Effect of Near-Threshold Ionization on Electron Attachment in Gaseous Dielectrics

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It has been predicted that near-threshold ionization (NTI) in a gaseous dielectric inhibits the development of electron avalanche when the gaseous dielectric has a sufficient capability for low-energy electron attachment. The NTI leaves little energy for the primary and secondary electrons involved in the ionization; thus, both electrons can be captured by dielectric gas molecules without further ionization. A computational estimation indicates that this process can occur in SF 6.

KEYWORDS: gaseous dielectric, electron attachment, ionization, threshold, electron avalanche, sulfur hexafluoride

Fig. 1. Ionization collision at energy e’ and residual energy sharing between the primary and secondary electrons.
and $\epsilon_u = 15.9$ eV, respectively; $\epsilon_{\text{res}}$ to be shared by a pair of primary and secondary electrons is at most 0.1 eV. In order to take account of the onset of the ionization cross section $q_{\text{ion}}$ of SF$_6$ from $\epsilon_{\text{ion}}$, $\epsilon'$ is chosen as $\epsilon' = \epsilon_0 + \sqrt{\chi(\epsilon_0 - \epsilon)}$ with the uniform random number $0 \leq \chi \leq 1$. $N$ is set at $3.54 \times 10^{16}$ cm$^{-3}$, assuming a gas pressure of 133 Pa (1 Torr) at 0°C. Because the probability density function for $\xi$ is unknown, we assume that $\xi$ distributes uniformly between 0 and 1.

Figure 3 shows $n(t)$ after the NTI. In the beginning, the number of initial electrons $n_0$ is 100,000 at $t = 0$ (o in Fig. 3), and the electrons multiply instantly from $n_0$ to $2n_0$ by ionization (from o to •). At this time, most of the energy of the primary electrons is lost as the ionization energy to release the secondary electrons. The electron energy after the NTI is low; thus, more than one-half of the electrons are captured by SF$_6$ in about 0.2 ns. Then, after a few nanoseconds of relaxation, the electrons establish an exponential growth.

The key point of this result is that the exponential growth of $n(t)$ starts effectively from electrons less than $n_0$. The IAA mechanism that one NTI induces more than one electron attachment has been verified. The NTI in SF$_6$ has a function to reduce the number of free electrons. This finding is also supported by the result of an additional calculation by a propagator method,$^4$ which is a numerical technique for solving the Boltzmann equation for the electron energy distribution. When we suppress the NTI of SF$_6$ in the energy range 15.8–15.9 eV forcibly, $(E/N)_{\text{critical}}$ becomes slightly lower while $\alpha$ decreases. This is due to the disappearance of the IAA. The decrease in $\eta$ due to the disappearance of the IAA is greater than that in $\alpha$ due to the elimination of the NTI, which makes $\tilde{\alpha} = \alpha - \eta$ higher.

The NTI that induces the IAA in SF$_6$ can occur in a limited energy range. However, as long as $q_{\text{ion}} \neq 0$ nearby $\epsilon_{\text{ion}}$, ionization in SF$_6$ involves the NTI to some extent. This indicates the presence of the IAA in SF$_6$ as an actual electron process.

In conclusion, we have explained the mechanism of the IAA and demonstrated the time-variant population of electrons involved in the NTI in SF$_6$. The increase in the number of electrons due to the NTI in SF$_6$ is compensated by the succeeding decrease in the number of electrons due to the attachment of the primary and secondary electrons. It has been indicated that the ionization process in SF$_6$ involves the IAA, which contributes to the suppression of electron avalanche in SF$_6$.

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