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Proposal of a novel peeling of nano-particle (PNP) process for localized material removal on a hard material surface by controllable magnetic fields

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Abstract

This article proposes a novel Peeling of Nano-Particle (PNP) process to locally remove material on a hard material surface using controllable magnetic fields. Fe3O4 particles in the size range of 50-100 nm in aqueous solution (pH value 11 adjusted by KOH) were magnetically controlled to adhere and remove from a 4H-SiC surface by two electromagnetic coils, which were sandwiched between the substrate. The particle controlling phenomenon on the surface was experimentally observed and verified by our developed apparatus applying an evanescent field. According to the results, particles could be controlled to approach and remove from the substrate surface with 12mT of magnetic field at the selective area on the substrate surface to realise the proposed PNP process.

Hard material, Nanoscale phenomena, Magnetic nanoparticle, Peeling of nano-particle, In situ observation

1. Introduction

In recent years, single-crystal hard materials such as silicon carbide (SiC) and diamond have become widely used in high-power and high-frequency semiconductors. Because of their extreme physical properties, such as large bandgap, high thermal conductivity, high chemical stability, and high hardness[1,2]. These hard materials are definitely difficult to achieve an ultra-precise surface. Chemical Mechanical Polishing (CMP) is one of processes that produces an effective atomically flat defect-free surface in semiconductor fabrication by employing an abrasive nanoparticle slurry[3]. However, the CMP process is fundamentally not able to locally remove material only a selective area because the abrasive nanoparticles are uncontrollable. Thus, we propose a novel Peeling of Nano-Particle (PNP) process to locally remove material on the hard material surface using controllable magnetic fields. The concept of the PNP process, as shown in figure 1. Two electromagnetic coils are sandwiched upper and under between the substrate to generate the magnetic fields for controlling the magnetic nanoparticles (MNPs) to adhere and remove the material at only the selective area. In this article, Iron (II,III) oxide (Fe_3O_4) MNPs in the size range of 50-100 nm in aqueous solution (pH value 11 adjusted by KOH) were employed to experimentally observe and verify the particle controlling phenomenon of the PNP process on a 4H-SiC surface using our developed apparatus.

2. Near a surface phenomenon observing by evanescent field

Generally, total internal reflection occurs when the light is irradiated at the high refractive index n_1 material and lower refractive index n_2 material interface at an incident angle i is larger than the critical angle: $\theta_c = sin^{-1}(n_2/n_1)$. On the reflection surface in lower refractive index n_2 side, a localized

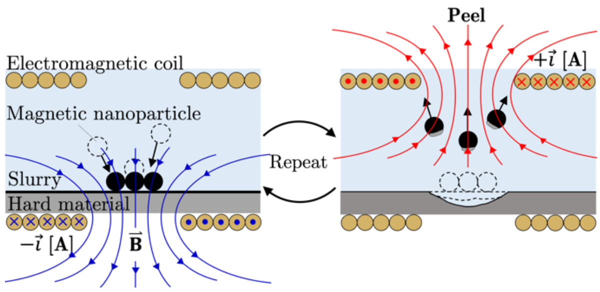

Figure 1. Concept of localized material removal on a hard material substrate surface by a novel peeling of nano-particle (PNP) process

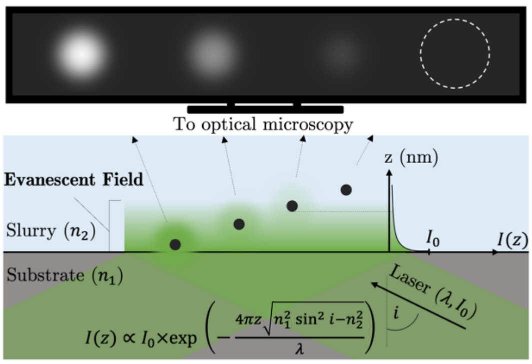

Figure 2. Scattering light of nanoparticle in an evanescent field

light called an evanescent field, which is generated only nearby the surface in a range of a few hundred nanometers.

The evanescent field I_z exponentially decays according to the distance from the reflecting surface, as shown in figure 2 [4-7]. The scattering light occurs when a nanoparticle nearly approaches the surface in the limited range of the evanescent field. Their scattering light is able to be visualized or investigated by an optical microscopy system[7].

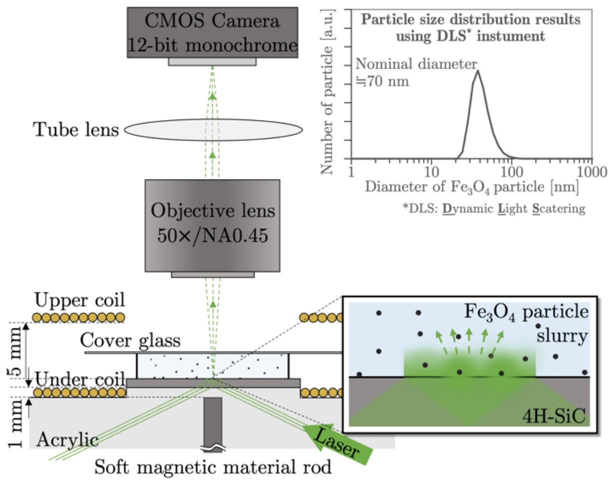

Figure 3. Schematic diagram of experimental setup of the PNP process

Table 1 Experimental PNP process conditions

Spiral electromagnetic coil		
- Copper wire diameter	mm	0.4
- Number of turns	turns	60
Work piece		
- Silicon carbide (4H-SiC): C-face	mm³	10×10×t0.5
Iron(II,III) oxide (Fe_3O_4) particle slurry		
- Particle size in range	nm	50-100
- in KOH solution with pH value		11

3. Experimental setup

Figure 3 and table 1 show the experimental setup and experimental conditions, respectively. A soft magnetic material rod (ϕ 1mm×L 10mm) was inserted into acrylic at the center of under coil for enhancing the magnetic field intensity [8]. The magnetic fields generated by under and upper coils were measured on the substrate surface, which were ≒17mT and 12mT, respectively. The magnetic nanoparticle powder was dispersed in KOH solution and was filled into the pool set on the substrate. After generating the evanescent field, the nanoscale phenomena can be observed and visualized by a CMOS camera.

4. Experimental observed results of MNPs controlling

Figure 4 shows the detected scattering intensity results (green line) and the experimentally observed squence images of the first operating at each coil (below) during the PNP process. Without generating the external magnetic fields, the particles moved freely, and did not normally attach to the surface due to the similar negative charge zeta potential, as shown in figure 4 (thin green line). At t= 4.50 s, the magnetic field was generated by the under coil, the individual particles or aggregated particles were magnetically pulled to approach the surface. The detected scattering light intensity evidently increased. When the under coil was off, MNPs still had residual magnetism due to their diameter are not small enough to be a superparamagnetic stage[9]. Thus, particles might aggregate to be the bigger cluster and fall down on the surface by their weight. When the magnetic field generated by the upper coil, the particles were pulled out from the surface. Hence, the detected scattering light intensity gradually decreased. Moreover, two particles could be observed during the process, as shown in figure 4 (below) at t=4.50-5.00 s. Both particles could be evaluated the z position from the 4H-SiC surface to understand the particle controlling phenomenon by detecting the scattering light intensity I of each particle , as following equation in figure 2, where I_0 is the light intensity

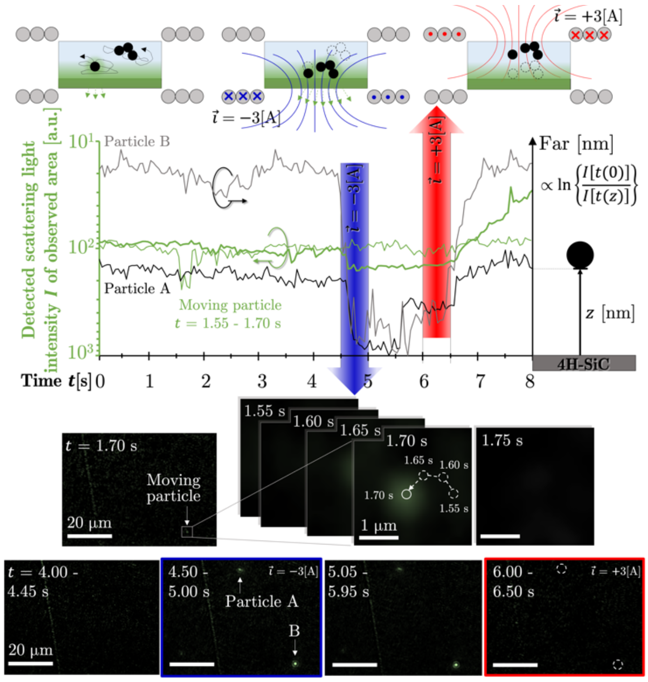

Figure 4. Observation of MNPs controlling in area 70(H)µm×52(V)µm

when particle is at the surface ($z = 0$). According to the results, particles approached and move far away from the surface, which relates to the generated magnetic fields periods, as shown in figure 4 (black line). Namely, MNPs could be controlled to adhere and pull out at the selective area on the substrate surface to realise the proposed PNP process.

5. Conclusion

We proposed a concept of a novel peeling of nano-particle (PNP) process for localized remove material on a hard material surface by controllable magnetic fields. The Fe_3O_4 particles in the size range of 50-100 nm in KOH solution (pH value 11) were employed to be controlled and experimentally observed for realizing the controllability of particles in the PNP process on a 4H-SiC substrate surface by our developed apparatus applying an evanescent field microscopy. We found that;

(i) The particle controlling phenomenon could be observed by our developed optical system.
(ii) The particles were able to be controlled to approach and to pull out from the surface by 12mT of magnetic fields.

In future works, we attempt to locally remove material on the hard material surface by PNP process, and the resolution of the process will be experimentally evaluated, such as the dimension of the processed area, and the material removal rate.

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