Pramāṇa – J. Phys., Vol. 35, No. 5, November 1990, pp. L503–L507. © Printed in India.

Possible observation of coulomb blockade at room temperature

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M S received 11 June 1990

Abstract. We have studied the (I–V) characteristics of the tunnel junction formed between the tip and the substrate in an STM at room temperature. We find that in such an arrangement it may be possible to get a junction capacitance $\simeq 10^{-19}$ F and junction conductance $< 1\,\mu$s. When the junction conductance is $< 1\,\mu$s strong nonlinearity is observed in the (I–V) characteristics. We explain this nonlinearity as onset of coulomb blockade of tunneling electrons.

Keywords. Tunneling; ultrasmall capacitance; tunnel junction; scanning tunneling microscope; coulomb blockade.

PACS No. 73·40

Discrete transfer of single electron in a tunnel junction of small capacitance ($C < 10^{-15}$ F) is a topic of current interest [Likharev 1988; White *et al* 1986; Fulton and Dolan 1987]. Single electron charging effect has also been observed in an array of small metal particles [Cavicchi and Silsbee 1984; Mullen *et al* 1988; van Bentum *et al* 1988]. If the charging energy $e^2/2C \gg k_B T$ one observes effects arising out of discrete electron transfer. Generally it shows up in the (I–V) characteristics of the tunnel junction where one finds for $V \gg e/2C$,

$$I = G(V - e/2C). \tag{1}$$

But for $V \ll e/2C$ one finds the conductance to be much less than G and the current follows the relation,

$$I = (2CG/\pi e)\, V^2. \tag{2}$$

The low conductance region arises due to blocking of further charge transfer when one electron has been transferred through the junction. This is generally known as coulomb blockade of tunneling electrons (Averin and Likharev 1986).

A very simple way to get an ultra small capacitance tunnel junction is to use a scanning tunneling microscope (STM) where the tip and the substrate forms a tunnel junction. It has been shown recently that in such a junction one can achieve a $C \simeq 10^{-18}$ F and $G \simeq 0{\cdot}1 - 1\,\mu$s such that $e^2/2Ck_B = 10^3$ K and one is able to observe coulomb blockade at $T = 4$ K (van Bentum *et al* 1988).

A recent calculation (GeigenMuller and Schon 1988) shows that a clear observation of coulomb blockade at a finite T is possible for $e^2/2Ck_B T \geqslant 10$. If the ratio is lower than this the nonlinearity below $V = e/2C$ gets smeared out by thermal fluctuations.

In this paper we show that it is possible to achieve a tunnel junction with $C \simeq 10^{-19}$ F in an STM, so that $e^2/2Ck_B \simeq 10^4$ K and it is possible to observe coulomb blockade even at room temperature.