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Sustainable management of electronic and semiconductor waste in the era of advanced photonic technologies

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The rapid advancement of advanced photonic technologies has accelerated the production of semiconductor devices used in artificial intelligence, optical communication, quantum computing, biomedical imaging, renewable energy systems, and integrated photonic circuits. While these technologies have significantly improved industrial innovation and digital transformation, they have also increased the generation of complex electronic and semiconductor waste containing hazardous substances, critical raw materials, and rare earth elements. Existing electronic waste management frameworks primarily address conventional electronic products and provide limited attention to the distinctive waste streams generated by photonic and semiconductor technologies. This research therefore investigates sustainable management strategies for electronic and semiconductor waste generated by advanced photonic technologies from the perspective of environmental sustainability and circular economy. The study has three objectives: **(**1) to identify the environmental challenges associated with semiconductor waste generated by advanced photonic technologies; **(2)** to examine the relationship between photonic technology development, waste generation, recycling practices, and circular economy adoption; and (3) to propose an integrated framework for sustainable semiconductor waste management. The research is guided by two questions: How do advanced photonic technologies influence the generation and management of electronic and semiconductor waste? and Which sustainable management strategies can improve resource recovery and environmental performance within photonic manufacturing systems? The research adopts a mixed-method design integrating quantitative and qualitative approaches. Primary data will be collected from approximately 150 respondents, including researchers, academic experts, environmental specialists, and professionals from the electronics and semiconductor sectors using structured questionnaires and semi-structured interviews. Participants will be selected through purposive and stratified sampling techniques to ensure representation of key stakeholder groups. Secondary data will be obtained from peerreviewed journals, international reports, semiconductor industry publications, and sustainability databases. Quantitative data will be analysed using descriptive statistics, correlation analysis, and multiple regression analysis in SPSS, while qualitative data will be examined using thematic analysis. The conceptual framework analyses the relationships among photonic technology advancement, semiconductor waste generation, recycling technologies, circular economy practices, and environmental sustainability. The study is currently in progress; therefore, no final empirical results

are reported. However, preliminary analysis of recent literature indicates that the rapid expansion of photonic integrated circuits, compound semiconductors, and optoelectronic devices is expected to substantially increase complex semiconductor waste, while existing recycling infrastructure remains insufficient to recover high-value materials efficiently. These observations emphasise the need for specialised recycling technologies, environmentally responsible manufacturing practices, and circular economy policies specifically designed for photonic industries. The expected outcomes will provide an integrated sustainable management framework linking advanced photonic technologies with semiconductor waste management, resource efficiency, and environmental governance. The study aims to contribute to the development of practical strategies for researchers, industry practitioners, and policymakers to improve the sustainability of nextgeneration photonic technologies while reducing the environmental impacts associated with semiconductor waste.

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