Nonparaxial Soliton Refraction at Optical Interfaces with $\chi^{(3)}$ and $\chi^{(5)}$ Susceptibilities

***J. M. Christian*[1], *E. A. McCoy*[1], *G. S. McDonald*[1], *J. Sánchez-Curto*[2], *P. Chamorro-Posada*[2]**

1. Materials & Physics Research Centre, University of Salford, Greater Manchester M5 4WT, U.K.

2. ETSI Telecomunicación, Universidad de Valladolid, Campus Miguel Delibes Paseo Belén, E- 47011 Valladolid, Spain

In their most general form, wave-interface problems are inherently angular in nature. For instance, the interaction between light waves and material boundaries essentially defines the entire field of optics. The seminal works of Aceves *et al.* [1,2] considered scalar bright spatial solitons impinging on the planar interface between two Kerr-type media with different $\chi^{(3)}$ susceptibilities. While these classic nonlinear Schrödinger models undeniably paved the way toward understanding how self-collimated light beams behave at material discontinuities, they suffer from a fundamental limitation: the assumption of slowly-varying wave envelopes means that, in the laboratory frame, angles of incidence, reflection and refraction (relative to the interface) must be near-negligibly small. This intrinsic angular restriction may be eliminated by adopting a mathematical and computational framework based on the solution of nonlinear Helmholtz equations. To date, we have considered bright [3] and dark [4] soliton refraction in dissimilar focusing and defocusing $\chi^{(3)}$ materials, respectively.

In this presentation, we give the first detailed overview of beam refraction at the interface between materials whose nonlinear polarization has contributions from both $\chi^{(3)}$ and $\chi^{(5)}$ susceptibilities [5]. The governing equation is of the inhomogeneous Helmholtz class with a cubic-quintic nonlinearity, and analysis is facilitated through the exact bright soliton solutions of the corresponding homogeneous problem [6]. By respecting field continuity conditions at the interface, a universal Snell's law may be derived for describing the refractive properties of soliton beams. This compact nonparaxial law contains a supplementary multiplicative factor that captures the interplay between system nonlinearity, discontinuities in material properties, and finite beam waists. Extensive numerical calculations have tested analytical predictions, providing strong supporting evidence for the validity of our modelling approach across wide regions of a six-dimensional parameter space. Our Snell's law also provides theoretical predictions for critical angles that are in generally good agreement with full simulations of beams at linear and weakly-nonlinear interfaces. We have quantified Goos-Hänchen shifts [7] at such interfaces (see Fig. 1). Of particular interest are regimes involving external linear refraction [8], since these physical contexts have no counterpart in conventional (Schrödinger-based) theory [1]. For strongly nonlinear interfaces, new and potentially exploitable qualitative phenomena can emerge.

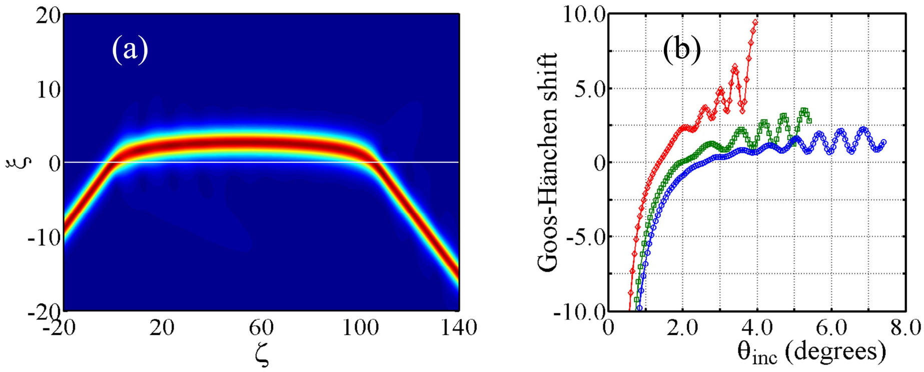

Fig. 1 (a) Simulation showing a typical giant Goos-Hänchen (GH) shift at a cubic-quintic interface with external linear refraction [where the linear refractive index is higher in the second medium (region $\xi > 0$)]. (b) GH shifts at nonlinear interfaces can exhibit non-monotonic behaviour. In these simulations, the $\chi^{(3)}$ susceptibility is lower the second medium (while $\chi^{(5)}$ is uniform throughout) and the incident solitons have relatively high peak intensities to enhance self-focusing.

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