CHARGING AND ACCELERATION OF MICROPARTICLES

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Abstract

Nickel microparticles of the order of 1 μm in radius were highly charged by contacting with fine carbon fibers kept at high voltage and accelerated electrostatically up to 2MV. Preliminary experiment on microcrater formation with these hypervelocity microparticles has been made.

Introduction

The experiments to change the crystal structure of solid materials by using shock wave compression have been made for about 30 years. The special features of the shock wave compression are as follows:

(1) The pressure due to shock wave compression is extraordinarily high in comparison with that due to static compression.
(2) Time duration of shock compression is so short as 10^{-7}-10^{-5} sec.
(3) Temperature-rise during shock compression is relatively low.

Due to the feature of (2) only a little modification of initial crystal structure takes place by compression, and instead of the phase transition with random flow of individual atoms does not occur.

In usual, shock wave have been produced by bombarding a solid target with a hypervelocity projectile mass. The bombarded target is broken in pieces which must be gathered afterwards. If the projectile is very small mass, only the surface of the target can be modified without destroying the bulk material. Such modification of material surface is impossible with the static hyperpressure processes. The bombardment with hypervelocity microparticles has two excellent features; production of extraordinary high pressure and possibility of surface modification. Therefore it is expected to become the new technique for creating new materials. In Fig.1 are shown shock wave pressure and temperature-rise as a function of collision velocity. These relations are obtained for many combinations of colliding materials by solving the Rankin-Hugoniot equation with experimentally estimated parameters, and are found to be in the hatched belt region in this figure.

The trial to accelerate microparticles are unexpectedly few, and no work has been made about phase transition with shock wave high pressure even after the success of acceleration. The convenient way to accelerate microparticles is to charge up them and to accelerate with some electrical accelerator. The most important problem in this acceleration is to charge up the particles as high as possible. Although several ion sources for highly charged microparticles (macron source) were developed, they were somewhat complicated and unsuitable for use with ordinary static accelerators. We have developed simple macron sources and accelerated macrons with a Cockcroft-Walton accelerator and a Van de Graaff accelerator.

Macron sources

Parallel plate macron source

For charging microparticles, we must contact them with high voltage electrodes or spray electrons on them. We first studied a parallel plate type macron source. This type of macron source is now used as a feeder for supplying microparticles to a macron source.

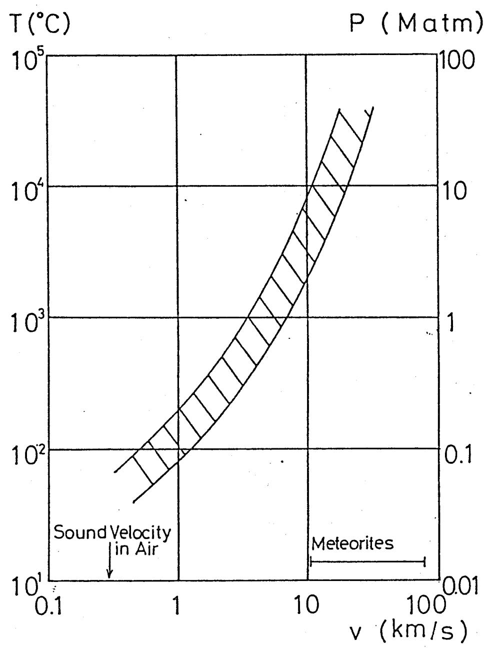

Fig.1 Variation of shock pressure and temperature with collision velocity.

Two parallel plate electrodes are placed horizontally, and microparticles (powder) of some metal are put on the lower electrode.

When dc voltage is applied between two electrodes, microparticles on the lower electrode are charged and repelled up against gravitation to the upper electrode, where they reverse their charge and are accelerated downward. In such a way, macrons move up and down between two plates, and cause electric current.

The macron used in the present experiment is commercially available nickel powder. The size distribution is the log-normal distribution for the particle radius as shown in Fig.2.

With this powder, the current due to macron oscillation between two electrodes was measured as a function of applied voltage. The measured V-I relation is shown in Fig.3. This relation can be explained by considering the size distribution and charging process of macrons. In general, the charge q(r) on a spherical macron with radius r, loaded by contact with a sphere of radius R having surface electric field E_R, is given by

$$q(r)=4\pi\varepsilon_0 r^2 E_r, \qquad (1)$$
$$E_r=\eta(r/R)E_R, \qquad (2)$$

where $\eta(r/R)$ is a function of r/R, and $\eta=\pi^2/6$ for r<<R. In the case of a non-spherical macron, we can roughly estimate E_r by using a form correlation factor G, which is 1 for a sphere, and radius r of a sphere with same volume as the macron:

$$E_r=G\eta(r/R)E_R. \qquad (3)$$

For the parallel plate electrodes with distance d and applied voltage V, E_R is V/d. The maximum size of the repelled macron is determined by balancing the Coulomb repulsive force and gravitational force, and is a function of applied voltage. The sum of carrying

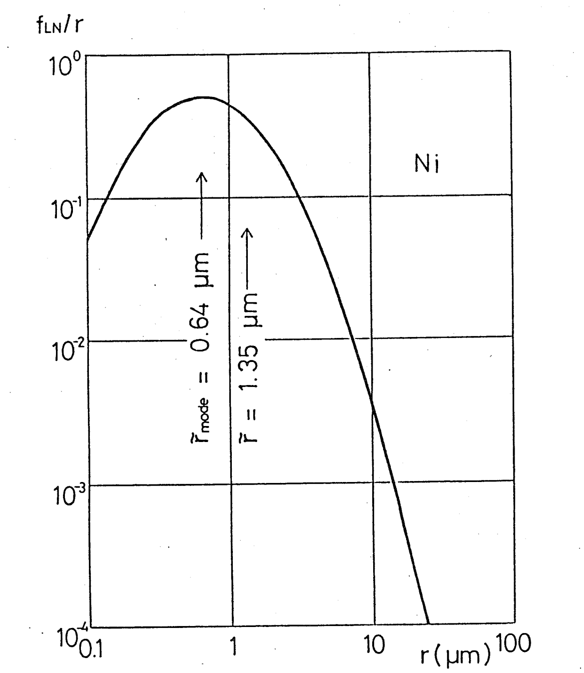

Fig.2 Size Distribution of nickel powder as the sphere of radius r.

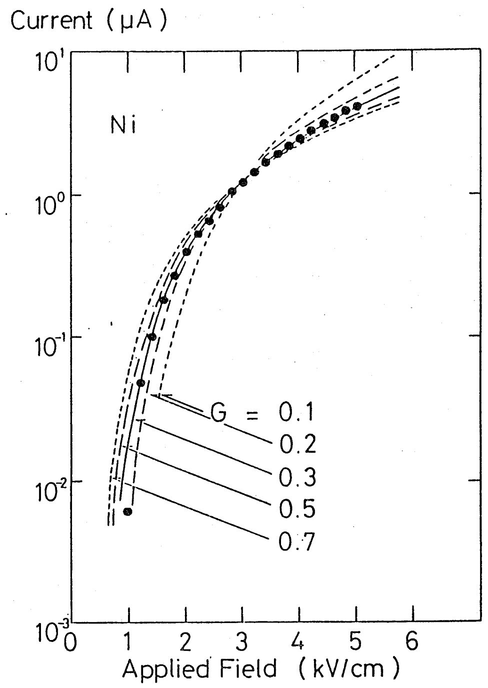

Fig.3 V-I relation of a parallel plate nickel macron source.

charges of macrons of which size is smaller than the maximum size gives total current. The curves in Fig.3 are the calculated ones, and in best agreement with experimental data if we take G=0.3.

The macrons are extracted through a hole at the center of the lower plate (Fig.4(a)) and focused by a unipotential lens. Each charge of macrons can be measured with a faraday cup connected to a preamp-amp system. In Fig.5 is shown an example of the charge distribution (p.p.). The experimental results can be reproduced fairly well by the calculation considering the size distribution and the charge formulae Eqs.(1) and (3).

Fiber type macron source

For an electric acceleration of macrons, it is desirable to make a macron charge as high as possible. On the other hand, there is a limiting maximum value of a macron charge, corresponding to an initiation of surface discharge which takes place at the electric field of about $2x10^{10}$V/m. In our present experiment, macrons from the parallel plate type source have only $1/10^5$ of this maximum value.

Use of sharp point or edge for contact charging electrode gives very large value of E_R in Eq. (3), resulting high charge on macrons. A razor blade with edge radius 4μ m was used for this purpose (Fig.4(b)). By collision with the edge of a high voltage blade edge, a macron charge increased to about $1/10^2$ of the limiting maximum value. Such collisions, however, took place only with small probability.

Next, we bundled many blades as shown in Fig.4(c). At first, high charge macrons were extracted plentifully. After operating a few minutes, however, clearances between adjacent edges were stuffed with macrons and high charge macrons were no longer produced.

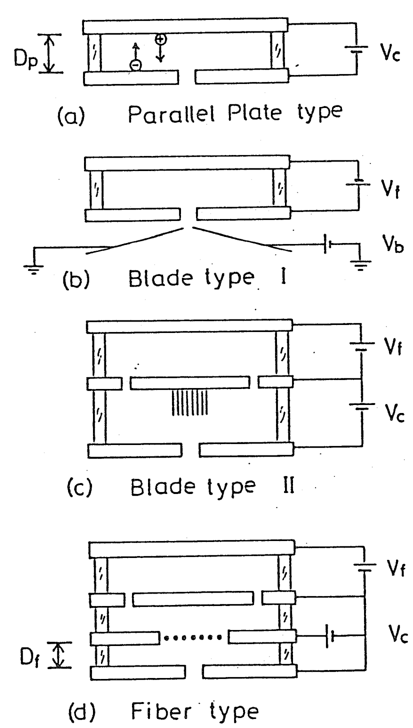

Fig.4 Various Types of macron source.

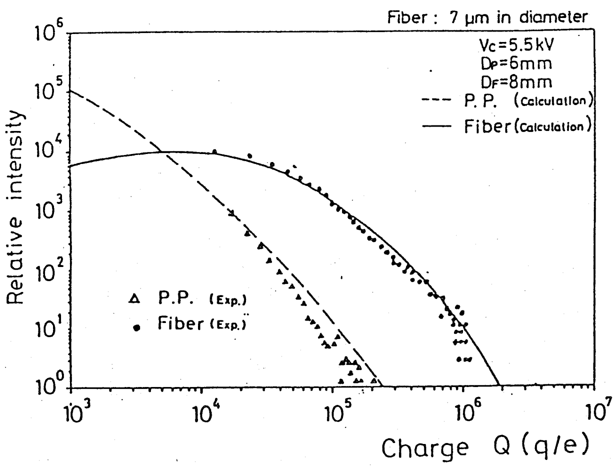

Fig.5 Charge distributions of macrons from a parallel plate type (p.p.) and fiber type (Fiber) sources.

After many trials, we found that the fiber type macron source is the most favorable. As shown in Fig.4(d), an intermediate electrode which has a central hole spanned with many fine carbon fibers ($7\mu m$ in diameter) is placed between two parallel plate electrodes. Macrons oscillate between the intermediate electrode and two parallel plate electrodes. When a macron collides with a carbon fiber, it gets high charge and is extracted through the hole of the lower electrode. The collision probability of a macron with a fiber is much larger than the case of blade type. In Fig.5, the charge distribution of macrons from the fiber type source is shown and compared with that from the parallel plate type source. Solid curve in this figure is the charge distribution calculated by taking into account the gravitational effect to the macron trajectory between electrodes.

Acceleration and crater formation

The macrons are accelerated with the Van de Graaff accelerator which is enclosed in a high pressure insulating gas tank. We have replaced the electron gun on the electron Van de Graaff accelerator with a negative macron source. The arrangement is shown schematically in Fig.6. A mechanical macron feeder was developed to enable long time operation in such an enclosed type accelerator. The particle reservoir can contain 40g of nickel powder. By vibrating intermittently the supplying tube, proper quantity of powder is fed, through a TEM mesh, into the electric feeder. With this mechanical feeder, we can operate the macron source for about 10 hours.

A macron beam extracted from this source is converged with a unipotential lens and accelerated up to 2MV to bombard targets. Fig.7 is a SEM photograph of microcraters formed on the bombarded copper target. Many such microcraters are observed and analyzed.

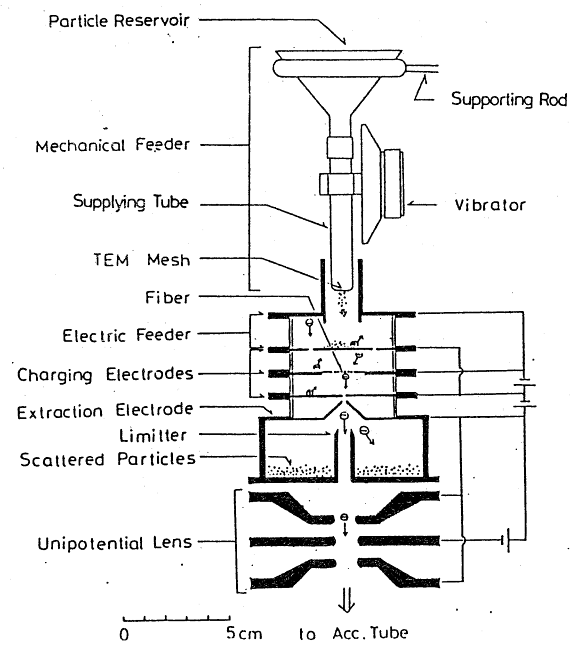

Fig.6 The fiber type macron source used on a electron Van de Graaff accelerator addition of mechanical and electrical particle feeders enabled long time operation.

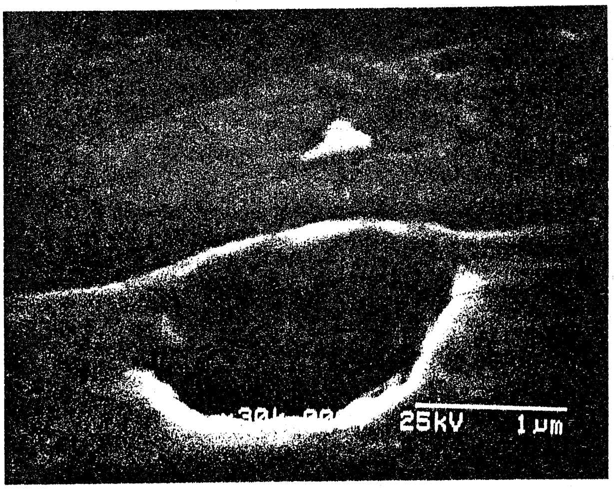

Fig.7 Microparticles produced on Cu plate bombarded by 2MV-accelerated nickel SEM angle 60^{o}.

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