Strong Non-Linear Non-Reciprocity Using Leaky-Waves on Multi Quantum Well Layers

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Magnet-less non-reciprocity has recently attracted significant attention as a solution to the limitations of conventional non-reciprocal devices based on magnetic materials. Different approaches have been exploited so far, including transistor-based metamaterials, spatiotemporal modulation, and non-linear structures. Non-linear non-reciprocity is particularly interesting in the case of high-power applications, and when biasing through external signals needs to be avoided. Such an approach is usually based on asymmetric resonance shift via third-order non-linearities for excitation from different directions. However, in the majority of materials, third-order non-linear effects are weak and, as a result, high input intensities are required in order to observe strong isolation. Multi-quantum-wells (MQWs) are materials with extreme non-linear effects in the far- and mid-infrared bands. In such materials, the non-linear response is associated with engineered intersubband-transition resonances, and it is accompanied by loss. The closer we are to the band resonance, the stronger the non-linearity and the associated loss is. Basic calculations show that the frequency shift due to the non-linearity in MQW materials can never be larger than the bandwidth due to loss and, as a result, non-reciprocity cannot be achieved through the conventional approach of asymmetric resonance shift. However, as we will show in detail during our talk, it is possible to exploit the giant nonlinearity in MQW materials by taking advantage of the associated loss, to realize a unique one-way mirror with large isolation for relatively small input intensities. To this goal, we choose to operate exactly at the intersubband transition resonance, for which loss is maximum, and we exploit the material's saturation mechanism, according to which absorption decreases as the input intensity increases. In this way, we obtain a bistable absorber, with different transition intensities from high-to-low absorption states for excitation from different directions. Interestingly, the operation of such a device does not involve any frequency shift, but a change in the resonance quality factor due to the change in material absorption as the input intensity is increased. An optimal structure to realize this effect is based on a metallic grating on top of a thin MQW substrate, supporting leaky modes, whose quality-factor can be easily controlled by changing the gaps of the grating. If the periodicity of the grating is larger than half wavelength, the leaky waves are associated with multiple diffraction orders, which generally exhibit different decay rates. Therefore, by exciting the structure from different directions, we are able to induce different field intensities in the MQW material, thus creating the required asymmetry to induce non-reciprocity. Our simulation results show that isolations of more than 15 dB can be achieved with input power intensities in the order of 10 MW/cm^2, demonstrating the robustness of the saturable-absorption approach to achieve strong non-linear non-reciprocity.