

# Spectral and Polarization Control of Smith-Purcell Radiation via Chiral Dielectric Gratings

L. Cavenaile<sup>1</sup>, T. Delplace<sup>1</sup>, M. G. Abebe<sup>1</sup> and B. Maes<sup>1</sup>

<sup>1</sup>*Micro- and Nanophotonics Materials Group, Research Institute for Materials Science and Engineering, University of Mons, Place du Parc 20, 7000 Mons, Belgium*

The interaction between free electrons and periodic photonic structures enables the generation of tunable electromagnetic radiation, known as the Smith-Purcell (SP) effect [1]. This mechanism is fundamental for developing compact and novel light sources, e.g., in terahertz and X-Ray regimes. While initial designs relied on metallic gratings, recent advancements have shifted towards high-index dielectric structures. These offer lower losses and support resonances with high quality factors, allowing for maximal photon emission and optimized energy loss [2].

Current research focuses on tailoring these resonances to control the emission properties. Recent works have explored anomalous Doppler effects [3] and utilized geometric symmetry breaking, such as glide symmetry in coupled gratings, to direct radiation into specific half-spaces [4]. However, a persistent limitation in conventional two-dimensional (2D) SP devices is the polarization constraint: the electron beam naturally couples to Transverse Magnetic (TM) modes, leaving Transverse Electric (TE) modes largely inaccessible in standard 2D achiral models.

To overcome this limitation, we investigate the introduction of constitutive symmetry breaking via chirality [5]. Magneto-electric coupling in chiral (Pasteur) media is known to mix electric and magnetic dipoles, potentially allowing an electric source to excite TE modes [6].

In this work, we present both a theoretical framework and numerical demonstrations of a SP source combining a chiral layer ( $n = 1.4$ ) with a silicon (Si) grating separated from a Si substrate. We develop a Coupled-Mode Theory (CMT) framework [7] to phenomenologically describe the mode hybridization and cross-polarization dynamics induced by the chiral environment. These analytical insights are corroborated by full-wave frequency-domain simulations. We demonstrate that the optical activity of the medium enables the excitation of a high-Q, TE-polarized resonance confined within the Si teeth, a mode strictly forbidden in standard achiral counterparts. By merging CMT models with rigorous numerical validation, this approach offers a robust new degree of freedom for wavelength and polarization shaping in free-electron photonics.

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