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THE 10 ATM HELIUM-METHANE STREAMER CHAMBER WITH HOLOGRAPHIC REGISTRATION

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INTRODUCTION

Holographic registration of information from a streamer chamber (SC) not only makes higher the spatial resolution of the chamber used as a track detector, but also improves its sensitivity: allows a higher density of the number of detected streamers in the track with smaller dimensions than in case of photodetection[1]. Better sensitivity is due to the fact that in SC with holographic reading (HR) the registration is based on refraction and diffraction of a laser beam on optical inhomogeneities which appear in streamer channels[1,2], and not on luminosity of a streamer, as in classical SC.

Thus a hologram separates with a high spatial resolution (~10 μm) bright and dull streamers placed close to one another. It should be noted that in classical SC, images of adjacent streamers merge together due to large emulsion grain (high photosensitivity emulsion is used for detection). Therefore, the diameter of the photographed streamer becomes larger, and density of the number of streamers in the track becomes lower. Pressure also produces a strong effect on sensitivity: higher pressure leads to smaller diameter of the holographed streamer and to higher density of the number of streamers in the track[3-7].

One of the methods to increase sensitivity of HR is to increase the optical inhomogeneity degree in the streamer channel using mixtures with large values of refraction[2]. It is known that helium, being a good filling gas for SC, is characterized by a small value of refraction: $n-1 \approx 0.35\cdot10^{-4}$. Refraction is calculated by the Cauchy formula[8]

$$n-1 = A(1+B/\lambda^2), \tag{1}$$

where $A = 3.48\cdot10^5$ cm^2, $B = 2.3\cdot10^{11}$cm^2, $\lambda = 580$ nm (radiation wavelength of a laser with rhodamine 6G).

On the other hand, refraction of a mixture can be determined if the reflection and percentage of its components are known:

$$100(n-1) = c_1(n-1)_1 + c_2(n-1)_2 + \dots \,. \tag{2}$$

From this point of view, methane is somewhat singular, since its reflection value is an order of magnitude larger, than that of helium: $n-1 = 4.44\cdot10^{-4}$ (for $\lambda = 580$ nm). Besides, methane

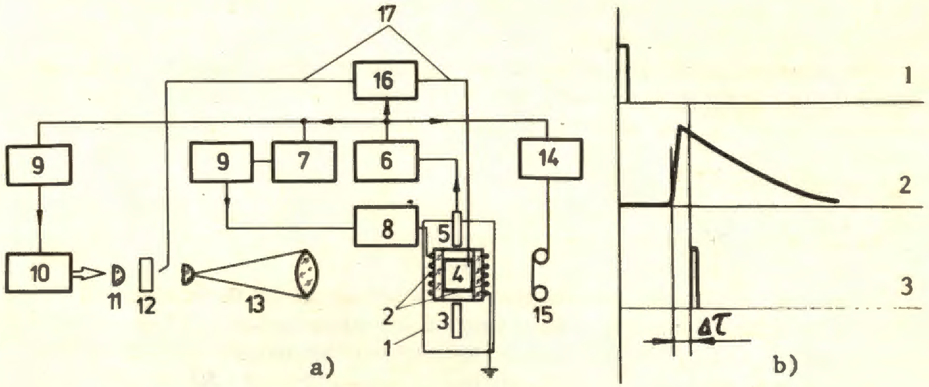

Fig.1. a) Registration scheme, 1 - nitrogen tank, 2 - high-voltage and earth electrodes, 3 - radioactive source ^{90}Sr, 4 - streamer chamber, 5 - photomultiplier, 6 - univibrator, 7 - triggering block for voltage pulse generator, 8 - high-voltage pulse generator, 9 - delay line, 10- nitrogen laser, 11 - quartz lens, 12 - rhodamine 6G laser cavity, 13 - collimator, 14 - camera triggering block, 15 - camera, 16 - oscillograph C9-4, 17 - fiber optics. b) Time diagram of holographic registration: 1 - photomultiplier start signal, 2 - high-voltage pulse, 3 - laser pulse.

reduces photoionization and the number of charge-carriers in the whole chamber volume, thus improving localization of tracks in SC[3].

We used a filling mixture which comprised 25% of methane and 75% of helium (both gases were of 99.99% purity). On adding the mentioned amount of methane, the refraction value becomes $n-1 = 1.37\cdot10^{-4}$ ($\lambda = 580$ nm).

Besides, from the technical point of view this mixture is more suitable because of low working voltage of the voltage pulse generator (VPG) even at high pressure. The chamber with such a mixture is a good target-detector in experimental investigations of π-meson interactions with helium and carbon.

We investigated variations of the diameter and density of the number of optical inhomogeneities in streamer channels versus the laser pulse delay relative to the high-voltage pulses (HVP); we also investigated variations of the same parameters versus the delay of the HVP relative to a triggering pulse of photomultiplier (Fig.1b) at the constant laser time-delay 700 ns.

The paper presents the investigation results on sensitivity of holographic reading of information from a helium-methane chamber at 10 atm pressure. It is a continuation of our investigations into capabilities of a streamer chamber with HR, operating in self-shunted regime [3-7].

To investigate the effect of pressure upon sensitivity, the same experiments were carried out in the same chamber with the same mixture after decreasing the pressure from 10 to 5 atm.

EXPERIMENTAL SET-UP

The experimental technique differed from that described in [5] only by a smaller spacing of electrode step (1.2 mm instead of 3 mm). Gabor's track holograms of electrons from the radioactive source ^{90}Sr were being registered 50 cm off the median plane of the chamber (Fig.1a). The track shadowgrams were also registered by means of the "Helios-40" objective. Holograms and shadowgrams, as well as images reconstructed from holograms, were registered on the Micrat-300 photoemulsion with light-sensitivity 11 units GOST. Images were reconstructed from holograms according to the scheme in Fig.2. Holograms were illuminated by a He-Ne laser with ~2 mWt continuous radiation. Real images were photographed by the Helios-40 objective with extension rings. To determine comparatively the size of the reconstructed image of the optical inhomogeneity, appeared in the streamer channel, opaque strip miras 80 and 160 μm wide were placed in the real image formation plane. The miras were placed in such a way that the track image reconstructed from the hologram was between them. The laser pulse delay relative to the high-voltage pulse was 0.2, 0.5, 0.8, 2 and 9 μks, respectively. Tracks were reliably detected 200 ns after the high-voltage pulse was triggered. Separation of the shock wave front from the streamer channel was observed ~900 ns after the high-voltage pulse.

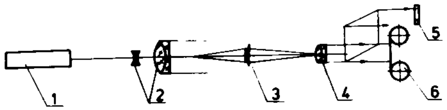

Fig.2. Reconstruction scheme. 1 - helium-neon laser, 2 - collimator, 3 - hologram, 4 - Gelios-4 objective, 5 - tarnished screen, 6 - "Zenith" camera.

Holograms and shadowgrams were measured in the UIM-21 microscope. Electron tracks were also photographed without illuminating the chamber volume by a laser (i.e., a classical method of reading). In this case the ISOPANCHROM-22 photoemulsion was used with light-sensitivity 1200 units GOST (Fig.6).

RESULTS

A. Reconstruction of Holograms

Figure 3 is a photographed hologram of the track of an electron from the radioactive source ^{90}Sr in the helium-methane chamber at 10 atm. The laser pulse delay in respect to the high voltage pulse was 200 ns. Reconstruction of the track image from this hologram is shown in Fig.4; above and below the track image one can see photoimages of both the miras. The reconstructed image shows that, despite a heavy diffraction of the laser irradiation on the wires of electrodes, the hologram registered a very sharp diffraction image of the optical inhomogeneity from each streamer. Influence of the diffraction on electrode wires could be reduced by placing the film immediately in front of the SC, which was impossible because of the external vessel in which the SC was placed (to avoid electrical break-down the vessel was filled with nitrogen at a pressure of 5 atm during the exposure). Influence of the diffraction on electrode wires can be completely eliminated by using side glasses with conductive coating as high-voltage and earth electrodes. On moving the hologram along the Z-axis (or moving the objective while the hologram is fixed, Fig.2) during the reconstruction, one can achieve a step-by-step reconstruction of the image of the whole optical inhomogeneity in the streamer channel. At a certain distance between the hologram and the objective focus plane corresponding to the distance between the film and the place where streamers' necks were formed (i.e., in places where electrons from ^{90}Sr passed) an image with the smallest diameter was reconstructed from the hologram. In this way the image reconstructed from the hologram shown in Fig.3 was pictured in the film (Fig.4).

Since the coherence length of our rhodamine 6G laser was ~70 μm [9], the depth of focus of the optical inhomogeneity image reconstructed from the hologram was ~1.5 mm, which was experimentally proved(small coherence length sets limits to the hologram diameter [9]). Because of strong cross-influence of the diffraction on electrode wires, it was difficult to find an exact diameter of the hologram, which would be useful; by the way using the formula $d = 0.77 \cdot \lambda z/D$ one could determine the inhomogeneity diameter d if the diameter of its hologram D is known.

By comparison with miras one could find that diameters of optical inhomogeneities in some streamer channel necks were ~80 μm while in other necks they varied within 100-180 μm.

Afore-mentioned figures were verified when measuring inhomogeneity diameters from shadowgrams.

Fig.3. A photo of the hologram of the electron track in a helium-methane chamber at 10 atm. Field intensity is ~125 kV/cm. HVP delay is 600 ns, laser pulse delay relative to the high-voltage pulse is 200 ns. The track length is ~0.8 cm.

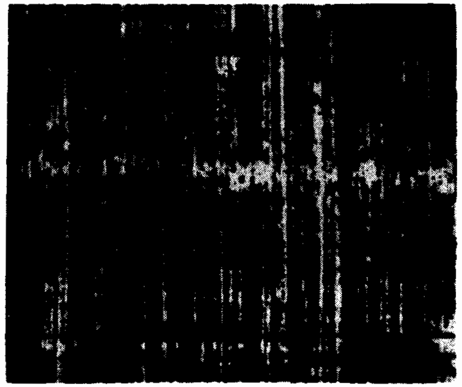

Fig.4. A photo of the image reconstructed from the hologram shown in Fig.3. Above and below the image there are images of miras 80 and 160 μm width. The track length is ~0.8 cm.

B. Measurements of Shadowgrams

Strong noise component due to diffraction on the electrode wires does not allow precise measurement and micrometry of the reconstructed images from hologram. Therefore, all measurements were made by shadowgrams (Fig.5) registered under the same conditions as holograms.

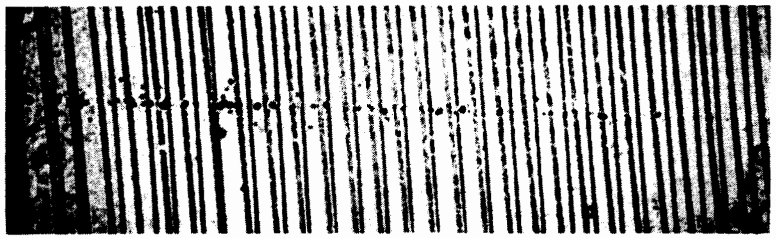

Fig.5. A photo of the electron track shadowgram under the same conditions as in the hologram in Fig.3. The track length is ~3 cm.

Since extension rings were used during the registration for precise focusing of the objective in the median plane of the SC, "compressed" images of the chamber volume were regisreted in the shadowgram ("compression" coefficient was 3.6). Despite all this, here also the "transparency" degree of shadowgrams was not high because of diffraction on wires which hampers microphotometry of tracks. Therefore, shadowgrams were measured in a microscope.

The optical inhomogeneity diameter was determined by the size of a light spot in each streamer channel to the first maximum of sharp blackening. An average diameter of inhomogeneity images was calculated by measuring 30-60 images at each delay (of the laser or VPG).

Table 1

Density of the number of optical inhomogeneity images η (streamers/cm) and their diameters d (μm) versus the laser pulse delay $\Delta\tau$; $\Delta\tau$ varying relative to the high-voltage pulse within 200-9000 ns, and versus high-voltage delay Δt = 600 ns and Δt = 900 ns ($\Delta\tau$ = 700 ns in both cases) relative to the signal from FEU

Parameter		Holographic method 5 atm		10 atm		Photographic method	
	$\Delta\tau$	Δt = 600 ns	Δt = 900 ns	Δt = 600 ns	Δt = 900 ns	Δt = 600 ns	
η	200 500 800 2000 9000	10±1	10±1	14±1	14±1	4±1	6±1
d	200 500 800 2000 9000	~180	~190	~150	~160	–	–

Results of those measurements are presented in Table 1. As is seen, a two-fold increase in pressure produces but a slight effect on the size of the diameter of the optical inhomogeneity. This should be expected, since the duration of the high-voltage pulse was always constant and equal to ~100 ns [10,11] (the table lists actual diameters of inhomogeneities, i.e., the size they have in the chamber itself).

At both pressures (5 and 10 atm) tracks were registered positively and without any change regarding density and diameter of the image at the high-voltage pulse delay relative to the photomultiplier pulse up to 1000 ns. As the chamber volume height was comparable with thickness of side glasses, due to difference in dielectric constants of the filling mixture and glasses, the field strength in the chamber exceeded the one calculated by the space between electrodes and equaled ~125 kV/cm. Probably, one could not observe dependence of the diameter and density of the number of inhomogeneity images upon the amplitude of the VPG high-voltage pulse because of the high field strength.

Higher pressures increase, undoubtedly, sensitivity of the method, which is testified by higher density of streamers, though the observed density is considerably lower than the primary ionization density calculated by the formula offered in /12/. It follows from this formula that for {E = 0.5421÷2.26 MeV} radioactive source is ^{90}Sr for helium at 10 atm.

$$\eta = \frac{A_1}{\beta^2} P \frac{273}{273+t^\circ} \left[B_1 + \ln\frac{\beta^2}{1-\beta^2} - \beta^2 \right] \sim 35 \text{ ion pairs/cm}, \quad (3)$$

where $A_1 = 0.244$ and $B_1 = 11.64$; P is the pressure; $\beta = v/c$. On the other hand, as is seen in the table, the streamer chamber with holographic reading has, however, higher sensitivity as compared with the classical photography method (Fig.6).

One can judge the indubitable advantages of SC with HR by the quality of images from shadowgrams and photograms. Unfortunarely, the advantages of holography are hardly revealed when photographing tracks from the hologram under white light. All the advantages of HR are displayed only if the hologram is reconstructed under coherent light, when a separate element of a track is reconstructed not only with high spatial resolution, but also with information on its Z-coordinate.

Fig.6. A photoimage of the electron track. Pressure is 10 atm, field intensity is ~125 kV/cm, VPG high-voltage pulse delay is 600 ns. The track length is ~3 cm.

Table 2

The dependence of density and image diameters on pressure, mixture, methane percentage and reflection

Pressure, atm	Mixture	Methane percentage %	Refraction $(n-1)\cdot 10^4$	Density of the number of images η, streamer/cm	Average image diameter, d, μm
5	$He + CH_4$	0.4-0.6	0.35	~ 4	-
5	$He + CH_4$	0.02-0.04	0.35	~ 5	150
5	$D_2 + CH_4 + H_2O$	0.1	1.38	9 ± 2	~120
5	$He + CH_4$	25	1.37	10 ± 1	~180
10	$He + CH_4$	25	1.37	14 ± 1	~150

On comparing our data on density and diameters of registered images from streamer channels of the helium-methane SC with HR at 10 atm with the data from refs. /5-7/, one can see that higher percentage of methane leads to higher sensitivity of HR (Table 2). This can be visualized by comparison of the obtained data with the data of experiments with a deuterium chamber, the reflection value of which is approximately the same as the refraction value of a helium-methane chamber with 25% of methane.

When considering the data in Table 2 one should bear in mind some differencies in parameters of the set-ups at which the data were obtained: different shock capacitance of VPG's, different spacing in winding of electrodes and different ways of their fastening, different purity of filling gases, etc.

CONCLUSIONS

1. Higher percentage of methane leads to increase of target degree of optical inhomogeneity and to better sensitivity of HR, though the achieved density of the number of images is significantly lower than the density of primary ionization under given conditions (10 atm pressure).

2. A two-fold increase in pressure (from 5 to 10 atm) leads to a decrease of the diameter of the optical inhomogeneity image from 180 to 150 μm and to an increase of the density of the number of images from 10 to 14 streamers/cm.

3. On changing the laser pulse delay relative to the high-voltage delay within 200-9000 ns, the density of the number of images and their average diameter remain constant.

Thus, the advantages of the holographic reading of information from streamer chambers can be fully realized only using a filling mixture with high refraction value at high pressures with a corresponding shortening of the high-voltage pulse.

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Иванов И.Ц. и др. Д1-83-798
10-атмосферная гелиево-метановая стримерная камера
с голографическим съемом информации

Впервые произведена голографическая регистрация треков электронов в гелиево-метановой стримерной камере при давлении смеси 10 атм. С использованием габоровской схемы голографирования вдоль электрического поля плотность числа регистрируемых голограммой изображений стримеров составляет 14±1 стрим./см. Величина действительного диаметра стримерного канала составляет ~150 мкм и мало меняется при изменении задержки лазерного импульса относительно высоковольтного импульса генератора импульсов напряжения в интервале 200-9000 нс. Камера работает в режиме самошунтирования с добавлением 25% метана к основному рабочему газу - гелию.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1983

Ivanov I.Ts. et al. D1-83-798
The 10 atm Helium-Methane Streamer Chamber
with Holographic Registration

Electron track holograms were registered at 10 atm helium-methane (3/1) self-shunted streamer chamber. From the Gabor hologram, the track was reconstructed with 14±1 streamer density (str./cm) and about 150 μm mean-value diameter of the streamer image. The density and diameter values remain constant during the 200-9000 ns laser time-delay relative to high-voltage pulse.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

r Research. Dubna 1983