SEMICONDUCTOR BLOCH LASER: A THEORETICAL ANALYSIS OF THE OPERATIONAL LIMITS OF A SUPERLATTICE TERAHERTZ EMITTER

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Theory predicts that with specifically engineered semiconductor structures it would be possible to create an inversionless Bloch laser or in simple terms a terahertz emitter [1]. It happens to be that this can be achieved with semiconductor superlattices which possess, compared to traditional semiconductor structures, extremely long lattice periods. Since the high-frequency gain in superlattices is related to the negative differential conductivity [1] and does not require population inversion, the device can operate at room temperature, though thorough theoretical work is still needed to fully understand mechanisms that allow pushing the frequencies to the THz range. Our interest in the problem was also stimulated by a recent experimental demonstration of dissipative parametric generation, which underlines the importance of plasma effects in active superlattice devices [2].

We start our analysis with a relatively simple model of a semiconductor superlattice proposed by Ktitorov et al. [3]. The solution of the Boltzmann equation allows us to analyse the high-frequency conductivity of the system, which can show if there are any gain resonances.

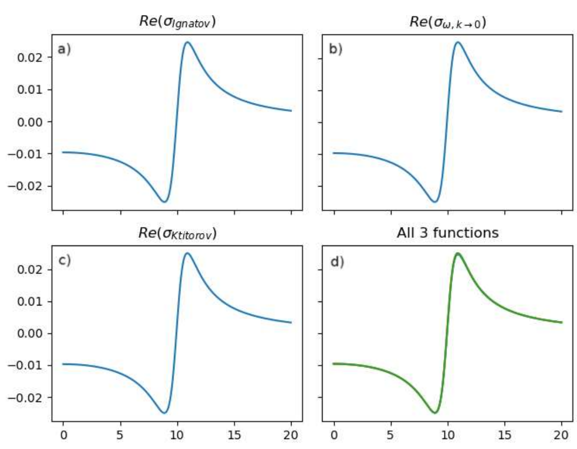

Fig. 1. Real part of high frequency conductivity of the superlattice. The graphs follow the Esaki-Tsu curve and predict a region of negative differential conductivity, where a theoretical Bloch laser could exist [1]. The graphs depict different conductivity calculation methods: a) Original Ignatov model b) Simplified Ignatov's equation when k→0 c) Original Ktitorov's model d) Comparison of all three calculation methods.

A more mathematically challenging approach, proposed by Ignatov et al., introduces a Bhatnagar-Gross-Krook (BGK) collision integral, that results in dependence of the conductivity on the wavenumber [4]. To our surprise, these two models are in good correlation. Additionally, the Ignatov model works in the limiting case (See Fig. 1).

With the knowledge of the conductivity, it is possible to find the eigenmodes of the plasma excitations in the system. From the combined results of these models, we see two main factors to consider (See Fig. 2). The first one is plasma frequency ω_p and the second one is Bloch frequency Ω_B. We believe that we have a combination of these effects interplaying with each other, thus forming a space-charge wave in the superlattice structure that predominantly defines the gain properties of the device.

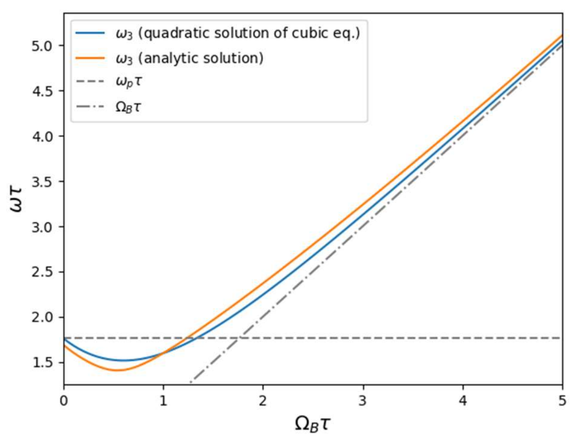

Fig. 2. The comparison of the real part of eigenmodes of the system, acquired from a cubic equation describing the oscillations in the system. The blue curve is a quadratic solution to a simplified cubic equation. The orange curve is an analytic solution to the full cubic equation. Both curves follow of what appears to be an interplay between two mechanisms: Bloch Ω_B and plasma ω_p oscillations.

References

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