with positron beam and a final pulse width of 325 ps of positron beam was achieved. A few experiments including the defect analysis of the polymer sample have been carried out using PALS. Pulsed positron beam has been used to probe the porosity of the surface and the bulk layer of Reverse Osmosis membrane of water purifier. The photograph of the PALS at RCD is given in Fig.3.

Conclusion

Various RF and other components/structures of PALS were aligned and characterized with RF. The indigenous multi frequency integrated RF system was coupled with the beam line. The final pulsed positron beam line was initially tested with a low energy DC electron beam. Upon energizing, tuning and synchronization of the chopper-pre buncher-buncher assembly, the electron beam was bunched up to 280 ps, thereby establishing the overall functionality of the pulsed beamline with its associated electronics. Subsequently, electron source was replaced with a positron source and further optimization and tuning of the beamline with a slow positron beam was completed to achieve and a final pulse width of 325 ps of positron beam [4] was achieved.

Acknowledgement

The authors would like to sincerely thank the PALS team from RCD comprising of Dr. Saurabh Mukherjee, Dr. Priya Maheshwari, Dr. S. K. Sharma, Dr. D. Dutta, Dr. Kathi Sudarshan, Dr. P.K. Mohapatra and Dr. P.K. Pujari for their excellent support and collaboration.

The authors acknowledge for the immense technical help and efforts provided by Shri Hitesh Kadam and Shri Jagdish Bowlekar. The authors thank Dr Gopal Joshi, Head

ACnD from his excellent support and guidance.

The authors sincerely thank Shri Vivek Bhasin, Director, BARC and Shri U. D Malshe, Group Director, MRG for their constant encouragement and continued support.

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