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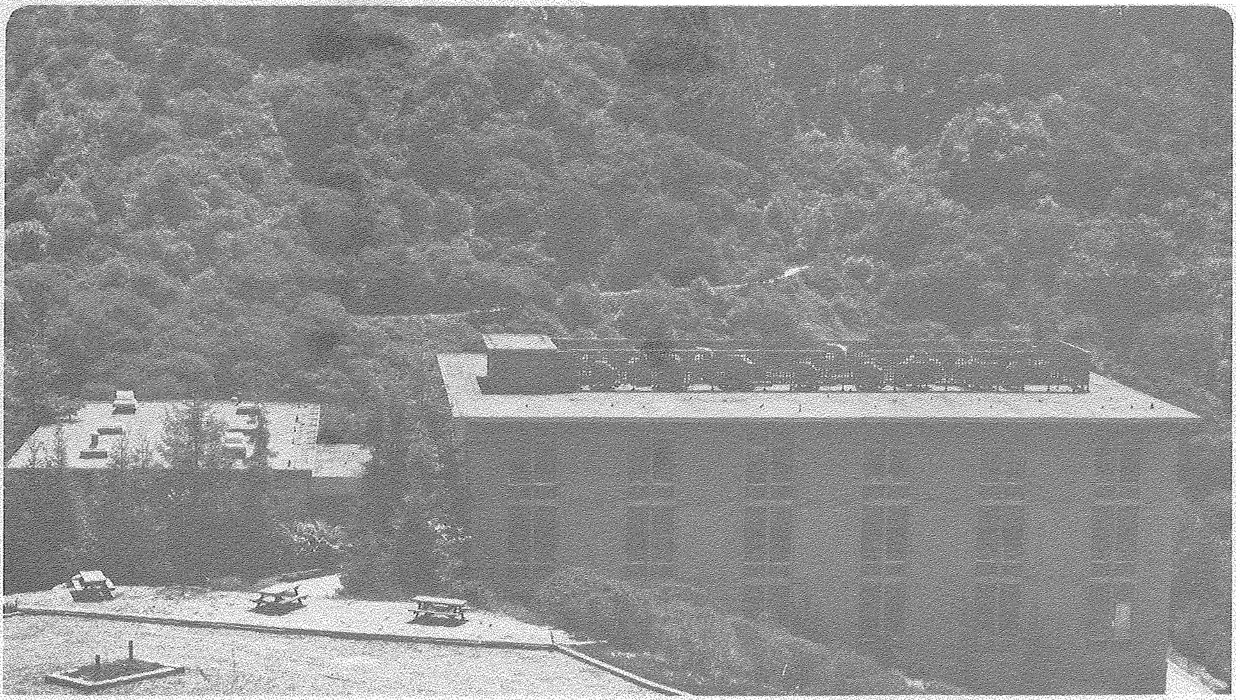

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SELECTIVE ABSORBER COATED FOILS FOR SOLAR COLLECTORS

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ABSTRACT

Solar absorber metal foils are discussed in terms of materials and basic processing science. Also included is the use of finished heavy sheet stock for direct fabrication of solar collector panels. Both the adhesives and bonding methods for foils and sheet are surveyed. Developmental and representative commercial foils are used as illustrative examples. As a result it was found that foils can compete economically with batch plating but are limited by adhesive temperature stability. Also absorber foils are very versatile and direct collector fabrication from heavy foils appears very promising.

INTRODUCTION

Coil finished energy absorbing foils with adhesive bonding can be applied directly to solar collector panels. The basic advantages of the solar selective absorber foil are: (a) it can be applied to a partially assembled collector, (b) it can be used for many different collector geometries, (c) it is generally substrate independent, and (d) it can be used for field renewals or upgrades. Also these foils are suitable for both active and passive solar collector systems.

To reduce cost these coated foils are usually manufactured in a continuous or semicontinuous manner. Deposition methods can vary widely. The coated foil may be further processed by application of contact adhesive and protective liner to the foil backing. Also, a quick release polymer top coating can be used to protect the absorber surface from abrasions. An extension of this coil coating concept is to use heavy starting stock which might be suitable for direct fabrication of solar collector panels. However, the finish must be durable enough to withstand the manufacturing process.

With a continuous plating process, as opposed to a batch operation, the finisher is freed from the problems of different collector sizes, designs and metallic bases. The requirements for the finisher are reduced to quality and uniformity of continuous coated foil. It is important that properties such as solar absorption (a) and thermal emittance (e) be monitored.

For the purpose of this study, foils are defined as thin metal with thickness of less than 75 microns (0.003 in.). Thick metal foils or thick sheet stock will be material with thickness greater than for foils but limited to sizes managable by automatic finishing equipment. According to one manufacturer this size limit is roughly 305 microns (0.012 in.).

The important point when using a foil is that it requires a high temperature adhesive, which may or may not be supplied with the absorber foil. The properties and stability of the adhesive are of paramount importance. Both properties and bonding techniques will be discussed in detail. Possibly the major shortcoming with absorber foils is that they do not easily cover complicated collector geometry, that is they are best suited for flat surfaces but can be used on more complicated geometries.

The thicker absorber sheets may be used directly for fabrication of solar collector panels. Here the major consideration is whether the coating is durable enough to withstand various mechanical forming and bonding steps. Care must be taken to see that the surface is not overheated during bonding. Various techniques such as soldering, adhesive bonding, high frequency welding and mechanical fitting can be used to attach tubes to the absorber sheet.

For the metal finisher the challenge is to adopt batch plating processing baths to continuous finishing of foil and strip. At least two commercial companies have developed processes and are marketing products. Examples are: Ergenics* which fabricates a unique nickel

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*Ergenics, a division of MPD Technology Corporation, International Nickel Company, Wyckoff, New Jersey.

foil absorber sold under the name of Maxorb®[†] and Berry Solar Products,[‡] manufacturers of a product known as SolarStrip®,[§] which consists of black chrome on nickel plated copper.

It must be noted that it is the intent of this study to use commercial manufacturers and their products to demonstrate the capabilities of continuous foil finishing for solar collectors; but it is not the intent to endorse a particular product or company.

ILLUSTRATIVE EXAMPLES OF COMMERCIAL SOLAR FOILS

Maxorb® solar foil is comprised of a black nickel-chrome oxide on 12 microns (0.0005 in.) of electroformed nickel foil. Applied to the back of the coated foil is an adhesive with protective liner. The black absorber is created by a proprietary chemical conversion process. This consists of an automated and electronically controlled acidic oxidizing bath. The finished product exhibits approximately a thermal emittance, $e_N(100^\circ C) = 0.10 \pm 0.03$ and solar absorptance, $a_N = 0.97 \pm 0.01$. These values were determined by the manufacturer using a McDonald Emissometer and Willey Alphameter.[‖] The structure of this coating has very interesting scientific implications since it is one of the few chemically converted coatings that shows a high a_N/e_N ratio.[1] The surface structure and ele-

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[†] Maxorb® a registered trade name of Ergenics.

[‡] Berry Solar Products, a division of The Berry Group, Edison, New Jersey.

[§] SolarStrip®, a registered trade name of Berry Solar Products.

[‖] McDonald Emissometer and Willey Alpha Meter are products of INTEC, Satellite Beach, Florida.

mental analysis is shown in Figure 1. Hemispherical spectral reflectance is plotted and compared to black chrome in Figure 2.

The black oxide coating is comprised of ~200 Å of $NiCrO_x$ (from the surface) which then grades in composition with depth to NiO. The total thickness is approximately 0.3 microns as determined from Auger depth profiles.[2] However in view of this work the exact microstructure and spatial composition is not well known. It is possible that metallic nickel or chromium may coexist with an oxide phase, much like black chrome.

Berry SolarStrip® is finished by a proprietary continuous electroplating process. Both thin and thick black chrome nickel plated foils are produced. The nickel interfacial layer serves as a corrosion barrier. The product does not have an adhesive backing as processed but does offer a quick release polymer top coating. This coating protects the finished surface from abrasion. The heavy foil or strip can be directly fabricated into collector panels.

For a continuous electroplating operation the deposition parameters and characteristics are quite different from those used in batch plating, according to the manufacturer. However, the microstructure of the coating is very similar to the batch variety.[3] For this processing operation a small bath volume is used which requires accurate chemical control but needs less waste water management.

The manufacturer guarantees that the coating will exhibit approximate $e_N(RT) = 0.10 \pm 0.02$ and $a_N = 0.95 \pm 0.2$. These values were measured by an ambient emissometer[**] and Willey Alphameter. Surface

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[**] Ambient Emissometer is a product of INTEC, Satellite Beach, Florida.

analysis of this coating reveals a microstructure similar to the Maxorb product, compare Figures 1 and 3. Reflectance data is plotted in Figure 2. The only surface difference between batch plated black chrome and the foil arises from preferential plating along rolling lines.

Finished thick foils on sheet can be directly formed into air or water solar collector panels. Liquid collectors require pipe bonding, and can be bonded by a variety of methods. The Thermafin†† collector uses high frequency welded pipes. With the higher temperature processes in excess of 350°C heat sinking is required to protect the absorber from thermal degradation.

PERFORMANCE EVALUATION OF FOIL COVERED COLLECTORS

Both absorber finished foils and strip have been used only recently in commercial collectors. Due to this, only short term testing data is available. International nickel researchers have performed standard efficiency tests on the Maxorb® coated flat plate collector.[4] The outcome was that this type of collector performs (in terms of efficiency) as well as the black chrome batch plated collector, as attested in Figure 4. A similar collector has been tested for 140 days at 97% relative humidity at 92°C (200°F). No degradation has been noted by the manufacturer. Also it is known that this surface is stable in air for 140 days at 150°C (302°F). Preliminary testing indicates that the optical properties are stable to 200°C (292°F) for at least 56 days and

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††Thermafin is a registered trademark of Therma Tool Corp., Solar Products Div., Stanford, Connecticut.

stable for at least 14 days at 250°C (482°F). At higher temperatures the adhesive is expected to break down.

The Berry foil has been compared with a black painted absorber using parallel collectors operating under the same conditions. As a result a gain in heat flux extraction of 23-117% was noted over that of the painted surface. (Although one must note that these values were obtained under particular conditions, stated in manufacturer product literature).

The net effect of having a thin adhesive layer on efficiency appears to be negligible. In an isolated case it was shown that with 50 microns (0.002 in.) of low conductivity ($0.073\ w/m^2\ {}^{\circ}C$) adhesive, the fin efficiency declined 1%,[5] resulting in a collection efficiency drop of 0.33%. To substantiate such a claim, parallel testing of batch plated and foil coated collectors should be performed.

SOLAR FOIL RESEARCH AND DEVELOPMENT PROJECTS

With the expansion of the solar foil market, other companies are becoming involved with the development of new foils.

The Optical Coating Laboratory Inc. (OCLI, Santa Rosa, California) is developing a multilayer absorber of metal with a special adhesive backing.

The Telic Company (Santa Monica, California) is presently involved with the development of methods for the production of low cost selective absorbers employing reactive sputter deposition from a cylindrical magnetron source. In this fashion it is possible to create the AMA ($Al_2O_3/Mo/Al_2O_3$) high temperature absorber and stainless steel/oxide absorber.[6]

Another process noted a few years ago used aluminum foil as a substrate to deposit black chrome.[7]

ADHESIVES FOR ABSORBER PLATES

The two principal applications of adhesives are for foil bonding and bonding absorber pipes to the plate surface. In each case different properties of adhesive media are required.

It has been calculated that nonconductive adhesive film for the solar foils should not exceed 127 microns (0.005 in.) for proper thermal conductivity[8] and should be greater than 50 microns (0.002 in.) for good adhesion. The resulting laminate should be able to withstand continuous temperatures in excess of 120°C (250°F) and thermal stagnation of 232°C (450°F). For the Maxorb® surface it has been noted that for exposures up to 130°C (266°F) an adhesive peel strength of at least 35 Kg/m (1.96 lb/in.) is required to resist delamination.[3] In Table 1 there are various types of prospective adhesives and there may be others. If the peel strength of 35 Kg/m is a prerequisite for all foils, then very few adhesives noted in Table 1 are acceptable. Another major consideration for selection is the cost of adhesive and ease of application and curing steps.

The other application is for adhesive bonding of pipes to collector plates. The bonding joints tend to be thicker for mechanical strength than for the foils; under these conditions a conductive sealant may be required. Bond joint and conductance depends directly upon adhesive conductivity, bond joint area, and interfacial resistance and depends inversely upon joint thickness. As a recommendation, a bond joint

TABLE 1. ADHESIVES FOR BONDING OF THIN ABSORBER FOIL TO SOLAR COLLECTORS

The adhesives listed in this table have been suggested for bonding solar foils. For a particular foil and collector design the suitability of a specific adhesive should be determined by the user. Manufacturers' data has not been verified for accuracy.

Adhesive	Type	Max. Service Temperature °C	Cure @°C	Peel Strength kg/m (°C), 90°
Dupont				
Surlyn A	Thermoplastic ionomer film	260	220-232	8.9(176)
General Electric				
SR 529	silicone resin	260	165-175	31.3(150)*
SR 573	silicone resin	260	20 sec @ 120 @ 20 psi	19.0(150)*
SR 574	silicone resin	260	----	9.4(150)*
American Cyanamid				
BR 34B-18	Polyimide 75% solids	250(360)	90 min @ 40 psi @ 285	----
Dow Corning				
DC 280A/284	Silicone Rubber 60% Solids	250(316)	min @ 150-200	44.6(176)
DC 282	Silicone Rubber 60% Solids	250(316)	min @ 150-200	55.4(176)
3 M				
Isotak Y9469	Acrylic pressure sens. tape	204(260)	none	39(176)
National Starch				
Duro-Tak 80-1047	Acrylic pressure sens. adh.	176	2-3 min @ 121	----
Duro-Flex 25/28	Acrylic Moist. Cure adh.	----	----	----
3 M**				
2214 HT	Epoxy paste 100% solids + Al	149	40 min @ 121	36(121)

Source Refs. 3, 8 and Manufacturers' Data.

*180° peel strength

**Epoxy may be too brittle for this application.

should have conductance greater than 30 W/m (32.5 Btu hr/ft). Suggested adhesives are outlined in Table 2; this data comes in part from another study.[9]

COST COMPARISON

A preliminary cost comparison is necessary to judge the relative competitiveness of adhesive foils with batch plating methods. The following prices are only for comparative uses as their actual values change continually. These prices are not representative of very large scale production facilities.

Currently (April 1980), the total cost of a thin absorber foil ranges roughly from \$11-22/m^2 (\$1-2/ft^2) in 10,000 ft^2 sizes dropping downward to small quantity orders. This price range can also include an adhesive. The cost of black chrome including nickel-plated copper strip, which can be formed directly into absorbers is in the upper part of the range for foils in the same quantities. The cost of black chrome plating alone is \$0.90/ft^2 for this process.

Without making an in-depth study (which is required), the overview appears to indicate that there could be a substantial savings advantage in using the coated strip for direct forming of solar collectors. For comparison, batch black chrome plating with nickel, not including the collector cost, for flat collectors ranges from \$12 to \$27/m^2 (\$0.90 - 2.50+/ft^2) for amounts ranging from 10,000 ft^2 to small quantities. Notice that these costs are quite comparable to foils without the expense of two-way shipping and packaging for the batch platers. This, of course, assuming the finisher and the collector manufacturer are not

TABLE 2. ADHESIVES FOR COLLECTOR PIPE BONDING

The following list is a sampling of adhesives suggested for absorber plate to pipe bonding. The specific suitability of a particular adhesive is left to the user. Manufacturers data has not been verified for accuracy.

Adhesive	Type	Maximum Service Temp. °C	Intermittent Service °C	Cure °C	Thermal Conductivity*** W/m°C
Dow Corning					
732 RTV	Silicone	260	316	12 hr. @ RT	(0.173) 0.19
738 RTV	Silicone paste	260	316	72 hr. @ RT	(0.175) 0.21
790 RTV	Silicone	260	316	7-14 days @ RT	(0.19) 0.21
General Electric					
RTV 90	2 part Silic.	260	316	72 hr. @ RT	(0.27) 0.31
RTV 116	Silicone	260	316	72 hr. @ RT	0.21
RTV 156	Silicone	260	316	72 hr. @ RT	0.21
RTV 580	2 part Silic.	260	316	72 hr. @ RT	0.31
Emerson & Cuming					
Eccobond 276	100% solids Epoxy paste	232		121-176°C	1.38
Eccobond 281	Epoxy paste	205		121-176°C	1.44
Castall					
1200 HTC	Cond. Epoxy	205	300	24 hr. @ RT	(0.73) 1.44
Devcon					
C1	Epoxy + 80% Al	204		1 hr. @ 204	(0.71) 1.28
Castall					
341	Cond. Epoxy	155	330	24 hr. RT	(0.87) 1.11
1520	Epoxy	155	330	24 hr. RT	(0.63) 1.38
Hysol					
EA 929	Epoxy	149		3-4 hr. @ 126	(0.138) 0.35
EA 934	Epoxy	149		1 hr. @ 126	(0.311) 0.35

***For thermal conductivity quantity in parenthesis was measured by Ref. 9. For comparison, the thermal conductivity for copper is 385 W/m°C; steel is 47.6 W/m°C and water 0.6 W/m°C. Source after Ref. 9 and manufacturers product literature.

one and the same. Also, it must be noted that there is a labor cost involved in applying the foil and again a one-way shipping charge to deliver the foil to the collector manufacturer. The convenience of having foil on the manufacturing site may also carry hidden advantages, such as faster production time and price stability.

CONCLUSIONS

Solar selective foils can be manufactured successfully by a variety of methods including chemical conversion (Ergenics), electrodeposition (Berry Solar), vacuum deposition (OCLI) and by magnetron sputtering (Telic). The first two are commercial processes, marketing foil for roughly \$11-22/m^2 (1-2ft^2). Contact adhesives definitely limit the upper temperature of these foils to about 250°C. For black chrome this is significant, because it is stable to 350°C. However, for most flat plate applications bonding adhesives are adequate. Low cost highly conductive high temperature adhesives are a very necessary development area now.

Solar absorber foils offer restricted thermal stability and are competitively priced with batch plated black chrome. Foils offer advantages such as savings on collector production turn-around time, packaging, shipping and the ability to be used on different substrate materials. However, for a realistic comparison foil coated collectors have to exhibit long lifetime and durability, without significant increased costs during bonding and handling, roughly to that of batch plated collectors. Foils show a definite economic advantage for low quantity custom collectors over prototype batch plating.

Another application for foils is to upgrade or replace damaged or aged absorber surfaces in the field. Foils can be used for passive solar designs, such as in Trombe walls.

Heavy sheet foils can be used for direct fabrication or air collectors; for liquid types pipes have to be bonded to the sheet. Thick foils used in this manner offer a considerable economic advantage over conventional collectors.

The developments which may stifle the increased use of foils and strip are significant cost reduction in batch plating operations and the development of durable high temperature solar selective paint. Also new improvements in foil processing such as low cost reactive magnetron sputtering may make foil even more attractive.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Fig. 1. Surface microstructure of Maxorb® nickel solar absorber foil examined by SEM at 20 kV (original mag. 2kX and 5kX). (a) typical surface showing rolling lines. (b) EDAX of region C showing nickel and a trace of sulfur and chromium. The aluminum peak is from the sample holder. (c) details of particulate coating.

Fig. 2. Hemispherical spectral reflectance for SolarStrip® and Maxorb® selective surfaces. SolarStrip® finish resembles the typical reflectance of batch plated black chrome.

Fig. 3. Surface microstructure of SolarStrip® as seen by SEM at 20 kV (original mag. 2kX and 5kX). (a) typical surface with rolling lines, (b) particulate coating, (c) EDAX of region B showing chromium, nickel and a trace of cobalt as principal constituents. (The aluminum peak is from the sample holder.)

Fig. 4. Comparative collector performance measure in terms of integrated instantaneous efficiency to the ratio of net temperature change above ambient $(\bar{T} - T_a)$ and incident solar radiation (I). Data from Ref. 5.

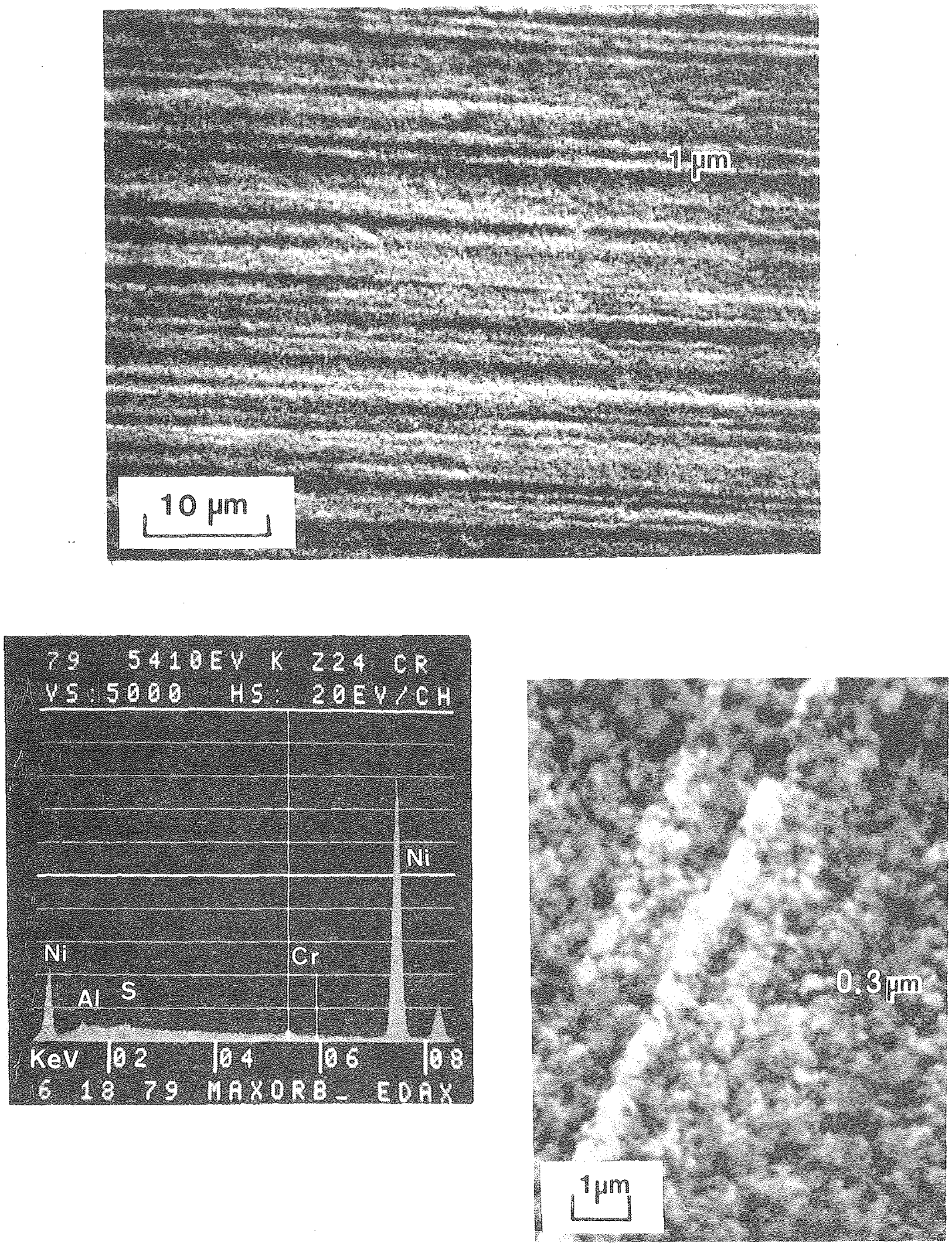

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Fig. 1

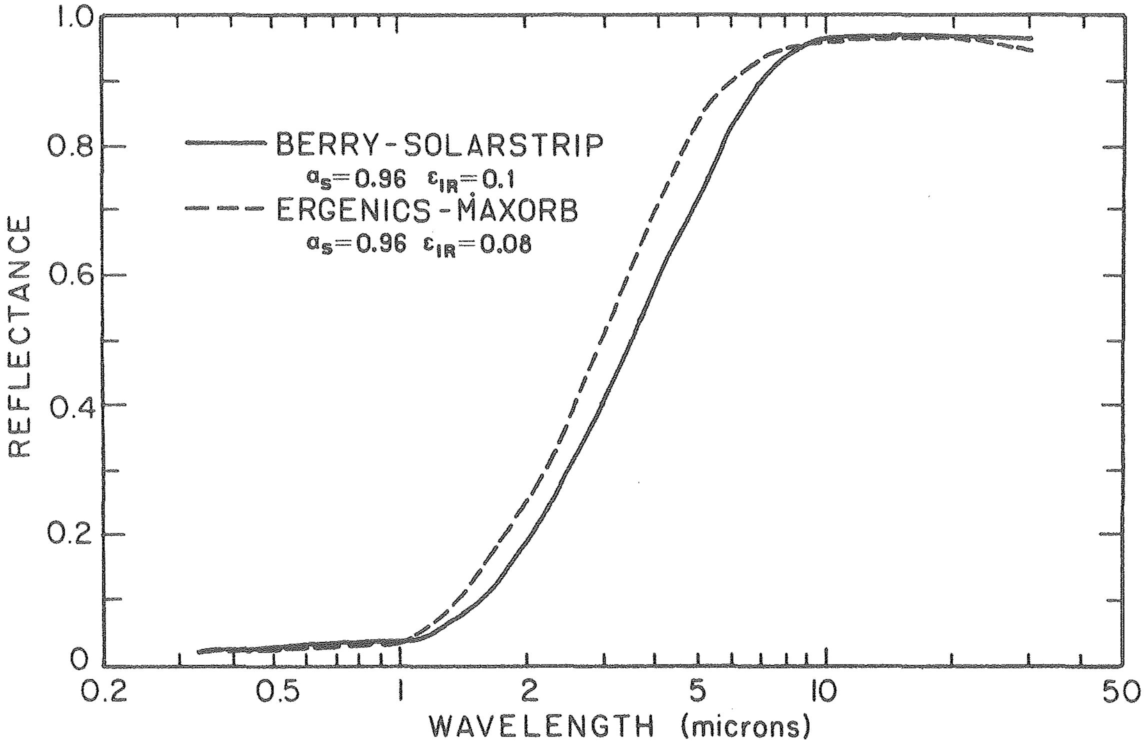

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Fig. 2

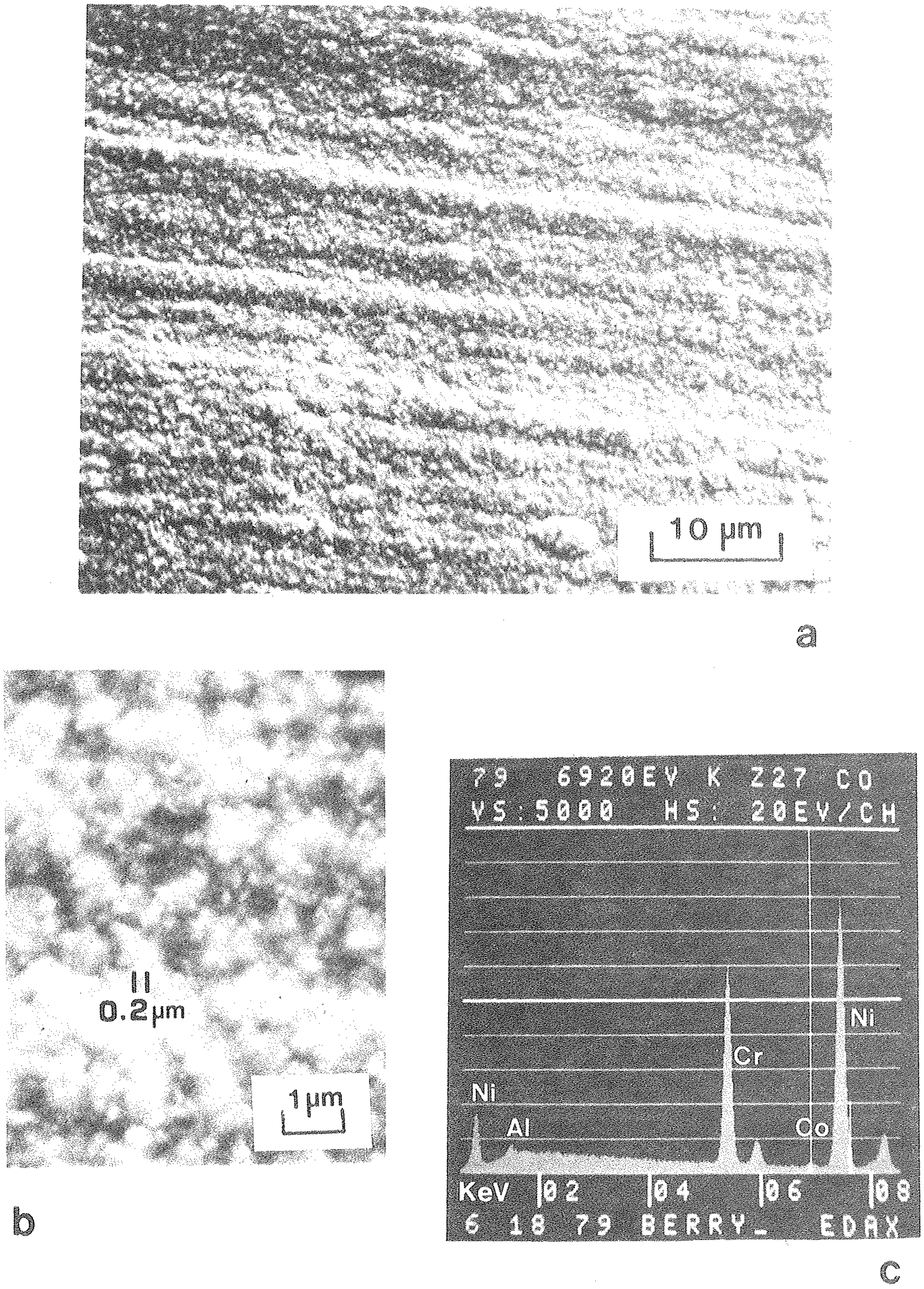

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Fig. 3

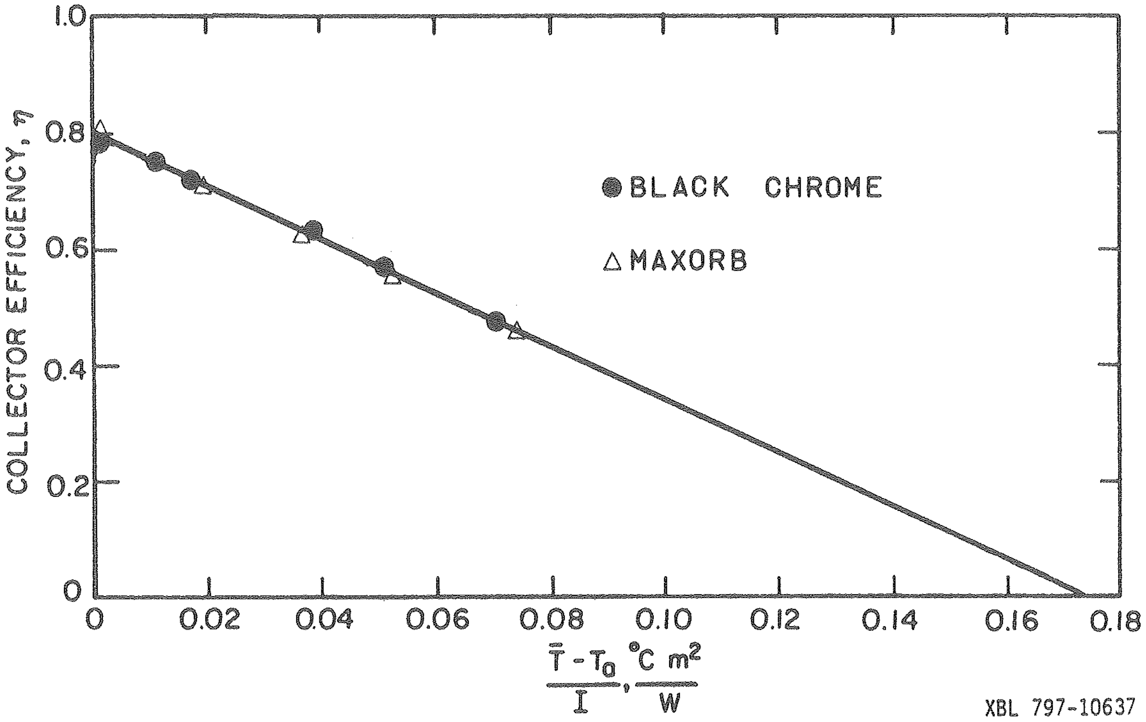

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Fig. 4