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論文 / 著書情報
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題目(和文)	プラズモンのバンド構造及びプラズモニックディラックコーンの理論
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種別(和文)	論文要旨
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	物性物理学　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（ 理学 ）
学生氏名： Student's Name	北村有司	指導教員（主）： Academic Advisor(main)	村上修一
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In recent years, importance of controlling surface plasmons polaritons has increased in the field of metamaterials. Surface plasmons are electromagnetic modes coupled to the motions of electrons at metal surfaces. An attractive aspect of surface plasmons is the ability of concentrating light. Since surface plasmons are localized at the surface, the energy of the electromagnetic field at the surface is enhanced compared to usual electromagnetic waves. This property leads to small-scale nanophotonics. For example, negative refraction at visible frequencies is realized experimentally by using simple metal-insulator-metal structures as surface plasmon waveguides.

The motivation of the present research comes from analogies between photonic and electronic systems.　Conical dispersion similar to the Dirac cone in graphenes appears in the photonic crystals, and in recent researches the Hall effect of light and the quantum Hall effect of light have also been proposed. Similarly to electromagnetic waves in photonic crystals and electrons in usual crystals, surface plasmons form band structures in periodically corrugated metal surfaces called plasmonic crystals. Therefore, physical phenomena based on band structures for photons and electrons imply existence of plasmonic counterparts.

In this thesis, we formulate a theory of band structure of surface plasmon polaritons in periodically corrugated metal surfaces. Previous theoretical researches on the plasmonic band structures have been developed mainly by numerical calculations. Although there have also been analytical researches on the one-dimensional plasmonic crystals, these works contain some technical difficulties, and cannot be used for pursuit of plasmonic phenomena similar to electrons and photons. For example, theoretical discussions of the Hall effect for these particles require calculations of the Berry's curvatures of bands. To discuss the plasmonic counterparts to the same degree as in photonic crystals, at least an analytical form of band dispersion around the specific wavevector is needed. Therefore, in this thesis we develop an analytical perturbation theory for the plasmonic band structures.

In chapter 3, the band theory for one-dimensional plasmonic crystals is developed. We start our theory with the Maxwell's equations. Plane-wave solutions of the Maxwell's equations in the vacuum can be regarded as non-perturbed eigenstates. To treat the corrugation as a perturbation, a coordinate transformation proposed in a previous work is introduced. We derive an eigenvalue equation from the matching conditions of the electromagnetic fields at

the metal surface. The eigenvalue equation is hermitian outside the light cone, and the surface plasmons at these frequencies become long-lived excitations. On the other hand, the eigenvalue equation becomes non-hermitian inside the light cone, and plasmon modes in this region decay with time. This behavior coincides with the experimental fact that the plasmons inside the light cone couple to the transverse electric modes and radiate, and hermiticity of the eigenvalue equation holds. Solutions of the eigenvalue equation are also derived at specific wavenumbers, and the band gap at the Brillouin zone is calculated.

In chapter 4, we develop a plasmonic band theory in two-dimensional plasmonic crystals forming a triangular lattice. We derive an effective eigenvalue equation similar to the one-dimensional case. Non-perturbed solutions at the zone corners are three-fold degenerated, and the perturbation splits these states into one singlet state and doubly degenerated states. These results are also consistent with the group theory. Furthermore, we calculate the dispersion of the degenerated states near the zone corner and show that it is conical. This is the plasmonic counterpart of the Dirac cones in graphenes. The linear dispersion can also be seen from numerical simulation, and the group velocity well reproduces the analytical result. Finally, the magneto-optical effect is also discussed. Presence of the static magnetic field is represented by the off-diagonal elements of the dielectric functions, and a simple perturbation theory shows band splitting at the Dirac point. The mathematical structure of our theory coincides with the electronic and photonic quantum Hall effect, and we conclude that plasmonic quantum Hall effect occurs. The plasmonic quantum Hall effect appears as a presence of the edge modes of the sample, and it can be experimentally confirmed by measuring a signal of the edge modes.

We expect that the present research provides a basis for researches on novel phenomena related to the Berry's phases. The plasmonic quantum Hall effect in the present triangular lattice structure is among such examples, and there can potentially be other suth phenomena related with the Berry's curvatures of bands such as Hall effect and topological insulators. The advantage of the plasmonic systems compared to the photonic systems is the length scale of the systems. Since in surface plasmons polaritons the electromagnetic fields are well localized spatially, the plasmonic circuits can be miniaturized compared to photonic circuits. Furthermore, the dispersion of the surface plasmons polaritons outside the light cone never couples to the natural light and therefore plasmonic systems in this region can be realized in experiments.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).