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实现能量低于 **3 MeV** 且具有低能散的强流质子束横向均匀分布

摘要

基于质子辐照的载流子寿命控制可以提升二极管和绝缘栅双极晶体管等功率半导体器件性能，如降低漏电流、减小反向恢复损耗等，其典型辐照能量低于 3 MeV。基于清华大学电机系功率半导体辐照需求，在清华大学微型脉冲强子源 13 MeV 强流质子直线加速器基础上，通过衰减掉进入到 DTL 加速器中的微波功率，在 DTL 出口获得能量为 3 MeV 的质子束流，并通过铝降能片进一步降能，能够保证质子束流能散低于 0.2 MeV。通过非线性磁铁法与扩束法相结合的方式获得直径 149 mm 辐照范围内的束流不均匀性为 9.8%，并通过靶片旋转的方式进一步降低束流不均匀性到 4% 以下。

关键词

质子辐照，束流均匀化，微型脉冲强子源

Abstract

Carrier lifetime control through proton irradiation has proven effective in enhancing the performance of power semiconductor devices such as diodes and insulated gate bipolar transistors (IGBTs), offering advantages including reduced leakage currents and suppressed reverse recovery losses, with typical irradiation energies below 3 MeV. To fulfill the proton irradiation demands for power semiconductor research at Tsinghua University's Department of Electrical Engineering, a tailored irradiation system was developed based on the existing 13 MeV high-current proton linear accelerator at the Compact Pulsed Hadron Source (CPHS). By attenuating the microwave power fed into the Drift Tube Linac (DTL), a 3 MeV proton beam was extracted at the DTL exit, followed by energy reduction using aluminum degraders while maintaining a beam energy spread below 0.2 MeV. To achieve uniform irradiation across a 149 mm diameter area, beam uniformity was optimized through a synergistic approach integrating beam expansion and nonlinear magnet method, yielding an initial beam nonuniformity of 9.8%. This uniformity was further improved to below 4% by implementing dynamic target rotation during irradiation.

Keywords

Proton irradiation, Uniform distribution, CPHS

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