

	SURFACE VEHICLE INFORMATION REPORT	
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Absorptive and Interference Coatings Applied on Replaceable Headlamp Bulbs		

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1. SCOPE

This report investigates the use of single and multi-layer coatings on replaceable headlamp bulbs and how such coatings can affect the performance of bulbs in terms of light scattering, which can contribute to glare, and spectral separation in headlamps. Tests were developed to investigate the effects of absorptive and interference (multi-layer) coatings on bulbs, and on bulbs in headlamp systems. These tests provide validation for a proposed bulb color separation test, which establishes limits for spectral separation within the boundaries of SAE J578 white color requirements. The bulb color separation test provides a definitive selection criterion to identify bulbs that cause excessive light scatter (glare) and/or spectral separation in an optical system.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

1. Bucher, K., Holt, D., King, G., Lüttgens, G., Rice, L., Schug, J., Terburg, B., Visser, A. de, Woodward, R., *"Investigation into the Effects of Absorptive and Interference Coatings Applied on Replaceable Headlamp Bulbs"*, SAE technical publication, SP-1875, #2004-01-0802, Society of Automotive Engineers, Warrendale, PA (2004).
2. Tessnow, T., Reiners, T., Hering, O., *"Optical Near Field Measurements and Ray-Tracing Simulation of Coated and Uncoated Halogen Lamps for Glare Analysis"*, SAE technical publication, SP-1787, #2003-01-0929, Society of Automotive Engineers, Warrendale, PA (2003).
3. ECE Economic Commission of Europe Regulation 5, <http://www.unece.org/trans/main/wp29/wp29regs.html>.
4. SAE Standard J578, *"Color Specification"*, Society of Automotive Engineers, Warrendale, PA, 2002.
5. ASTM E 308-66, *"Method for Computing the Colors of Objects by Using the CIE System"*, American National Standards Institute, Inc., 25 West 43rd Street, New York, NY 10036-8002.

6. FMVSS (Federal Motor Vehicle Safety Standards) (1998) Standard 108: "Lamps, reflective devices, and associated equipment". In: Code of Federal Regulations, 49CFR571, Washington, D.C.: Office of the Federal Register.
7. Terburg, B.P., et al. *"Review of Color Coated Bulb Test Methods and Data"*, report to United Nations Economic Commission for Europe's Working Party on Lighting and Light Signaling, report #GRE44/inf.1 (2000).
8. ECE Economic Commission of Europe Regulation 8, <http://www.unece.org/trans/main/wp29/wp29regs.html>.
9. ECE Economic Commission of Europe Regulation 20, <http://www.unece.org/trans/main/wp29/wp29regs.html>.

3. INTRODUCTION

The introduction and sale of tinted replaceable headlamp bulbs first appeared in the late 1990s. The lamps initially sold used standard replaceable capsules, which were coated with interference (multi-layer) coatings to produce a "HID color". A survey of bulbs that were being sold in the aftermarket showed that some of the bulbs did not meet performance specifications for light output or wattage. Another characteristic of the multiple-layer interference coating was that the light output was separated into bands of color which depending on the viewing angle could range from reddish to greenish to blue-ish white. The color separation was still noticeable when placed in a headlamp.

An oncoming vehicle could produce a change of color that could confuse drivers or more typically produced a higher level of offending glare.

Existing tests and regulations did not anticipate tinted headlamp bulbs. To address this issue an international group of engineers from the bulb manufacturers under auspices of SAE assembled a task force to investigate the effects and recommend the appropriate test methods for governing their design and use.

4. BACKGROUND AND TEST METHODS

The initial investigation of color separation focused on the investigation of the color separation as it pertains to the light output from the bulb. The typical US replaceable bulbs were used in the investigation. These bulbs were ANSI 9004, 9005, 9006 and 9007.

After the first round of tests were completed and a proposed method was documented, the scope of the investigation was broadened to include the consideration of the effects of glare from the bulb in a lighting system such as a headlamp. For this reason the testing was separated into Round 1 Testing and Round 2 Testing.

Round 1 testing initially investigated two types of methods: The Bulb Haze Method and Bulb Color Separation test. A color separation test standard was later adopted into European regulations and a US version was developed simultaneously. These methods are described below.

Round 2 testing investigated four potential test methods: the Bulb Haze Method, a Reference Reflector Method, Bulb Optical Properties and Near Field Imaging. Of these the Reference Reflector method and the Near Field Imaging were used. Near field imaging is widely accepted method in the study of the optical performance of bulbs [2].

5. PHYSICS OF COLOR SEPARATION

In understanding what causes spectral (color) separation in certain types of coated bulbs, one has to investigate the phenomena that occur when white light from a tungsten filament in a halogen bulb traverses the glass bulb wall of the coated bulb. A coated bulb has the outside bulb wall coated with a thin film that filters light either through absorption, or through interference. In the latter case the thin film is a multi layer film. In either case of filter technologies the purpose of the filter is to achieve a more bluish white color of light, either by absorbing some light in the yellow wavelengths (absorption coating), or by reflecting yellow and red light out of the spectrum (interference coating). The process of light traversing the coating is illustrated in Figure 1. Note that the schematics in Figure 1 are simplified to show the processes that occur in the coating layer only. Specular reflection and transmission on the surfaces of glass bulb wall have not been graphically depicted.

Figure 1a shows transmission of white light (shown as composed of its spectral components) through the wall of a bulb that has been coated with an absorption coating. In this case specular transmission is the dominant process, and the overall transmitted color is bluish white.

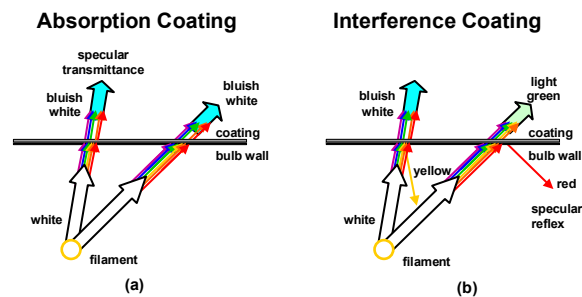


FIGURE 1 -TRANSMISSION OF WHITE LIGHT (SHOWN AS COMPOSED OF ITS SPECTRAL COMPONENTS) THROUGH THE WALL OF A BULB THAT HAS BEEN COATED WITH (A): AN ABSORPTION COATING. IN THIS CASE SPECULAR TRANSMISSION IS THE DOMINANT PROCESS. (B): AN INTERFERENCE COATING. IN THIS CASE SPECULAR TRANSMISSION AND SPECULAR REFLECTION OCCUR. YELLOW AND RED COMPONENTS OF THE LIGHT ARE REFLECTED BACK INTO THE INNER PART OF THE BULB.

Figure 1b shows transmission of white through the wall of a bulb that has been coated with an interference coating. In this case specular transmission and specular reflection occur. Yellow and red components of the light are reflected back into the inner part of the bulb. The light will appear bluish white, light green, reddish, or another color different from bluish white dependent on the angle that the bulb is viewed from. In regard to this it is worth noting that, when subjected to spherical photometry, bulbs using both technologies will show an integrated color of bluish white. The yellow and red components of the light that are reflected towards the inside of the interference-coated bulb generate virtual images of the filament in the respective colors. The virtual images are out of focus for the optical system design and give rise to color separation and glare when the bulb is used in an optical system (headlamp). Figure 2 shows an example of the virtual images generated in a H7 bulb with interference coating.

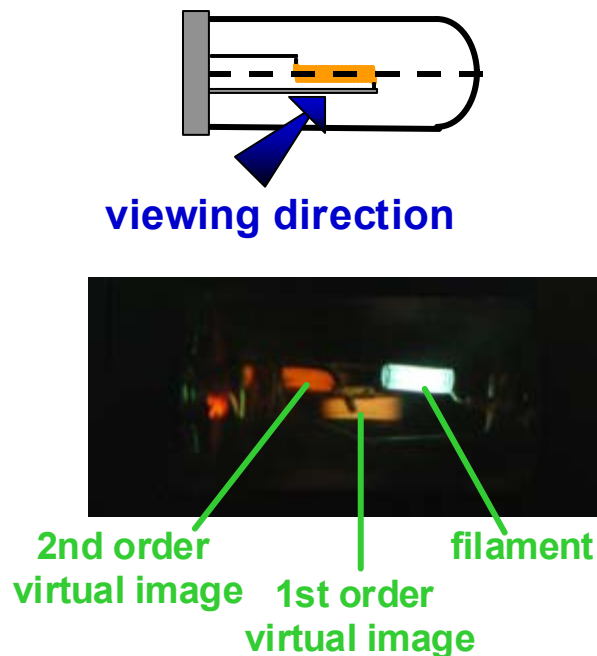


FIGURE 2 - PROJECTION ONTO THE WALL FOR A H7 BULB WITH INTERFERENCE COATING. THE FIRST (YELLOWISH) AND SECOND (REDDISH) VIRTUAL IMAGES ARE PRESENT FOR THE INTERFERENCE COATED BULB, BUT NOT FOR THE CLEAR AND ABSORPTION COATED BULB. A SKETCH OF THE VIEWING DIRECTION IS INCLUDED.

6. TESTING

6.1 Round 1 Testing

6.1.1 Bulb Haze Method

The bulb haze method is based on the assumption that glare is the end result of light scattering from bulb coatings. Measuring light scattering from the bulb will give information on the potential that a coating can create glare.

The measurement method is based on determining the brightness of light scattered from the bulb wall relative to the brightness of the filament. No widely accepted measurement method existed. The method described in this work was adapted from an ECE method used to measure haze caused by abrasion [3].

In the bulb haze (glare) measurement the filament is aligned such that the broad view is projected on a plane. The filament is energized and focussed on a detector that has a stripe that blocks the filament. Readings are taken with and without the light block. The haze or glare level is the ratio of light scattered from the bulb to the total light. The acceptable values could be confirmed by using the reference reflector to evaluate the effects on the system. Figure 3 shows a schematic of the measurement system used.

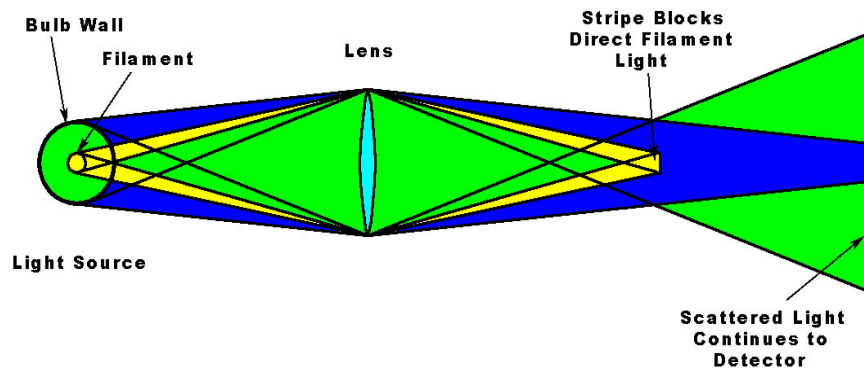


FIGURE 3 - BULB HAZE MEASUREMENT SYSTEM. AN ACHROMATIC LENS IS USED TO CREATE THE IMAGE.

TABLE 1 - BULB HAZE MEASUREMENT RESULTS

Tracking Number	Bulb Type	Coating Type	Measured Filament	Blocking Filter	No Filter	% Ratio
3	S 9004	Absorption	Low Beam	0.183	18.23	1.0
5	S 9004	Absorption	Low Beam	0.178	14.61	1.2
1	S 9004	Absorption	Low Beam	0.241	19.29	1.2
4	S 9004	Absorption	Low Beam	0.216	16.16	1.3
2	C 9004	Multi-Layer	Low Beam	0.249	9.41	2.6
13	E5 9004	Multi-Layer	Low Beam	0.454	9.08	5.0
14	E6 9004	Multi-Layer	Low Beam	0.552	8.59	6.4
11	P3 9005	Absorption	-	0.084	14.19	0.6
12	P4 9005	Absorption	-	0.079	12.71	0.6
8	C 9005	Multi-Layer	-	0.149	11.54	1.3
9	P3 9006	Absorption	-	0.062	11.91	0.5
10	P4 9006	Absorption	-	0.071	9.92	0.7
7	C 9006	Multi-Layer	-	0.104	7.3	1.4
6	C 9007	Multi-Layer	Low Beam	0.173	8.16	2.1
Measurements made at 12.80 volts						
7-Dec-99						

Data from a wide range of bulbs with absorption and multiple layer interference coatings were taken in order to make a comparison of the performance of the different coating technologies possible. Table 1 gives a summary of the results that were obtained with this method. The last column in the table lists the ratio between the light measured with the blocking filter to the light measured without the blocking filter. This is assumed to be proportional to the ratio of light scattered from the bulb to the total light. As can be observed, the ratio is considerably higher for the coated bulbs with multi-layer technology. This implies increased light scattering for those bulb types.

Although these results are encouraging, this method has several limits. The alignment of the optical system is difficult due to the small image size. In addition to that measurements are sensitive to alignment errors. Furthermore, the method requires different striped plates for each bulb type and each filament design. Lastly, the data cannot be evaluated using alternate methods.

6.1.2 BULB COLOR SEPARATION TEST

In the bulb color separation test chromaticity readings of an energized bare blue bulb are taken in directions that fall within a conical volume of revolution, where the axis of revolution is parallel to the bulb axis. Figure 4a illustrates the measurement arrangement. Within the conical volume, a measurement grid can be defined, for instance the one that was used in this study where the polar angle α and azimuthal angle β both vary over a range of $\pm 30^\circ$. Figure 4b shows the grid of measurement directions that is constructed within the α and β intervals

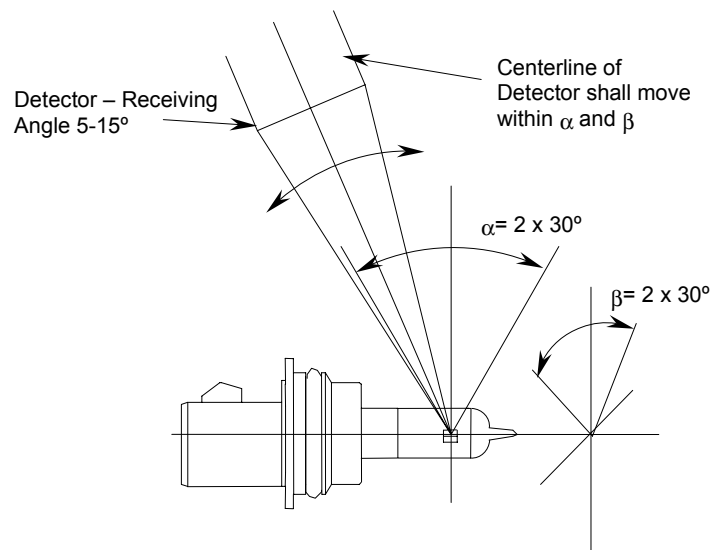


FIGURE 4A - BULB COLOR SEPARATION TEST MEASUREMENT SET-UP

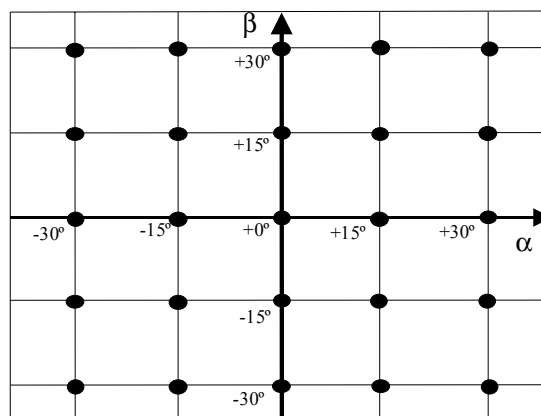


FIGURE 4B - BULB COLOR SEPARATION TEST MEASUREMENT GRID

The chromaticity readings are made with a receiver that is centered on an axis that is perpendicular to the bulb axis and the filament axis (in the case of a double filament lamp, the main or high beam filament is used). The detector-receiving angle should be between 5° and 15°. The test is designed so that it can be performed with a standard type A or type B goniometer, as well as on any dedicated goniometer set-up.

The test requires that measured bulb chromaticities fall inside a specified acceptance area that is situated within the SAE J578 white light area [4] in the CIE chromaticity diagram [5], and has its center located anywhere on the black body curve. Figure 5 shows a section of the CIE chromaticity diagram, with outline of the SAE J578 white light area as a solid line. The bulb color separation test acceptance area within the white light area is indicated by the dashed rectangle, and has its center on the black body curve. An arbitrary position of the acceptance area is shown.

Coated Bulb Chromaticity Diagram

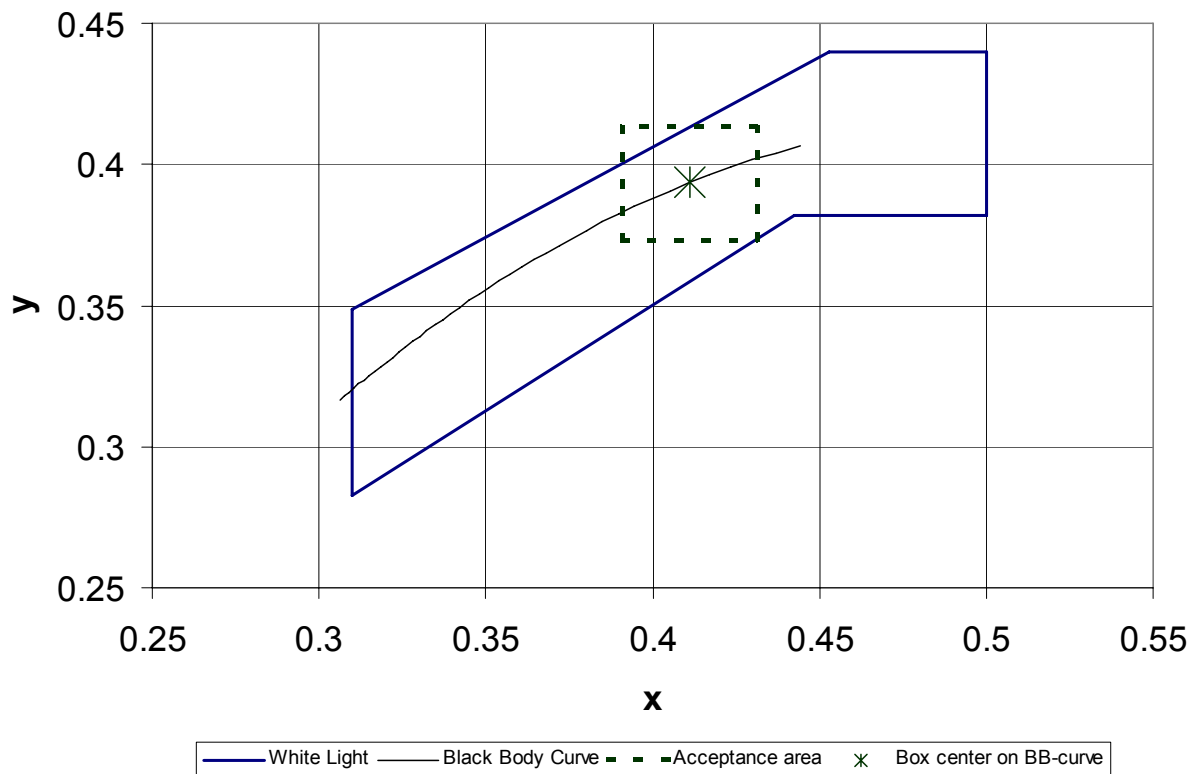


FIGURE 5 - DETAIL OF THE CIE 1931 CHROMATICITY DIAGRAM SHOWING THE SAE J578 WHITE LIGHT AREA; ALSO SHOWN IS BULB COLOR SEPARATION TEST ACCEPTANCE AREA, HERE LOCATED WITH ITS CENTER AT AN ARBITRARY POSITION ON THE BLACK-BODY CURVE

For brevity, results of the Round 1 color separation testing will not be discussed, as they are similar to the outcome of the Round 2 color separation testing that will be discussed in detail in a later section.

6.2 Round 2 Testing

6.2.1 Introduction to Round 2 Testing

In follow-up to the results of the first round robin the SAE Coated Bulb Task Force initiated further studies and launched a second round robin to establish a quantitative correlation between the quantity measured with the bulb color separation test, and headlamp glare. The assumption was made that the physical properties of the color filter mechanism that is used in the construction of the bulb will control both color separation of the bare bulb, and headlamp glare for a headlamp equipped with that type of bulb. The study involved three parts that built on each other, and was carried out with commonly used single and double filament headlamp bulb types. The first part consisted of gathering near field filament image data of energized bulbs. The goal was to identify and examine higher order filament images, which are often the cause of glare. The brightness of these secondary filament images can be affected by the added filter technology used in the coated halogen lamp. Part two of the study involved U.S. beam photometry with a reference reflector. Beam photometry readings at the seeing point, as well as points corresponding to rear view mirror glare and opposing driver glare were taken. In part three the round robin bulbs were subjected to the bulb color separation test.

In the round 2 testing the selection of commonly used U.S. headlamp bulbs included the 9004, 9005, 9006, and 9007. The bulbs in the round robin were circulated to the various laboratories that carried out the tests. The details of these bulbs and their designations used throughout this report, are listed in Table 2. Note that all, or a selection of these bulbs, were used, dependent on the test they were subject to. Interference type bulbs were split into two categories, "heavy" and "light". When the color for a bulb with a "heavy" interference coating is measured in an integrating sphere the chromaticity is more shifted towards the blue, than for a bulb with a "light" interference coating.

TABLE 2 - BULBS USED IN THE ROUND 2 TESTING, LISTED BY BULB TYPE THEIR STUDY DESIGNATION, AND THE TYPE OF FILTERING TECHNOLOGY USED

Bulb Type	Bulb designation	Bulb Coating type
9004	CLR-Ref 1	None
9004	CLR-Ref 4	None
9004	ABS-1	Absorption
9004	ABS-3	Absorption
9004	ABS-4	Absorption
9004	ABS-5	Absorption
9004	Light-INT-E5	Interference (light)
9004	Light-INT-E6	Interference (light)
9004	Heavy-INT-E2	Interference (heavy)
9004	Heavy-INT-4004	Interference (heavy)
9005	ABS P	Absorption
9005	ABS	Absorption
9006	CLR-R	None
9006	ABS 1	Absorption
9006	ABS-2	Absorption
9006	ABS-3	Absorption
9006	INT-5	Interference (heavy)
9007	CLR-Ref 2	None
9007	CLR- Ref	None
9007	CLR-BTF 301	None
9007	CLR-BTF-302	None
9007	CLR-BTF-303	None
9007	ABS-BTF-304	Absorption
9007	ABS-BTF 305	Absorption
9007	ABS-BTF 306	Absorption
9007	INT-E6	Interference (light)

6.2.2 Goniometer Scans

In comparison to the Bulb Haze measurement method, the goniometer measurement method which is described in this section has the advantage that it uses a widely available measurement system, with low cost additional equipment (lens and fixture). Measurements are easy to replicate and the data can be evaluated using many techniques. With the goniometer optical set-up a near field image of the filament can be measured.

Figure 6 shows a picture of the goniometer measurement set-up. A bulb is clamped in a fixture that is mounted on a goniometer table. In front of the bulb a 12 mm diameter Vis-Nir Coated Plano Convex lens was mounted with 30 mm focal length.

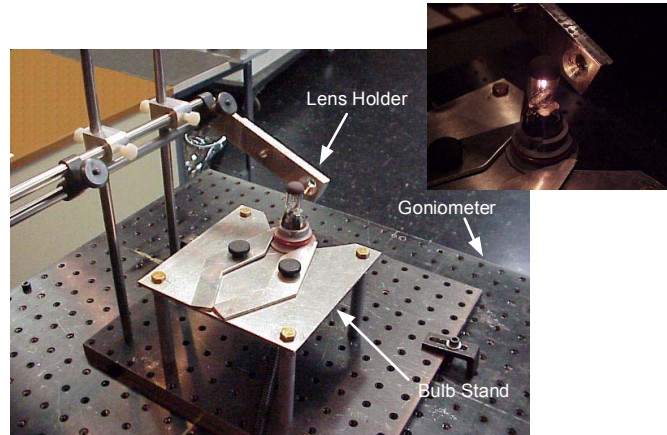


FIGURE 6 - GONIOMETER SCAN TEST SET-UP;
INSET: CLOSE-UP VIEW OF BULB AND LENS HOLDER

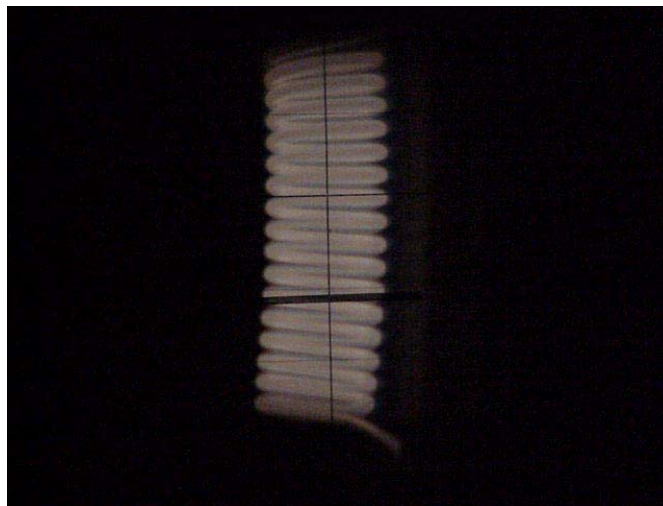


FIGURE 7 - SCREEN PICTURE OF A TYPICAL FOCUSED FILAMENT
IMAGE MADE WITH THE GONIOMETER SCAN SET-UP

During the measurement the bulb was energized and the image of the energized filament was focused and centered on a screen at 25 ft. A typical picture of a filament focused on the screen is shown in Figure 7. After focusing the filament, the baffle was put in place and the isocandela diagram recorded. For double filament bulbs the low beam filament was energized.