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REGULAR PAPER

Fabrication of nitrogen-containing diamond-like carbon film by filtered arc deposition as conductive hard-coating film

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Diamond-like carbon (DLC) films, which are amorphous carbon films, have been used as hard-coating films for protecting the surface of mechanical parts. Nitrogen-containing DLC (N-DLC) films are expected as conductive hard-coating materials. N-DLC films are expected in applications such as protective films for contact pins, which are used in the electrical check process of integrated circuit chips. In this study, N-DLC films are prepared using the T-shaped filtered arc deposition (T-FAD) method, and film properties are investigated. Film hardness and film density decreased when the N content increased in the films because the number of graphite structures in the DLC film increased as the N content increased. These trends are similar to the results of a previous study. The electrical resistivity of N-DLC films changed from 0.26 to 8.8 Ω cm with a change in the nanoindentation hardness from 17 to 27 GPa. The N-DLC films fabricated by the T-FAD method showed high mechanical hardness and low electrical resistivity.

1. Introduction

There are several product inspection processes undertaken for an integrated circuit (IC) chip. During the product inspection processes, an electrical inspection is conducted to ascertain whether the IC chip meets the required specifications. Contact pins are used in the electrical inspection process. During the inspection process, the contact pins contact with the solder of the IC chip and send a test signal, whereby it is possible to judge whether the product is good or defective, on the basis of the returned signal. The tip diameter of the contact pins is several tens of μm to several hundred μm. Copper and silver are used as the base material of the contact pins. These materials oxidize in air and thus most of the contact pins are plated with gold.

For gold plating, alloy plating to which nickel or cobalt is added is common. Gold plating is difficult to oxidize and can impart excellent conductivity. However, gold plating has some problems when gold plating contact pins come into contact with the solder of the IC chip several thousand times or tens of thousands of times. The first problem is low abrasion resistance. Since gold is a relatively soft material, when it repeatedly contacts with the solder, the surface tends to wear out. The second problem is low adhesion resistance. By contacting with the solder many times, the solder is scraped off. The contact resistance is increased by the solder adhering to the contact pin surface. Therefore, in recent years, as a new protective film to replace gold plating, a protective film that has excellent conductivity, abrasion resistance, and adhesion resistance has been required.[1,2] In a previous study, polycrystalline diamond films were used as a protective film for contact pins.[1] Conductivity was obtained by doping boron (B) into a diamond film having features such as high hardness and high abrasion resistance. However, since the diamond film had a polycrystalline structure and the irregularities on the surface were large, adhesion resistance was poor. It is difficult to fabricate a single-crystal diamond, and polycrystalline diamonds are common. In addition, a diamond film has disadvantages such as requiring an extremely high deposition temperature.[3]

A diamond-like carbon (DLC) film is a material with a hardness close to that of a diamond film. The DLC film is an amorphous carbon film composed of sp^2 and sp^3 bonds. Similar to a diamond film, the DLC film has characteristics such as high hardness and high abrasion resistance. Furthermore, owing to its amorphous structure, the surface is smooth and it has excellent adhesion resistance.[4] The DLC film is produced in various ways, for example, chemical vapor deposition (CVD),[5] ion implantation in plasma,[6] equilibrium/unbalanced magnetron sputtering,[7] and cathodic vacuum arc deposition (CVAD).[8–10] The deposition temperature of the DLC film is room temperature.

Among the various film forming methods, it is possible to fabricate a hard DLC film by CVAD. Among the common DLC films, the hard DLC film fabricated by CVAD shows an insulation property because of few sp^2-bond fractions in the film. As a method for imparting excellent conductivity to the DLC film, another element such as B or nitrogen (N) is added. There are several reports on B-containing DLC (B-DLC) films.[11,12] Kleinsorge et al. fabricated a hard B-DLC film by the filtered cathodic vacuum arc (FCVA) method.[11] B content was 0 to 8%, and electrical resistivity decreased from 10^6 to 10^1 Ω cm. There are several reports on conductivity in N-containing DLC (N-DLC) films.[13–25] In addition, this type of film improves friction characteristics and easily changes the optical band gap. Broitman et al.

