Essential mechanisms behind surface-plasmon formation

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Surface plasmons, localized waves on a metal surface, can squeeze light into extremely small volumes, enabling the miniaturization of optical devices. Although their wide range of applications has been studied for more than half a century, the reason why surface plasmons form at the surface of a metal has remained elusive. This study theoretically reveals two general physics behind surface plasmon formations. These complement each other, explaining the explicit and implicit origins of surface plasmons.

The first mechanism is based on self-duality, which is symbolically illustrated in the Chinese "yin-yang symbol" [1]. Since surface plasmons appear at the interface between dielectric and metallic materials, they could be attributed to the interface symmetry. However, the interface does not have a naive mirror symmetry. The key idea to resolve this issue is introducing the nongeometric swapping operation between metal and dielectric materials and the mirror reflection. So, the relevant symmetry involves duality, giving a nontrivial correspondence between two different interfaces. When we focus on a self-dual interface, which is dual to itself (under the combination of the above operations), the frequency of surface plasmons becomes zero. This observation is generalized to the understanding that the surface plasmons originate from exceptional surface fields protected by self-duality, as shown in Fig. 1(a).

The second mechanism is related to the topological nature of band structures [2]. Using the analogy between circuit theory and electromagnetism, we derived the right/left-handed composite transmission line as the minimum circuit model representing dielectric and metallic materials according to circuit parameters. When considering an interface between dielectric and metallic materials, the dispersion relation is "inverted" near the interface, as depicted in Fig. 1(b). The topological twist of the dispersion relation near the interface suggests the existence of a surface plasmon as an LC resonance. This topological mechanism is proved by classical results on general circuit response and extended to plasmonic bulk-edge correspondences that generally ensure the existence of surface plasmons at complicated interfaces.

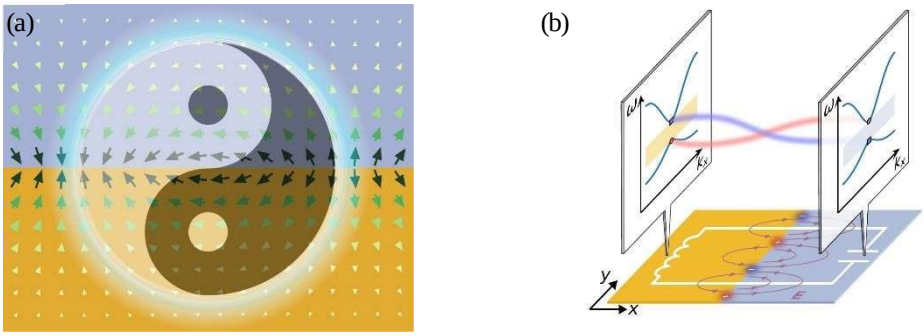

Fig. 1(a) Self-duality-protected electric field at the interface between dielectric and metallic materials. (b) Band inversion at the dielectric-metal interface.

References

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