EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/85-205
December 20th, 1985

The Emission Spectra of Ar, Kr or Xe+TEA

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Geneva, 17 December, 1985

Abstract:

The emission spectra of Ar, Kr or Xe+6%TEA gas mixtures are measured by using a single wire proportional counter as the emission source. Asymmetric emission bands are observed in the range of 270nm to 350nm, which can be attributed to the radiative deexcitation of excited TEA molecules. For the practical application of optical read-out of avalanche chambers, Ar+2.0%TEA+20%isobutane gas mixture is also examined, and nearly the same emission band is observed.

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1. INTRODUCTION

Considerable research is invested in the detection and imaging of UV photons in high energy physics and astronomy, and resulted in the development of the imaging multistep avalanche chamber[1-6], the imaging Cherenkov detector[7-10] and the photo-ionization proportional scintillation counter[11-18]. In these detectors, compounds of low photoionization potentials are used in order to convert UV photons to photoelectrons.

In connection with the imaging of UV photons, some groups have investigated recently the optical localization of the electron avalanches initialized by incident UV photons in multistep avalanche chamber with certain optical read-out systems[19-20]. The idea is to recognize the localization of UV photons by observing the light emitted from electron avalanches. In addition, this type of avalanche chamber coupled with the optical read-out system has a possibility to visualize the ionization tracks produced by high energy particles[19-23].

From the viewpoint of optical read-out of an avalanche chamber, the chamber gas should have a high emission intensity in visible or near UV regions to make detection easy. In addition, a stable electron multiplication is indispensable because the optical read-out system can be damaged by sudden sparks. Finally, it is essential to choose a gas mixture in which the emission is highly localized spatially since the localization of emission determines the spatial resolution of the optical read-out system.

In the course of a research for the optimum vapors which will be described elsewhere[20], we discovered that triethylamine has very favorable properties. Triethylamine (TEA) is known as a compound with a photoionization potential of about 7.5eV[24], and is also known as one of the saturated aliphatic amines having fluorescence quantum yields near unity with decay time of about 50ns[25,26]. As one of the authors reported recently[23], these properties of TEA led us to use Ar+TEA gas mixture as a chamber gas for optical read-out. So far as we know, however, the emission spectrum of Ar+TEA gas mixture has not been measured.

The purpose of this paper is to report on the measurement of the emission spectra of Ar, Kr or Xe+TEA gas mixtures and discuss the processes responsible for the emission. The emission spectrum of Ar+TEA+isobutane gas mixture is also reported and discussed from the viewpoint of chamber operation.

2. EXPERIMENTAL SETUP

As shown in Fig.1(a), the counter used in this study is nearly the same as described in Ref.[27]. The anode is a 35 μ diameter tungsten wire coated with gold. The cathode is a stainless-steel cross-pipe whose inner diameter and length are 3.4cm and 12cm, respectively. A ^{243}Am α -source of intensity 400Bq is mounted at one end of the counter. On

the opposite end, the counter has a LiF window with a thickness of 3mm, and is coupled with a vacuum monochromator(ARC VM502) through this window.

The monochromator disperses the emission coming from the counter with 1200 grooves/mm in the spectral range of 105nm to 548nm. The monochromatized UV photons are converted into visible photons with sodium salicylate coated on the inner surface of the exit glass window of the monochromator, and detected with a photomultiplier(RCA C31000M). The width of the entrance and exit slits are 1mm, and the resolving power of the system is of 5nm. The monochromator is evacuated down to 10^{-5} Torr with a turbo-molecular pump.

The block diagram of the electronic system is also shown in Fig.1(a). The charge collected on the wire is detected by a charge sensitive preamplifier(ORTEC 124). The output of the preamplifier is fed into a fast amplifier(ORTEC 474) and its output is sent to a timing discriminator(LeCroy Research System 621CL). The anode pulses of the photomultiplier are fed into another fast amplifier(ORTEC 474), followed by a timing discriminator(LeCroy Research System 621CL). The timing signals coming from both discriminators are sent into a coincidence circuit (Electronics Borer Co. CERN-NP N6235) and the number of coincidences is counted. The total ionization current is monitored with a micro-ammeter inserted between the high voltage supply and the anode wire. In order to measure the total emission intensity by adjusting the grating at $0\overset{\circ}{\text{A}}$, the anode current of the photomultiplier is measured with a pico-ammeter(DIPATO-3 Dr.Kamphausen).

The vacuum and gas supply system are shown in Fig.1(b) schematically. The chamber and the system are baked and evacuated to less than 10^{-6} Torr. The typical outgassing rate was about 10^{-7} Torr·l/s after 24 hours evacuation. The filling gases of Ar, Kr and Xe are commercially available with purities of 99.996%, 99.997% and 99.99%, respectively. These gases are used without further purification. The Liquid TEA is also commercially available (Merck-Schuchardt) with purity of 99%. Immediately after filling the bubbler with liquid TEA, the rest of the volume is evacuated and kept in Ar atmosphere. Under the regulation of a mass-flow meter (Brooks Instrument 5830, 5810), Ar, Kr and Xe gases are flowed with 50cc/min, and are guided into the bubbler where they are mixed with the gas phase of TEA. The bubbler is in a water bath to reduce the temperature of liquid TEA and to keep it at $15 \pm 1^\circ\text{C}$. The vapor pressure of TEA at 15°C is of 46 Torr [28], and the concentration of TEA is of 6% in those gas mixtures.

3. EXPERIMENTAL RESULTS

The dependence of total emission intensity on the applied voltage is shown in Fig.2 for Ar, Kr or Xe+6%TEA gas mixtures. The total emission intensity increases exponentially with increasing the applied voltage, and becomes steeper when going from Xe to Kr and Ar+6%TEA. The maximum points are limited by continuous discharge in these gas mixtures.

The observed emission spectra of Ar, Kr or Xe+6%TEA gas mixture are shown in Fig.3. These spectra were obtained with the applied voltages of 2.4kV, 2.6kV and 2.7kV for Ar, Kr and Xe+6%TEA gas mixtures, respectively, so that the ionization currents were 0.5 μ A, corresponding to the charge gain¹ of 3×10^4 approximately, in these gas mixtures. Under these condition, the ratio of emission intensities are 1.0 : 0.24 : 0.13 in Ar, Kr and Xe+TEA gas mixture, respectively, and the areas under the spectra are normalized by this ratio. The efficiency of the grating, the quantum efficiency of sodium salicylate and the quantum efficiency of the photomultiplier are not corrected in these spectra. Though the total emission intensity increases from Xe to Kr and Ar+6%TEA gas mixtures, their asymmetrical shapes are almost the same in those gases. Each spectrum rises up from 260nm and has a broad peak around 280nm whose FWHM is about 35nm, and then decreases continuously up to 350nm. Several shoulders on the spectra may be recognized at 288nm, 298nm and 310nm. No emission was observed in VUV region.

¹

The charge gain, G , can be written as $G = I_w / e r E_\alpha$, where I denotes the anode current, w the w -value for the gas mixture, e the elementary charge, r the disintegration rate of the α -source, and E_α the energy of the α -particles. Although there is no data available about the w -value in Ar, Kr or Xe+TEA gas mixtures, it is natural to assume that w -value is around 20eV in those gas mixtures[12]. With this value, G can be estimated to be 3×10^4 roughly.

In order to study the dependence of emission spectrum on TEA concentration, the emission spectrum of Ar+1.6%TEA gas mixture has been also measured with the applied voltage of 2.1kV corresponding to the ionization current of 0.5 μ A. The obtained emission spectrum is shown in Fig.4 together with that of Ar+6%TEA gas mixture. The ratio of total emission intensity in Ar+6%TEA gas mixture to that in Ar+1.6%TEA is found to be 1:0.4 in this condition. As can be seen from Fig.4, both spectra show nearly the same asymmetric form.

As mentioned before, it is interesting to study on Ar+TEA+isobutane gas mixture because this mixture is a promising one for the optical read-out of multistep avalanche counter. The dependence of total emission intensity on the applied voltage is also shown in Fig.2 for Ar+2.0%TEA+20%isobutane gas mixture. The total emission intensity increases much slower than in Ar+6%TEA gas mixture with increasing the applied voltage. The obtained emission spectrum for this gas mixture is shown in Fig.5 with the applied voltage of 6kV. It can be found that the emission spectrum is nearly the same as Ar, Kr or Xe+6%TEA gas mixtures.

4. DISCUSSIONS

4.1. The possible reaction dynamics in Ar, Kr or Xe+TEA gas mixtures

Halpern[25] and Fletcher et al.[29] observed the emission spectra of pure TEA in gas phase excited by UV photon and electric discharge, respectively. Their spectra are essentially the same as those observed in this study for Ar, Kr or Xe+TEA gas mixtures. Halpern attributed this emission to the radiative transition of TEA from planar excited state(TEA^*) to the pyramidal ground state(TEA);

Now we consider the possible reaction dynamics in these gas mixture. We use Ar+TEA gas mixture as a specific case, but the discussion also can apply to Kr and Xe+TEA gas mixtures. The electrons produced by α particles are accelerated under the influence of applied electric field, and lose their energies by excitation, ionization and dissociation processes[29,30];

Here, e denotes an electron, Ar the argon atom, Ar^* the excited argon atom, TEA^+ the TEA ion, and X and Y the products of dissociation process.

Through the three body reaction, Ar^* will be converted to an excited molecule Ar_2^* within 100ns for pressures of more than 1atm[31];

If there is no TEA in the gas mixture, Ar_2^* would de-excite with emitting VUV photon[27];

As we reported, however, there is no VUV photon detected in this study, and this fact can be explained by photoabsorption and the energy transfer processes;

Those processes of (4), (9) and (10) could be the main production processes of TEA^* , and it is presumable that the production rates of TEA increase in order of Xe, Kr and Ar because total emission intensity increases in this order. The variation in emission spectra of $Ar+TEA$ for different TEA concentration might conceivably result from the dependence of the production rates on the TEA concentration. At the same time, the Penning

ionization and dissociation process of TEA could occur by the collision with Ar_2^* ;

The electrons produced in the process of (11) will be fed back to the process (2) ~ (6), and will facilitate the formation of electron avalanches.

There would be another photon mediated processes resulting in the ionization and the dissociation of TEA by absorbing the VUV photons produced from process of (8) [30];

Though the processes of (9) and (14) can not be distinguished from the processes of (10) and (12), respectively, the process of (13) should be consider as minor ones in Ar, Kr or Xe+6%TEA gas mixture. It is known that TEA has a maximum photoionization quantum efficiency at wavelength of 150nm[32]. The VUV photons emitted from Kr_2^* through the process of (8) have the emission spectrum overlapping this maximum area much better than Ar and Xe[1]. If, therefore, the process of (13) is a significant process in the dynamics, Kr+6% TEA gas mixture should have the most intense emission among the gas mixtures. The experimental results, however, show that this is not the case.

4.2. The gas mixture for the optical read-out of avalanche counter

As reported in this paper, Ar+6%TEA gas mixture has a rather strong emission band from near UV to visible regions, but sudden sparks were observed in this gas mixture at higher applied voltage. This can be due to the electron feed-back process from the process of (11) to (2)-(6). The reduction of TEA concentration is, therefore, one of the possible way to suppress the sudden sparks. However, the reduction of TEA concentration will enhance the process of (13), then another electron feed-back process can proceed which is not a major process at high TEA concentration. Accordingly, it is desirable not only to reduce the TEA concentration but also to add an effective quenching gas to Ar+TEA gas mixture to kill the VUV photon before they create the secondary electrons through the process of (13).

The above argument led us to study on Ar+2.0%TEA+20%isobutane gas mixture because isobutane is a typical quenching gas used widely in high gain counters. As reported in section 3, the mixture of Ar+2.0%TEA+20%isobutane has nearly the same emission spectrum as Ar+6%TEA gas mixture, and has a stable dependence of emission intensity on the applied voltage, though the total emission intensity in the mixture is decreased. Since isobutane is transparent for the photon whose wavelength is longer than 175nm[33], it is quite natural that the same emission spectra were observed in both gas mixtures. The decrease in the total emission intensity could be attributed to the energy transfer process from Ar^*_2 to isobutane and/or the photoabsorption process of isobutane for VUV photons, resulting in the non-radiative deexcitation. The stable depen-

dence of emission intensity on the applied voltage supports the above argument that the low TEA and the high isobutane concentrations suppress the feed-back process of (11) and (13), respectively. And the quenching of VUV photons must result in better spatial resolution of the optical read-out system.

ACKNOWLEDGMENT

We are grateful to Professor S.Kubota who kindly lent to us the monochromator used in this study. We are glad to acknowledge fruitful discussions with Dr.D.Anderson on the gases favorable for the optical read-out. We would like to express our gratitude to J.C.Santiard, R.Bouclier and G.Million for thier technical assistances. One of the authors, M.Suzuki, wishes to acknowledge his indebteness to Nishina Memorial Foundation for their financial support.

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FIGURE CAPTIONS

Fig.1 (a)The single wire proportional counter and the block diagram of electronics. PA : charge sensitive pre-amplifier, FA : fast amplifier, TD : timing discriminator, CC : coincidence circuit.

(b)The vacuum and gas supply system. TMP : turbomolecular pump, MFM : mass flow meter.

Fig.2 The dependence of total emission intensity on the applied voltage for Ar, Kr or Xe+6%TEA gas mixtures. The dependence for Ar+2.0%TEA+20%isobutane gas mixture is also included.

Fig.3 The observed emission spectra for Ar, Kr or Xe+6%TEA gas mixtures with applied voltages of 2.4kV, 2.6kV and 2.7kV, respectively. The ionization currents collected on the anode wire are 0.5 μ A for all the gas mixtures. The areas under the spectra are proportional to the

total emission intensities for these gas mixtures.

Fig.4 The emission spectra for Ar+6%TEA and Ar+1.6%TEA with the applied voltages of 2.4kV and 2.1kV, respectively.

The ionization currents collected on the anode wire are 0.5 μ A in both gas mixtures, and the area under the spectra are proportional to the total emission intensities.

Fig.5. The emission spectrum for Ar+2.0%TEA+20%isobutane with the applied voltage of 6kV.

Fig.1(b)

Fig. 1(a)

Fig. 2

Fig. 3

Fig. 4

Fig. 5