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Penn D R. Wave-number-dependent dielectric function of semiconductors.
Phys. Rev. **128**:2093-7, 1962.
[Physics Department and Institute for the Study of Metals, University of Chicago, IL]

A simple model for a semiconductor is proposed. The model is isotropic: the electrons occupy a sphere in momentum space and are surrounded by an isotropic energy gap. The wave-number-dependent dielectric function is calculated. [The *SCI®* indicates that this paper has been cited in over 480 publications since 1962.]

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This article was my first publication. I had recently passed my preliminary examinations at the University of Chicago and had been accepted for thesis work by the solid state theory group. I needed a problem, and this one resulted from discussions with J.C. Phillips.

The work was done early in the computer era when band-structure calculations were very tedious and could be carried out only for directions of high symmetry in semiconductors or non-free electron metals. Whereas the dielectric response of a free electron metal had been known for many years, similar calculations for covalent semiconductors like silicon had not been attempted. The existence of an energy gap in such materials was of course expected to have a profound effect on the response of the system to both spatial and time-dependent probes.

In view of the state of the field at that time, we felt that it would be useful to study a highly simplified model of a semiconductor. The model presented in this paper is an isotropic one. The electrons are assumed to occupy a sphere in momentum space and are surrounded by an isotropic energy gap, E_g, which represents the minimum amount of energy required to excite an electron. We used this simple model to calculate the static dielectric function and spatial response to a time-independent probe. The only parameter in the theory is E_g.

When realistic band calculations and the response functions were calculated later, it was found that the predictions of the isotropic model were surprisingly accurate. This so-called "Penn model" has also been used to discuss the pressure dependence of the static dielectric function,[1,2] the optical absorption,[3] bonding,[4] and a variety of properties of pure and doped semiconductors.

The quantitative success of the isotropic model was surprising in view of the fact that real semiconductors are characterized by highly directional covalent bonds. The reason for this success has become clearer; despite the directional nature of the semiconductor bonding, the electrons occupy approximately spherical regions of momentum space surrounded by a uniform gap in the Jones zone. This was not originally evident because the relation between the Jones zone and the usual Brillouin zone is not simple.

I believe that this paper became a *Citation Classic* because it presents a simple and flexible model for covalent semiconductors with a strong connection to reality. Even in this era of increasingly detailed calculations, it has been worthwhile to have a simple model that gives a realistic description of covalent semiconductors.

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1. **Heine V & Jones R O.** Electronic band structure and covalency in diamond-type semiconductors. *J. Phys.—C—Solid State Phys.* 2:719-32, 1969. (Cited 165 times.)
2. **Weinstein B A, Zallen R, Slade M L & deLozanne A.** Photoelastic trends for amorphous and crystalline solids of differing network dimensionality. *Phys. Rev. B—Condensed Matter* **24**:4652-65, 1981.
3. **Sharma A C & Auluck S.** Model study of the frequency-dependent dielectric properties of semiconductors. *Phys. Rev. B—Condensed Matter* **28**:965-70, 1983.
4. **Cohen M L & Heine V.** The fitting of pseudopotentials to experimental data and their subsequent application. (Ehrenreich H, Seitz F & Turnbull D, eds.) *Solid state physics.* New York: Academic Press, 1970. Vol. 24, p. 37-248.
5. **Heine V & Weaire D.** Pseudopotential theory of cohesion and structure. *Ibid.* p. 249-463.